October 2017

Issue 35

Technical Series
IN BRIEF

Cow bites grass: what happens next?

Best irrigation practice saves water and grows more

Meeting nitrogen leaching reductions while retaining a profitable system

Efficient calves do not seem to have any negative traits as lactating cows

Contents

1 Cow bites grass: what happens next?

The interaction between plants and animals is a key driver of system performance, and the quantity of feed eaten (dry matter intake, DMI) is central to most of these interactions. It governs the supply of energy and nutrients available for metabolism and, also drives the components of nutrient cycles.

5 Best irrigation practice saves water and grows more

Big advances are being made in irrigation systems and management tools. Precision irrigation is important to avoid waste of water, loss of nutrients to the environment and loss of production.

10 Meeting nitrogen leaching reductions while retaining a profitable system – a Selwyn catchment example

Farmers in Canterbury are some of the first to face the challenge of reducing their nitrogen (N) losses, many to well below their current level. As more regional councils develop and implement policies to improve water quality, all farmers will benefit from key learnings of their Cantabrian counterparts.

14 Science snapshots

We appreciate your feedback
Email technicalseries@dairynz.co.nz or call us on 0800 4 DairyNZ (0800 4 324 7969). Alternatively, send to: Technical Series, Private Bag 3221, Hamilton 3240.

ISSN 2230-2395
DNZ04-035

Cow bites grass: what happens next?

The interaction between plants and animals is a key driver of system performance, and the quantity of feed eaten (dry matter intake, DMI) is central to most of these interactions. It governs the supply of energy and nutrients available for metabolism and, also drives the components of nutrient cycles.

Wendy Griffiths, David Chapman, DairyNZ

Did you know a cow removes 30,000-40,000 bites of pasture per day at peak production?

Like bricks of lego, the bite is the building block of DMI. To meet the lofty production goals we set them, our cows must work hard to harvest 35,000 bites daily[1], as well as make time to ruminate to convert pasture into milk.

Just as we have our own food preferences, every cow is faced with a suite of grazing decisions. She must decide:

- Where in the paddock she will graze relative to her peers.
- How long she will spend searching between bites.
- The duration she will stay in one position before moving in search of more appealing pasture.

When fully fed on pasture, cows will typically graze for between 8-10 hours per day, consuming on average approximately 2 kg DM per hour.

Key findings

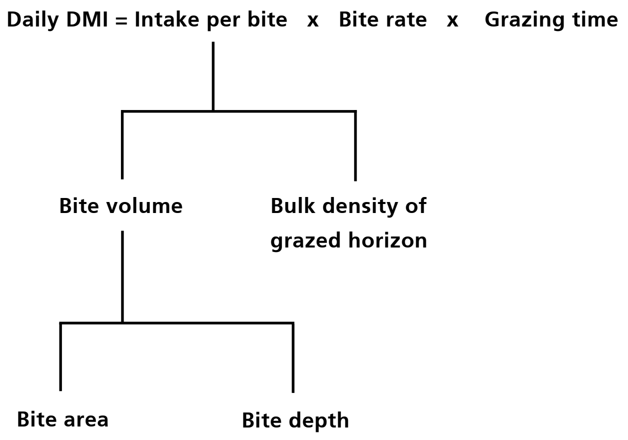
- A dairy cow will remove 30,000 to 40,000 bites per day at peak production. Offering the right amount of green and leafy pasture will encourage high intake per bite and daily dry matter intake (DMI).
- The more pasture offered the more cows will eat, but the extra (marginal) amount eaten will decline as allowances are increased, and pasture residuals will increase.
- Striking the right balance of pasture is critical- pasture height, structure and feed quality will all alter DMI.
- Perennial ryegrass cultivars with different phenotypic traits, for example leaf:stem ratio, tiller density are now available. The Forage value supporting research programme is evaluating the relationship between phenotype, sward structure and milk production in perennial ryegrass cultivars.

How much pasture can a cow eat per day?

This is related to her size: a 400 kg Jersey can consume up to 4% of her body weight which equates to about 16 kg DM, while a larger 550 kg Holstein Friesian eats approximately 3.3% of her body weight or about 18 kg DM.

Mathematically DMI is expressed as the product of the amount ingested per bite multiplied by the number of bites per minute multiplied by the duration of grazing (Figure 1)[2]. Grazing time is relatively fixed, reflecting constraints from non-grazing activities (i.e. milking), but pasture conditions influence the rate of intake (intake per bite x bite rate).

Figure 1: Components of daily DMI[2]



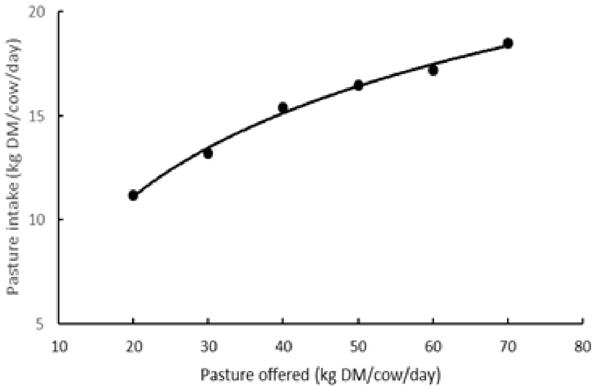
After removing the effect of body weight, the dominant factor controlling how much pasture cows consume is the amount offered per animal. The response to an increase in pasture offered depends on many sward and animal variables but the general principle is that intake of pasture increases, but at a decreasing rate, with the amount of pasture offered[3]. For example, in Figure 2, DMI increased from 11.2 to 18.5 kg DM/cow as pasture offered increased from 20 to 70 kg DM/cow/day.

Note, in this study pasture offered was measured relative to ground level, whereas in practice pasture is generally allocated with the aim of hitting the target post-grazing residual height of 4 – 5cm above ground level. Nevertheless, the general shape of the relationship shown in Figure 2 still holds. Across the range of allowances in Figure 2, the average DMI response was 0.14 kg per kg DM increase in pasture allowance. However, because of the curvilinear response, the DMI response was 0.18 kg per kg DM increase in pasture offered between 20 and 50 kg DM/cow per day.

Thus, the more pasture offered, the more cows will eat, but the marginal increase in DMI becomes smaller with higher pasture allowances.

The shape of the relationship means that pasture utilisation (measured as a percentage of pre-grazing mass consumed) is reduced at high allowances. Consequently, post-grazing residuals will increase[3,4]. For example, in the study presented in Figure 2, the mean pre-grazing pasture height was 13 cm, but pasture residuals increased from 4.9 cm to 7.8 cm as pasture allowance increased from 20 to 70 kg DM/cow per day. The ratio of pasture eaten to pasture offered (allowance) was 0.55 at 20 kg DM/cow allowance, but only 0.26 at 70 kg DM/cow.

Figure 2. Relationship between pasture offered (measured from ground level) and dry matter intake of cows grazing rainfed perennial ryegrass in spring[3].



This highlights why grazing systems must strike a balance between individual cow intake and pasture consumed per hectare –grazing management designed to maximise individual cow intake is inefficient at maximising pasture consumed per hectare due to poor pasture utilisation at higher pasture allowances. A moderate pasture allowance where cows are fed to 90% of potential intake has been recommended to achieve a good balance between per cow and per hectare performance[5]. It is noteworthy that total pasture consumed per hectare consistently emerges as a key driver of profitability because it governs the amount of milk produced per hectare and the cost of producing each unit of milk.

Viewing your pasture through the eyes of your cows

How spatially variable is the pasture in your paddocks? Is the pasture uniformly green and leafy?

Grazing management decisions at each grazing event influence the post-grazing residual, and therefore pasture state at the next grazing. An uneven residual means that, at the next grazing on that paddock, cows are faced with decisions to cope with:

1. increased spatial variability of pasture height (greater 'patchiness'),
2. poorer pasture structure for maximising bite rate and mass, and
3. lower quality feed.

These all potentially compromise their ability to harvest the 30,000 – 40,000 bites in the time available each day to achieve the production we expect from them.

The changes in 2), above are associated with lower concentrations of green leaf, higher concentrations of mature stem, particularly in summer, and more dead material. These all combine to negatively influence the feeding value of pasture because they influence the mechanics of grazing.

When intake per bite is restricted due to pasture conditions (see next section), a cow will attempt to compensate by increasing the rate of biting to maintain intake.

However, it is rare that cows can fully compensate for low intake per bite because of physical and time budget factors.

As a rule, small bites incur a high fixed time cost relative to the time required to chew and swallow the bite. The result is that the efficiency of handling bites declines below the point where bite rate can compensate[6,7].

This is illustrated in Table 1, where the components of intake (Figure 1) were measured when cows grazed short or tall swards at both low and high pasture allowance. Bite rate increased on the shorter sward at both pasture allowances – but only by 15 – 18%, whereas bite weight (milligrams of DM) fell by 27 - 40%. Total grazing time was similar for all treatments, so DMI was substantially lower on the shorter pastures[8].

Table 1: Components of daily DMI at two sward heights and two pasture allowances (measured above ground level)[8].

	Pasture allowance (kg DM/cow per day)			
	35		70	
	Sward surface height (cm)			
	14	28	14	28
Grazing time (min/day)	458	455	488	485
Intake per bite (mg DM/ bite)	348	585	554	763
Bite rate (bites/min)	65	55	60	52

Maximising intake per bite - plant phenotype and sward canopy structure

Pasture offered can be broadly described in terms of height and density, and it is generally accepted that intake per bite will be higher on tall sparse swards than short dense swards of equal pasture mass[9]. Since intake per bite is the grazing variable most closely correlated with DMI, and intake per bite is sensitive to variation in height, DMI will be greatest when animals are offered pasture of a height that is optimal for harvesting large bites (see Table 1).

The recommended mean herbage mass target of between 2600 – 3200 kg DM/ha from densely-tillered ryegrass swards aligns with achieving target cow intakes of 16-18 kg DM per day. Below 2600 kg DM/ha, short tillers will slip from the mouth, reducing intake per bite and daily DMI, and above 3200 kg DM/ ha, on very tall swards, each bite will require greater mastication and handling, reducing energy available for milk production. Further, staying within the recommended pre-grazing herbages mass targets will minimise the risk of high-post grazing residuals.

Peeling back the layers

So far we have talked mainly about how the horizontal variation in the pasture influences the grazing behaviour and intake of cows. There is another dimension to consider too: the vertical layers from top of the pasture down to the height the animals leave behind.

Dairy cows show a strong dislike for stem so they will graze the upper, leafy layers right across the allocated area of pasture first, then go back over the area again to take off the next layer. But that next layer will have less leaf and more stem than the first ‘bite’, so intake rate will be lower. Thus factors such as grass stem length, leaf and stem tensile/shearing strength, density of mature stems, leaf:stem ratio, and the arrangement down the sward profile will influence DMI.

Getting cows to take off that ‘last layer’ to reach the target residual is harder, and can be costly in terms of intake, if there is little leaf to encourage them to keep eating. The amount of green leaf has been shown to be strongly associated with DMI and milk production[10].

Grazing management is the single most important factor controlling sward structure and, the behaviour of the grazing cow. As explained earlier, pasture allowance is an important determinant of pasture utilisation and post-grazing residual which, in turn, impacts on sward structure.

Pasture breeding

While most of the attention directed toward ryegrass cultivars is on DM yield (see the DairyNZ Forage Value Index, www.dairynzfvi.co.nz), breeders have made important advances in the sward factors mentioned above – generally referred to as the grass ‘phenotype’.

There is now a wide range in phenotype among perennial ryegrass cultivars, from those with a very high density of tillers (typically associated with finer and smaller leaves, and a short, dense structure; e.g. Rely) to a low density of tillers (typically with large leaves and a more-open, tall sward structure; e.g. Bealey), and everything in-between. Seed catalogues provide a choice of diploids as well as tetraploids.

The manipulation of ploidy in grasses is a good example of efforts by plant breeders to alter the phenotypic traits of a cultivar to increase DMI. Tetraploids have higher leaf:stem ratios compared with diploids[11,12], and recent work indicates differences in the vertical availability of leaf within the canopy[13], which is a likely contributor to the preferential grazing and lower residuals observed with tetraploid cultivars.

The decline in leaf:stem ratio during flowering may also be less for tetraploids compared with diploids[14], again encouraging high intakes in late spring/early summer. Differences between phenotypes in intake rate (intake per bite x bite rate) have been observed in international studies[15,16] but despite these observations, there is no conclusive evidence of relationships between sward structure traits and grazing behaviour responses to identify selection criteria that can be used in plant breeding programmes.

Evidence from a recent modelling exercise using first year perennial ryegrass material, and a range of phenotypes, indicated that the influence of DMI on spring milk solids production was nearly six times greater than any chemical component of plant tissue[13].

New cultivars offer opportunities to achieve lower and more consistent residuals but they still require good tactical grazing management decisions.

More research on these cultivars is required to tease out the interactions among phenotype, grazing behaviour, plant chemistry and intake[17]. This information will allow us to identify whether an animal grazing related trait that represents a cultivar's 'feeding value' needs to be included in the FVI.

Summary

For the New Zealand dairy industry to hold a competitive advantage dairy farmers must utilise their cheapest feed source wisely and efficiently, and good tactical grazing management underpins success. The bite is the building block of DMI and knowledge of the bite mechanics and the plant and animal factors that optimise the amount of pasture harvested per bite and per hectare will contribute to higher farm profitability.

A two-year study investigating the relationships between phenotypic traits, sward structure and milk production is being undertaken within the Forage value supporting research programme.

This will provide much needed information to identify whether forage values indices need to include a 'feeding value' trait, alongside other traits of interest: DM yield, nutritive value (metabolizable energy) and persistence traits.

References

1. Hodgson, J. 1990. Grazing management. Science into practice. Longman Scientific and Technical, United Kingdom.
2. Hodgson, J. 1985. The control of herbage intake in the grazing ruminant. Proceedings of the Nutrition Society 44: 339-346.
3. Dalley, D.E., J. R. Roche, C. Grainger, and P.J. Moate. 1999. Dry matter intake, nutrient selection and milk production of dairy cows grazing rainfed perennial pastures at different herbage allowances in spring. Australian Journal of Experimental Agriculture 39: 923-931.
4. Bryant, A.M. 1980. Effect of herbage allowance on dairy cow performance. New Zealand Society of Animal Production 40: 50-58.
5. Peyraud, J.L., and R. Delgarde. 2013. Managing variations in dairy cow nutrient supply under grazing. Animal 7: 57-67.
6. Newman, J.A., A.J. Parsons, and P.D. Penning. 1994. A note on the behavioural strategies used by grazing animals to alter their intake rates. Grass and Forage Science 49: 502-505.
7. Parsons, A.J., J. H.M. Thornley, J. Newman, and P.D. Penning. 1994. A mechanistic model of some physical determinants of intake rate and diet selection in a two-species temperate grassland sward. Functional Ecology 8: 187-204
8. Tharmaraj, J., W. J. Wales, D. F. Chapman, and A. R. Egan. 2003. Defoliation pattern, foraging behaviour and diet selection by lactating dairy cows in response to sward height and herbage allowance of a ryegrass-dominated pasture. Grass and Forage Science 58: 225-238.
9. Laca, E.A., E. D. Ungar, N. Seligman, and M.W. Demment. 1992. Effects of sward height and bulk density on bite dimensions of cattle grazing homogeneous swards. Grass and Forage Science 47: 91-102
10. Hoogendoorn, C. J., C. W. Holmes, and A.C.P. Chu. Some effects of herbage composition as influenced by previous grazing management, on milk production by cows grazing on ryegrass/white clover pastures. 2. Milk production in late spring/summer: effects of grazing intensity during the preceding spring period. Grass and Forage Science 47: 316-325.
11. Gowen, N., M. O'Donovan, I. Casey, M. Rath, L. Delaby, and G. Stakelum. 2003. The effect of grass cultivars differing in heading date and ploidy on the performance and dry matter intake of spring calving dairy cows. Animal research 52: 321-336.
12. Griffiths, W. M., C. Matthew, J. M. Lee, and D.F. Chapman. 2017. Is there a tiller morphology ideotype for yield differences in perennial ryegrass (Lolium perenne L.)? Grass and Forage Science (in press).
13. Griffiths, W. M., R. J. Higgs., E. S. Kolver, and D. F. Chapman. Fiber digestion kinetics of perennial ryegrass (Lolium perenne L.) cultivars: predicted milk production, environmental emissions and opportunities for plant breeding (unpublished work).
14. Wims, C. M., M. McEvoy, I. Delaby, T.M. Boland, and M. O'Donovan. 2013. Effect of perennial ryegrass (Lolium perenne) cultivars on the milk yield of grazing dairy cows. Animal 7: 410-421.
15. Orr, R. J., J. E. Cook, R. A. Champion, and A. J. Rook. 2004. Relationships between morphological and chemical characteristics of perennial ryegrass varieties and intake by sheep under continuous stocking management. Grass and Forage Science 59: 389-398.
16. Orr, R. J., J. E. Cook, K. L. Young, R. A. Champion, and S. M. Rutter. 2005. Intake characteristics of perennial ryegrass varieties when grazed by yearling beef cattle under rotational grazing management. Grass and Forage Science 60: 157-167.
17. Chapman, D. F., G. R. Edwards, A. V. Stewart, M. McEvoy, M. O'Donovan, and G.C. Waghorn. 2015. Valuing forages for genetic selection: which traits should we focus on? Animal Production Science 55: 869-882.

Best irrigation practice saves water and grows more

Big advances are being made in irrigation systems and management tools. Precision irrigation is important to avoid waste of water, loss of nutrients to the environment and loss of production. Mapping the soils and the use and management of farm blocks/paddocks, measuring soil moisture and drainage, and utilising weather forecasts are proven methods to increase irrigation efficiency. However, technical solutions are not the only answer. Regulatory and irrigation scheme infrastructural factors also influence decision making and have to be aligned to achieve efficient irrigation.

Carolyn Hedley, Landcare Research,
Ina Pinxterhuis, DairyNZ

Background

Major advances in the New Zealand irrigation industry over the last 30 years, supported by substantial investment in upgrading irrigation systems, has seen irrigation efficiency improve by 50%, as reported by Irrigation New Zealand **(irrigationnz.co.nz)**. Newer irrigation equipment may have real-time water metering and soil moisture sensors, and some also have precision application ability. New Zealand's irrigated area has grown from 460,000 ha in 2002 to approximately 720,000 ha in 2015. More irrigation schemes are planned which have the potential to significantly grow the irrigated area in New Zealand.

Pastoral based activities make up approximately 75% of our irrigated area (dairy 50%; sheep & beef finishing 25%), and the other 25% supports predominantly vegetable and arable crops alongside fruit and viticulture (e.g. wine grapes). In 2012 it was estimated that irrigated farms provided $2.7 billion to New Zealand's economy, and more than double this in terms of the benefits to the wider community.

When irrigation is introduced, productivity gains are significant, e.g. conversion of dryland to irrigated pasture in Canterbury can typically increase dry matter production by 50-100% (~8-10 t DM/ha to ~14-16 t DM/ha[1]).

Methods to best manage the increased input of water and nutrients into the system that accompany these productivity gains are a focus of our research. Water quality is declining in many water bodies[2] and irrigation poses a risk of over-applying water and increasing drainage of nutrients to water bodies, which can contribute to declining water quality.

Irrigation design

New irrigation systems need to be designed so that they can deliver the correct amount of water at an appropriate intensity **(www.dairynz.co.nz/environment/water-use/irrigation/).** If a system cannot do this then the operator will find it difficult to perform efficient irrigation. Also the need for precision or variable rate application should be assessed at the design stage, although variable rate can be retrofitted to older machines. Precision sprinkler systems can be installed to vary sprinkler by sprinkler the amount of water applied. Some of these machines are software-controlled so that 'prescription maps' (zone maps) can be uploaded to control the irrigation pattern.

Precision irrigation systems have many uses, providing greater flexibility for management.

They can vary irrigation to:

- Variable soils
- Variable topography
- Different crops and pasture planted side by side
- Renovated pastures
- Areas sprayed for weeds
- Areas where fertiliser has been applied.

Dairy farmers are also using precision irrigation systems to avoid irrigating races/laneways (reducing lameness in cows), wet boggy areas (e.g. around water troughs), and to give better control where systems move close to waterways and roads.

Optimum or Deficit?

In the Forages for Reduced Nitrate Leaching programme, Carlton et al[5] examined the effect of optimum and deficit irrigation regimes (based on soil moisture holding capacity) on herbage N uptake and dry matter yield from a spring-applied simulated urine patch on diverse and standard pasture grown on a Paparua fine sandy loam, and the effect this had on nitrate leaching. On this soil type, optimum irrigation was 18 mm and deficit irrigation was 9 mm every three days. Yield was the same for standard (perennial ryegrass and white clover) and diverse pasture (perennial ryegrass, white clover, red clover, chicory, plantain and prairie grass); N yield and N uptake were higher for optimum irrigation. Nitrate leaching from the spring applied urine patch was relatively low, but significantly lower when optimum irrigation was applied (Carlton et al., unpublished results).

Maps for Irrigation

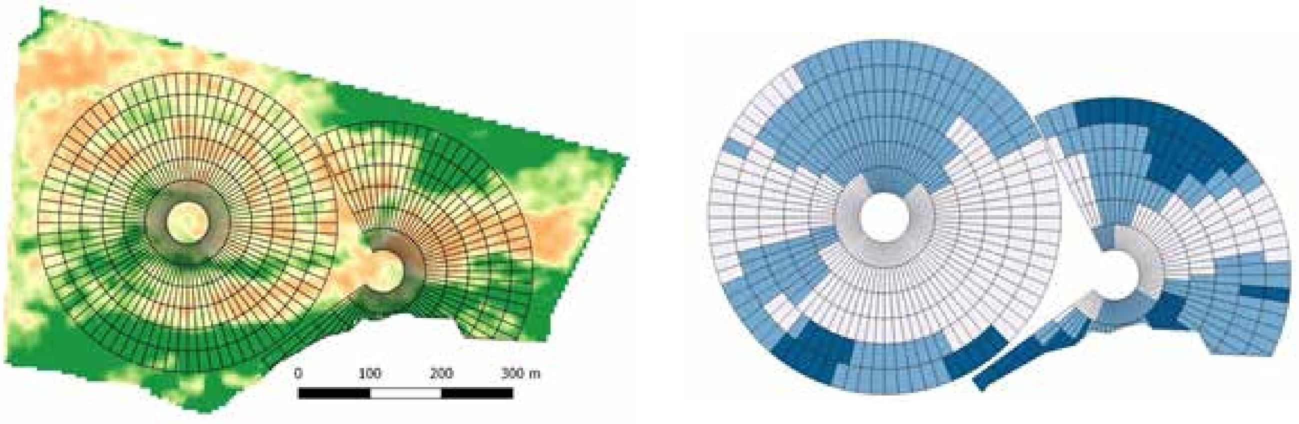
The prescription or zone map is a map that identifies zones likely to require different irrigation schedules, and then it prescribes appropriate amounts of irrigation.

The map can simply be drawn up using the farmer's knowledge. Google Earth images can be used to draw around different paddocks, raceways and e.g. wet boggy areas; and paddock-scale soil maps can be used to identify soils that require different irrigation.

Research being undertaken in the MBIE "Maximising the Value of Irrigation" Programme is developing methods to produce these maps, which include the use of proximal soil sensor survey data (e.g. data derived from gamma radiometric or electrical conductivity sensors).

The sensor data are used to identify different irrigation management zones and after checking the soils visibly on the farm, this information is used to select the location of soil moisture sensors (Figure 1).

Figure 1. Proximal soil sensor surveys are used to investigate soil differences (a), and for producing management zones (b).



a) EC (electrical conductivity) map derived from an EM (electromagnetic) sensor survey.

b) Management zones derived from the EC map, used to guide monitoring positions, e.g. for soil moisture.

These methods are being trialled at seven focus farms in Canterbury (Winchester, Rakaia, Dorie), Hawkes Bay (Takapau, Waipawa, Otane) and Horowhenua (Levin); and at a research site at Massey University, Palmerston North. Soil moisture monitoring has occurred at each site over the last two or three seasons, with sensor positions guided by the zone maps.

At three sites, customised wireless soil moisture sensor networks are being used to provide soil moisture data in near real-time to the farmers via cell phone apps and webpages (Figure 2); and farmers provided positive feedback that this timely soil moisture data assists their irrigation scheduling decision making.

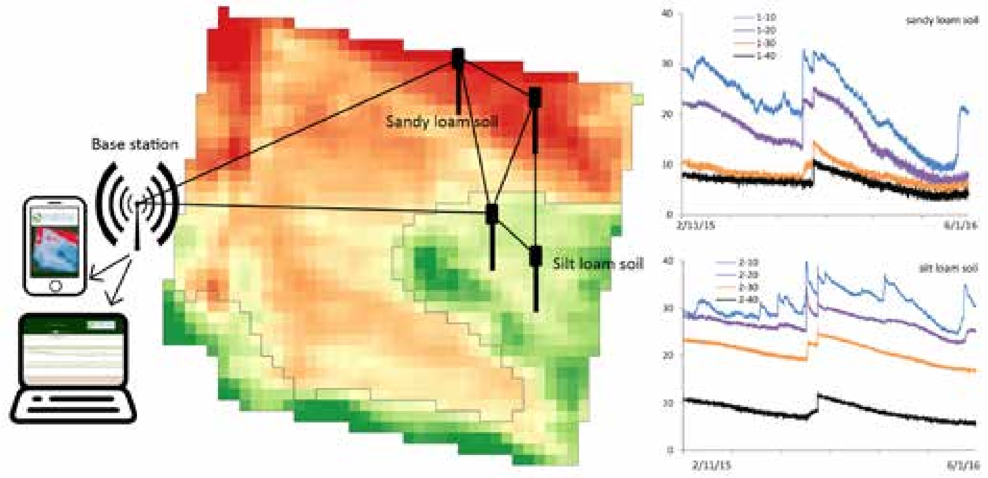


Figure 2. Wireless soil moisture sensor networks (WSNs) have been developed and are being tested at three sites. This figure shows a graphic representation of the smart phone apps and web pages receiving near-real-time soil moisture data from soil management zones at one site (left). The map is of the Massey University experimental plot, soil moisture data is being collected from four depths in two soil zones (see graphs on the right)

Note that the sandy zone drains faster than the silty zone, and is drier at depth.

In collaboration with Plant & Food Research and Lincoln AgriTech, crop sensors are also being trialled to see how well they can track plant stress factors. For example, near-infrared (NIR) sensing methods are being developed to monitor plant water stress (Figure 3a). NIR sensors use light as an indication of plant health as it is reflected strongly from healthy plants; this property makes healthy plants easy to identify on NIR images even at large scales such as on satellite images. Internationally, research has shown that an index based on NIR can be used to detect plant stress caused by insufficient irrigation.

Thermal cameras are also being trialled to monitor water stress indirectly by monitoring leaf surface temperature (Figure 3b). Evaporation of water through the stomata cools the plant leaf, but when water is limited, this tends to restrict evaporation from the leaf surface which in turn increases the temperature of the plant. So a small increase in plant leaf temperature is an indication of the initiation of water stress. The resolution of the image in Figure 3b is 640×480 pixels with an accuracy of about 0.05 °C. A chassis was built to hold the camera vertically to look at plants from above at a height of 1.9 meter from the ground. A Crop Water Stress Index (CWSI) expresses the difference between ''well-watered'' and ''total stress'' on a scale of 0 to 1, and we are conducting research to see if it can be used as an indicator for irrigation scheduling.

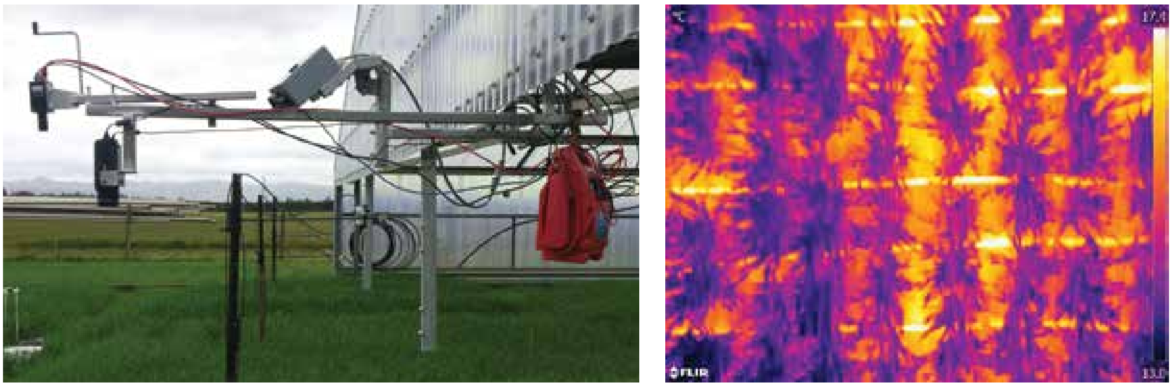
Soil moisture monitoring

Dairy pastures need to be irrigated when the plant available water (PAW) stored in the soil starts to limit growth. The soil moisture content at which this occurs varies from soil to soil; and ideally site specific information is used to characterise this soil characteristic.

For example, a clay soil at a volumetric soil moisture content of 25% (i.e. 250 mm in 1 metre soil depth) may require irrigation, whereas a stony soil that contains this amount of water is likely to be very wet and will not require irrigation. The PAW range for NZ soils varies between very low for very stony soils (<30 mm) to very high for deep finer textured soils (>250 mm) **(smap.landcareresearch.co.nz).**

Very stony, coarse textured soils can only store small amounts of plant available water (PAW), whereas sandy loam textured soils can store more than 200 mm of water for plant water

Figure 3. Sensors are being trialled to directly monitor plant water stress. Source: Lincoln Agritech[3].



a) Sensors mounted onto the Plant & Food Research Lincoln rain shelter.

b) Thermal image of barley at an early growth stage. Scale inserted in the right part of the image represents temperature in °C (yellow indicates the warmer bare soil and purple indicates cooler plant leaves).

use. A depletion factor (typically 30 - 60%) of this PAW is used as a trigger point for irrigation, and this is calculated for the rooting depth of the plant, which in the case of established dairy pastures is typically set at 0.6 - 0.7m.

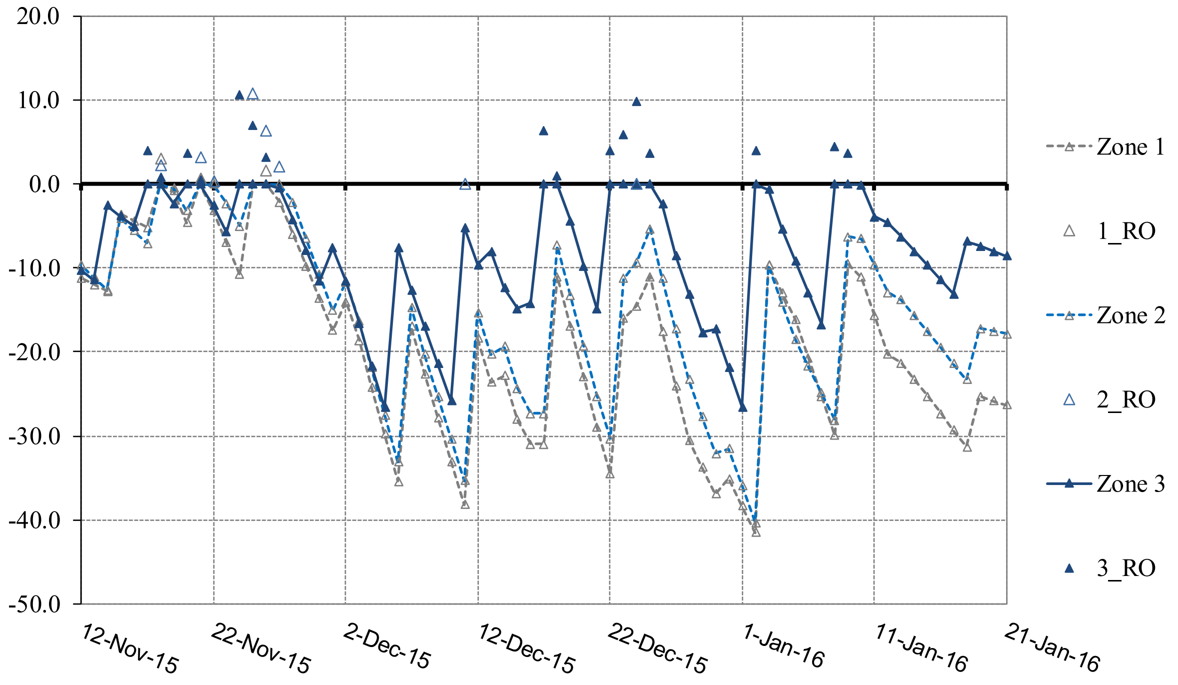
For example, Figure 4 reports soil moisture monitoring results for three soil zones over an irrigation season for the paddock and pivot represented shown in Figure 1. Here irrigation was applied uniformly to maintain adequate water in the soil for plant growth (soil moisture deficit < 40mm). However, the Zone 3 soil is an imperfectly draining soil and it remained wetter than the other two zones. This meant that for the last half of the irrigation season, the soil was wetter than field capacity, at which point there is a high risk of drainage and nutrient leaching. Ideally irrigation should have been withheld from Zone 3 while continuing to irrigate Zones 1 and 2.

This suggests that of the 150 mm of irrigation applied to these soils, approximately 40 mm could have been withheld from Zone 3 while maintaining adequate soil moisture, during the irrigation season. This equates to eight days of unnecessary irrigation assuming an evapotranspiration rate of 5 mm per day. This typifies results which are obtained from other trial sites where defining the zones to guide soil moisture monitoring are effective strategies to maintain water productivity and minimise drainage and nutrient leaching losses.

Drainage Costs

The NIWA-led Waimakariri Water Use Efficiency project ran from 2012 to 2017 and aimed to enable informed decision-making by irrigators in the Waimakariri Irrigation Scheme. Water was not always available in this irrigation scheme, so irrigators tended to apply water when it was available without taking soil moisture or weather forecast into account. NIWA supplied farmers with data on soil water demand (measured on farm using soil moisture meters) and 2- to 15-day rainfall forecasts via daily emails. Several meetings were held to discuss how farmers could integrate the updates into their irrigation practices. It was estimated that drainage due to over-irrigation costed these farms $2 per ha for every mm of drainage below the root zone due to loss of nutrients, reduction in pasture growth, costs of pumping and cost of water. The project identified that on-farm irrigation decisions are influenced by on-farm and off-farm factors: hydrological, climatic, infrastructural, and regulatory. Thus for successful uptake of more precise irrigation management, it is important to understand the external stimuli that, directly and indirectly, conflict or align with proposed practice changes[4].

Figure 4. Soil moisture graphs for three management zones, showing that Zone 3 soils are at field capacity or wetter for several periods during the last half of the irrigation season, while Zone 1 and 2 soils are being maintained at optimum soil moisture for plant growth. The solid triangles above the Field Capacity line are a 'risk indication' of drainage and nutrient leaching losses for these soils. RO = run-off/drainage ; SMD = soil moisture deficit (mm)



Conclusions

To achieve efficient use of water and nutrients and protect New Zealand's water quality, irrigation systems and management need to precisely apply water. Current research is focussing on the implementation of technology that can assist achieving this goal.

- Zone maps guide positioning of soil moisture sensors for monitoring irrigation requirement
- Soil moisture monitoring has multiple uses:
    - tracking soil moisture and predicting the number of days before irrigation is required
    - tracking soil moisture to avoid irrigation-related drainage events
- Crop sensors can be used to monitor water stress in plants, but no crop sensor method has been found to date that predicts irrigation timing before stress occurs.

Acknowledgement

The "Maximising the Value of Irrigation" Programme is a collaborative research programme led by Landcare Research, Plant & Food Research and the Foundation for Arable Research, and subcontracting Lincoln AgriTech and Massey University. The aim is to help integrate the next generation of irrigation management tools for cropping, horticultural and pastoral farms. The principal funder is the Ministry of Business, Innovation and Employment (MBIE) with co-funding from the Foundation for Arable Research, Horticulture New Zealand, Environment Canterbury, Hawke's Bay Regional Council and Irrigation New Zealand. DairyNZ contributes to the Programme through its Industry Advisory Group.

The Waimakariri Water Use Efficiency project was supported by the Waimakariri Irrigation Scheme and funded by the Ministry of Business, Innovation and Employment through the Primary Innovation and Justified Irrigation programmes.

References

1. Thorrold BS, KP Bright, CA Palmer and ME Wastney (2004), Modelling the effects of irrigation reliability on pasture growth in a dairy system in Canterbury. Proceedings of the New Zealand Grassland Association 66: 31–34.
2. Ministry for the Environment (2011), National Policy Statement for Freshwater Management 2011. Ministry for the Environment, Wellington, New Zealand. 11 pp.
3. Jafari A, A Werner, J Fourie, C Hedley (2016), Using thermal imaging for assessing the water status of barley. Accepted presentation to CIGR-AgEng International Conference on Agricultural Engineering "Automation, Environment and Food Safety", Aarhus, Denmark, 26-29 June, 2016., 26–29 June 2016.
4. Srinivasan MS, D Bewsell, C Jongmans and G Elley (2016), Just-in-case to justified irrigation: Applying co-innovation principles to irrigation water management. Proceedings of the International Farm Systems Association Symposium, Harper Adams University, United Kingdom, July 2016. 11pp.
5. Carlton AJ, KC Cameron, GR Edwards, HJ Di and TJ Cough (2016), The effect of optimum vs. deficit irrigation on plant nitrogen uptake and nitrate leaching loss from soil. In: Integrated nutrient and water management for sustainable farming. (Eds L.D. Currie and R.Singh). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 29. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 4 pages.

Meeting nitrogen leaching reductions while retaining a profitable system – a Selwyn catchment example

Farmers in Canterbury are some of the first to face the challenge of reducing their nitrogen (N) losses, many to well below their current level. As more regional councils develop and implement policies to improve water quality, all farmers will benefit from key learnings of their Cantabrian counterparts. Here we investigate options for one Canterbury business, Canlac Holdings, by using scenario modelling to identify management strategies that meet requirements while retaining profitability.

Key findings

- Many catchments will require reduced agricultural nutrient loss to improve water quality.
- Options to reduce N leaching include: more efficient use of water, fertiliser and effluent; using low-N supplements; and reducing cow numbers in autumn.
- These strategies reduce the amount of surplus N in the farm system and N deposited on pasture in autumn when plant N uptake is slowing and risk of drainage is increasing.
- Each farm will require its own reduction strategies to achieve nutrient obligations, yet options are available to improve the efficiency of N use while retaining a profitable system.

Ina Pinxterhuis, Paul Edwards DairyNZ
Tony Coltman, Canlac Holdings
Leighton Parker, Perrin Ag Consultants Ltd

The majority of N loss to water comes from urine patches in grazed dairy systems, but also includes N leached from areas between urine patches, N loss from run-off and direct deposit of dung or urine into waterways (if accessible by animals). N leaching is defined as all N drained to below 60 cm soil depth, assumed to be the depth of the root zone. Poor irrigation management contributes to drainage while over-application of N from fertiliser and effluent increases the risk of N leaching.

Environment Canterbury, and regional zone committees, have developed policies in response to the National Policy Statement for Freshwater Management. The policy for the Selwyn/Te Waihora catchment became operative in February 2016. This policy requires all farms to implement good management practices (GMP) from 2017 as defined by the Matrix of Good Management (MGM) Project[1].

By 2022, dairy farms that have an N loss of more than 15 kg N/ha/yr, as estimated with the nutrient budget tool, OVERSEER®, must reduce losses by 30% (dairy milking platform) and 22% (dairy support) of the N loss rates. These have to be consistent with GMP for the property's baseline land use (the seasons 2009-2013). From 2037 no farm will be permitted to leach more than 80 kg N/ha/yr.

To achieve these requirements, farmers must know:

- Their baseline N loss rate consistent with GMP.
- The options available that will reduce N loss to meet their target.
- Decide which are most appropriate for their farm.
- Implement the chosen options successfully.

Industry effort is essential to make information available, to develop new practical and cost-effective options, and to help build suitable support for farmers.

Options to reduce N leaching

Options to reduce N leaching from agricultural farming systems were investigated in the Pastoral 21 (P21) research project, and further studies are being conducted in the Forages for Reduced Nitrate Leaching (FRNL) programme.

P21 farmlet studies in Waikato, Manawatu, Canterbury and Otago[2] compared current practice with strategies predicted to reduce N leaching significantly. These are less fertiliser and supplement N input, lower stocking rate, and standing cows off pasture from several hours per day to all day during wet conditions or in autumn/winter.

FRNL aims to find pasture plants and forage crops that reduce the surplus N intake of animals, reduce or alter urinary N excretion, and increase plant N uptake from the soil, e.g. through deeper rooting or cool season growth[3]. New Zealand's standard perennial ryegrass-white clover pastures contain more protein than grazing animals require, and the surplus N is excreted, mainly via urine. The urine patch, in turn, contains levels of N which are higher than pasture plants can take up. The soil mineral N, dissolved in soil moisture, is at risk of draining below the root zone and may end up in ground and surface water.

OVERSEER® contains key water and nutrient management principles confirmed in P21 farmlet trials and FRNL experiments. So far, it does not consider novel options of contol, e.g. combinations of plant species. Key components are:

- Apply irrigation efficiently to avoid drainage or plant water stress by monitoring soil moisture and taking account of the weather forecast and soil water holding capacity. This increases herbage production and plant N uptake, while managing the risk of N leaching, i.e. loss of water containing dissolved nutrients below the root zone.
- Align N inputs with plant growth: apply fertiliser or effluent only when plants are able to utilise the applied nutrients well (e.g. not during drought, high rainfall or low temperatures). This reduces the surplus N in the soil that is at risk of leaching.
- Use supplements with relatively low N content. This reduces the animals' N intake and hence N excreted in urine.
- Reduce N inputs to increase N use efficiency and reduce the farm N surplus. The farm N surplus is the amount of N input that is not converted to products and therefore is at risk of loss through leaching, ammonia volatilisation and gaseous loss, e.g. nitrous oxide, a potent greenhouse gas.
- Stand cows off pasture in wet or cold periods when pasture growth is low. This avoids depositing urine on the soil when risk of drainage is high or plant N uptake is less, and gives the opportunity to spread effluent on crop or pasture at times of the year when plants are growing and utilising the nutrients applied.

Canlac Holdings

Canlac Holdings, an FRNL dairy monitor farm in the Selwyn catchment, was modelled with OVERSEER® and Farmax (a physical and financial farm system model). Scenarios to achieve the future N loss requirements were developed using the principles outlined above, and tested in the models for impact on N leaching, production and profitability.

Canlac Holdings

Canlac Holdings is located 5 km west of Dunsandel in the Selwyn catchment. Since 2013 the dairy farm has been operated by Tony Coltman and Dana Carver, 50:50 sharemilkers with an equity interest. Physical and financial performance of the farm for the 2015-16 season are in Table 1. Most of the milking platform comprises a well-draining Lismore soil and 43 ha is a moderately well-draining Mayfield soil. Eighty two percent of the farm is irrigated by two large pivots, the remainder is irrigated by two rotorainers (9% of the area) and sprinklers (the remaining 9% of the area). Effluent is irrigated onto 41% of the milking platform, and a feed pad is used to optimise utilisation of purchased feeds.

Modelling good management practice

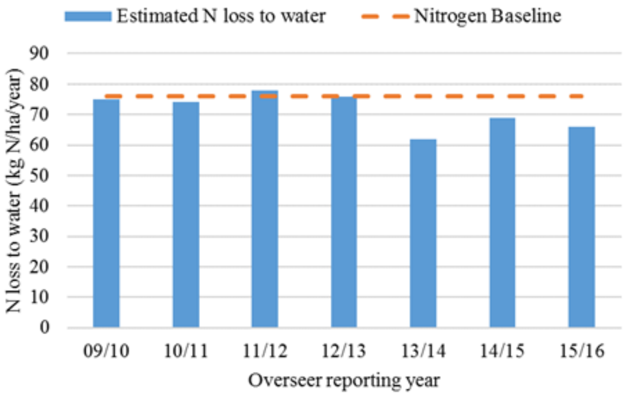
OVERSEER® (version 6.2.3) nutrient budgets were prepared for the 2009-10 to 2015-16 seasons. The first four years, i.e. 2009-10 to 2012-13, are considered the farm's nitrogen baseline, with an average N leaching of 76 kg N/ha/yr (Figure 1).

Improvements in irrigation and enlargement of the effluent area in 2013 reduced the estimated N leaching to 62 kg N/ha.

The Selwyn/Te Waihora Zone sub-regional regulation requires farms to operate at or below their baseline N loss at GMP from 2017-2018. We translated GMP into modelling rules for OVERSEER®:

- No N fertiliser applications in the months of May, June and July
- No more than 50 kg N/ha fertiliser applied per month on pasture blocks
- No more than 400 kg N/ha applied per annum from fertiliser and effluent combined on pasture blocks
- Total N/ha applied on the effluent block does not exceed the average N applied on non-effluent blocks
- Less water applied in shoulders of the season (September, October and March) than in summer (November to February). When selecting irrigation scheduling based on soil water budget or soil moisture sensors in OVERSEER, the model adjusts the amount of water applied to the

Figure 1. OVERSEER® estimated N leaching for the milking platform of Canlac Holdings. Nitrogen baseline is the average of the 2009-10 to 2012-13 years.



predicted rainfall. But if fixed depth and return rate are selected in the model, these should be altered in the shoulders of the season to avoid over-application of water

- Have less than three months fallow after cropping. If not, use a catch crop in between the main crops, e.g. an annual grass or (winter) cereal crop (e.g. oats)

Applying these rules to the nitrogen baseline OVERSEER files reduced the average N loss from 76 kg N/ha to 71 kg N/ha. The milking platform is currently operating below this baseline GMP N loss (Figure 1).

Targeting a 30% reduction

From 2022, milking platforms need to operate at 30% below their GMP baseline for N leaching, meaning a target of 50 kg N/ha N loss for Canlac Holdings.

Two scenarios were modelled:

1. Reduce the number of cows in autumn by culling 90% of the non-pregnant cows and other cull cows early (1 April)
2. Reduce the overall number of cows by 50 and maintain the current culling strategy.

Both scenarios reduced N fertiliser use from an average of 290 kg N/ha to 215 kg N/ha (less on the effluent blocks than elsewhere) and reduced the amount of N fertiliser in April. Through re-nozzling, water application by the rotorainers was reduced from 35 to 30mm every 6 days (5 mm/day). The proportion of low-N imported feed was increased from 8% to 52% by swapping pasture silage and some PKE for maize silage and fodder beet. In all scenarios, supplements were offered on the feed pad.

Table 1 summarises the modelling results. The scenario with early culling achieved an N loss below the target of 50 kg N/ha. The scenario with 50 fewer cows throughout the year did not. This illustrates that OVERSEER responds strongly to cow numbers and feed eaten in autumn, reflecting the relatively high risk of N leaching from urine patches at a time when plant growth and associated N uptake is slowing down and risk of drainage is increasing in the months ahead.

Both Scenario 1 and Scenario 2 reduced farm profit by 5% from Current, using a milk price of $6.00. This was due to 4% lower milk production from less pasture eaten (due to less N fertiliser applied), less PKE, and a 1-2% increase in costs (mostly feed).

Nitrogen efficiency parameters for the scenarios reflected the reduced amount of N brought onto the farm: the N surplus (without N fixation) was reduced by almost half and the N conversion efficiency was improved by a third.

Eco-efficiency is a measure of how much is produced per unit of environmental impact, e.g. kg MS produced per kg N surplus. Eco-efficiency can also be monetary, e.g. operating profit $ per kg surplus. Both measures were improved considerably in the scenarios: kg MS/kg N surplus increased by 64-69% and operating profit $/kg N surplus increased by 61-67%.

Table 1. Summary of results of modelling scenarios to reduce N leaching for Canlac Holdings. Current = modelled current system (2015-2016); Scenario 1 = early cull; Scenario 2 = 50 fewer cows at peak.

Physical Indicators	Current	Scenario 1	Scenario 2
Dairy farm total area (ha)	346	346	346
Effective area (ha)	335	335	335
Cows wintered	1,484	1,474	1,432
Peak cows milked	1,410	1,400	1,360
Stocking rate (peak cows milked/ha)	4.21	4.18	4.06
Production (kg MS)	698,031	671,083	671,455
– per hectare (kg MS/ha)	2,084	2,003	2,004
– per cow (kg MS/cow)	495	479	494
Pasture Eaten (t DM/ha)	18.5	18	18
N Fertiliser applied (kg N/ha)	290	215	215
Purchased feed (t DM)	1,032	976	898
Grass silage	148	0	0
Maize silage	41	532	401
PKE	801	381	442
Fodder beet bulb	42	63	55
– per hectare (t DM/ha)	3.1	2.9	2.7
– per cow (t DM/cow)	0.7	0.7	0.7
Winter crop (t DM/ha)	3.2	3.2	3.1
Financial Indicators			
Total income ($/ha)	13,731	13,240	13,211
Total operating expenses ($/ha)	8,154	7,965	7,922
– $/kg MS	3.91	3.98	3.95
Total operating profit ($/ha)	5,578	5,275	5,289
Change in profit (%)		-5%	-5%
Environmental Indicators			
Total N leached (kg N/yr)	21,076	16,995	18,368
N leached (kg N/ha/yr)	61	49	53
N surplus (kg N/ha/yr)[1]	215	126	122
N conversion efficiency (%)1	39	52	53
kg MS/kg N surplus[1]	9.7	15.9	16.4
Operating profit $/kg N surplus[1]	25.94	41.87	43.35

[1] *Excludes N fixation as input; see text for explanation.*

Benchmarking environmental performance

N leaching estimates for the current Canlac system are similar to the 64 kg N/ha estimated average for Canterbury dairy milking platforms[4]. However, N leaching varies widely in Canterbury due to differences in soil type and climate. Therefore, to assess nutrient management it is more useful to compare N surplus and N conversion efficiency (NCE) with relevant published data.

From the Matrix of Good Management project, the Canterbury average for N surplus (excluding N fixation) was 146 kg N/ha and

NCE was 48%[5]. The current high input Canlac system exceeds these averages, yet the modelled scenarios indicate this farm can make some changes to achieve better results than the MGM averages. Results from the P21 study indicate further potential to improve environmental outcomes.

Table 2 provides the key results for the two P21 farmlet systems implemented in Canterbury[6]. These systems were well-managed with maximum pasture production and utilisation, and efficient use of fertiliser and supplements. N leaching estimated for the P21 farmlets on Templeton sandy loam were lower than for Canlac, which has more freely draining soil types.

Table 2. N surplus and NCE (excluding N fixation) from well-managed dairy milking platforms of Canterbury Pastoral 21 farmlets[6]. Lower-Input = 3.5 cows/ha, 509 kg MS/cow and 1,782 kg MS/ha, 154 kg N fertiliser/ha, 70 kg DM cereal grain/cow and $4,302 operating profit/ha[1]; Higher-Input = 5.0 cows/ha, 476 kg MS/cow and 2,378 kg MS/ha, 309 kg N fertiliser/ha, 680 kg cereal grain/cow and $4,205 operating profit/ha[1].

Physical Indicators	Lower-Input	Higher-Input
N leaching (kg N/ha)	32	46
N surplus (kg N/ha) [1]	57	286
N conversion efficiency (%) [1]	68	36
kg MS/kg N surplus	31.3	8.3
Operating profit $/kg N surplus [2]	75.47	14.70

The two scenarios for Canlac show a significant improvement in N surplus, NCE and eco-efficiency (kg MS or operating profit per kg N surplus), but they do not achieve the efficiency of the P21 Lower-Input system. The P21 Lower-Input system operated at a considerably lower N input than Canlac's current and modelled systems and the P21 Higher-Input system, resulting in a much lower N surplus and higher NCE, higher eco-efficiency and lower N leaching.

Conclusion

The scenario modelling showed that a high-performing dairy farm such as Canlac Holdings has options available to reduce N leaching to the limits set in the catchment's regulations, i.e. a reduction of 30% from its baseline at good management practice. Major investments by Canlac, in the irrigation system and a feed pad, have already reduced N leaching and improved N efficiency since the baseline years, and, therefore, already contributed to achieving the 30% reduction. Nonetheless, a high profit was still achieved.

The Canterbury Pastoral 21 farmlet study showed that further reductions in N leaching are possible by reducing N inputs and N surplus even further.

Acknowledgement

This research was completed with support from New Zealand dairy farmers through DairyNZ and the Forages for Reduced Nitrate Leaching programme with principal funding from the New Zealand Ministry of Business, Innovation and Employment. The programme is a partnership between DairyNZ, AgResearch, Plant & Food Research, Lincoln University, Foundation for Arable Research and Landcare Research

References

1. Canterbury Matrix of Good Management Project 2015. Industry-agreed Good Management Practices relating to water quality. Version 2, 18 September 2015. 24 pp. http://files.ecan.govt.nz/public/pc5/MGM_Technical_Reports/Industry_Agreed_Good_Management_Practices_MGM_2015.pdf
2. Shepherd, M., M. Hedley, K. Macdonald, D. Chapman, R. Monaghan, D. Dalley, G. Cosgrove, D. Houlbrooke, and Beukes P. 2017. A summary of key messages arising from the Pastoral 21 Research Programme. In: Science and policy: nutrient management challenges for the next generation. (Eds. L. D. Currie and M. J. Hedley). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 30. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 10 pages.
3. Pinxterhuis, J. B., M. Beare, and G. Edwards. 2014. Forage systems to reduce nitrate leaching. DairyNZ Technical Series 24: 12-13. https://www.dairynz.co.nz/publications/technical-series/technical-series-october-2014/
4. DCANZ and DairyNZ. 2017. Sustainable Dairying: Water Accord. Three years on… Progress report for the 2015/16 season. 40 pages. https://www.dairynz.co.nz/media/5787310/water_accord_summary_3-years_on_web_v2.pdf
5. Pinxterhuis, I., B. Kuhn-Sherlock, and S. Dennis. 2015. Matrix of Good Management: Estimating nutrient loss of Canterbury Dairy farm systems operating at Good Management Practice. DairyNZ Report, Lincoln, Canterbury New Zealand. 191 pp. http://previous.ecan.govt.nz/publications/General/MGM_Dairy_Technical_report_final.pdf
6. Chapman, D. F., G. Edwards, D. Dalley, K. Cameron, H. Di, R. Bryant, A. Romera, A. Clement, B. Malcolm, and J. Curtis. 2017. Nitrogen leaching, productivity and profit of irrigated dairy systems using either low or high inputs of fertiliser and feed: The Pastoral 21 experience in Canterbury. In: Science and policy: nutrient management challenges for the next generation. (Eds. L. D. Currie and M. J. Hedley). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 30. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 12 pages.

Efficient calves do not seem to have any negative traits as lactating cows[1]

A series of experiments in New Zealand[2] with ~1,050 Holstein-Friesian calves (aged 6-9 months) has identified a 21% difference in dry matter intake (DMI) for the same live weight (LWT) and LWT gain. Thus, the most efficient calves ate 11% less (0.77 kg DM/day) and the least efficient 10% more (0.69 kg DM/day) than the group average. This measurement is called residual feed intake (RFI) and this is the difference between actual and predicted DMI required by individual animals, whether this be for growth or production.

To accurately measure intake, the calves were fed lucerne cubes in a specially constructed facility at Hawera, where intake for individual animals can be measured. The extremes in efficiency, 10% most and 10% least efficient, were retained for further studies as lactating animals. When lactating it was identified that these groups remained divergent in RFI during lactation, but at a reduced level (4 to 5%)[3].

The set of experiments was in collaboration with Australian researchers and their results for both calf and lactating cows were almost identical with that obtained in New Zealand[4].

One of the concerns with selecting for any trait and especially a trait such as RFI (where there is a lowered intake for the same product), is that there may be sacrifices to achieve this gained efficiency, such as LWT gain/loss negative effects on and reproduction. To investigate this, a farmlet experiment was established at Hawera in 2011 and managed for 3 years. In the experiment there were four stocking rates (SR) of 2.2, 2.6, 3.1 and 3.6 Holstein-Friesian cows/ha on self-contained farmlets. Each SR treatment had a equal number of cows that had been identified (as calves), as most and least efficient.

Selection for efficiency as calves, did not affect milk production, reproduction, LWT, BCS or changes in these parameters when the same animals were lactating. Immediately post-calving the most efficient animals lost similar LWT and BCS as the least efficient, and regained similar LWT and BCS before their next calving.

These results indicate that selection for RFI as calves to increase efficiency of feed utilisation did not negatively affect farm productivity variables (milk production, BCS, LWT and reproduction) as adults when managed under an intensive pastoral grazing system.

The importance of the RFI trait is that identification of the most efficient animals could lead to savings in feed costs during growth and while lactating. 'Feed saved' has been included in the breeding value for Australian dairy cattle. It has been estimated that if this trait is incorporated as a breeding value into Breeding Worth, there could be a saving in reduced feed costs of approximately $10 million per year to the New Zealand Dairy Industry.

References

1. Macdonald, K.A., B.P. Thomson, G.C. Waghorn. 2016. Divergence for residual feed intake of Holstein-Friesian cattle during growth did not affect production and reproduction during lactation. Animal. 10.1017/S1751731116000641
2. Waghorn, G.C., Macdonald, K.A., Williams, Y., Davis, S.R. and Spelman, R.J. 2012. Measuring residual feed intake in dairy heifers fed an alfalfa (Medicago sativa) cube diet. Journal of Dairy Science 95: 1462–1471.
3. Macdonald, K.A., Pryce, J.E., Spelman, R.J., Davis, S.R., Wales, W.J., Waghorn, G.C., Williams, Y.J., Marett, L.C. and Hayes, B.J. 2014. Holstein-Friesian calves selected for divergence in residual feed intake during growth also exhibit divergence in residual feed intake in their first lactation. Journal of Dairy Science 97: 1427–1435.