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TECHNICAL SERIES

SCIENCE IN ACTION

LIGHTER FOOTPRINT

Can we reduce leaching without eating into profit?

- Improving egg quality
- Better Breeding Values for farmers
- Tools for reducing methane emissions

DairyNZ

CONTENTS

Abbrev/symbol	Meaning
cm	centimetres
DM	dry matter
g	grams
GHG	greenhouse gases
ha	hectares
kg	kilograms
km	kilometre
m	metres
ME	metabolisable energy
ml	millilitres
mm	millimetres
MS	milksolids
L	litres
PKE	palm kernel expeller/extract
t	tonnes
<	less than
>	greater than
~	approximately, about

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Significant leaching reductions achieved by forage research

The DairyNZ-led Forages for Reduced Nitrate Leaching programme ran from 2013 to 2019. It delivered new knowledge, tools and technologies for forage production that can provide more than a 20 percent reduction in nitrate leaching from dairy, arable, sheep and beef, and mixed-farming systems.

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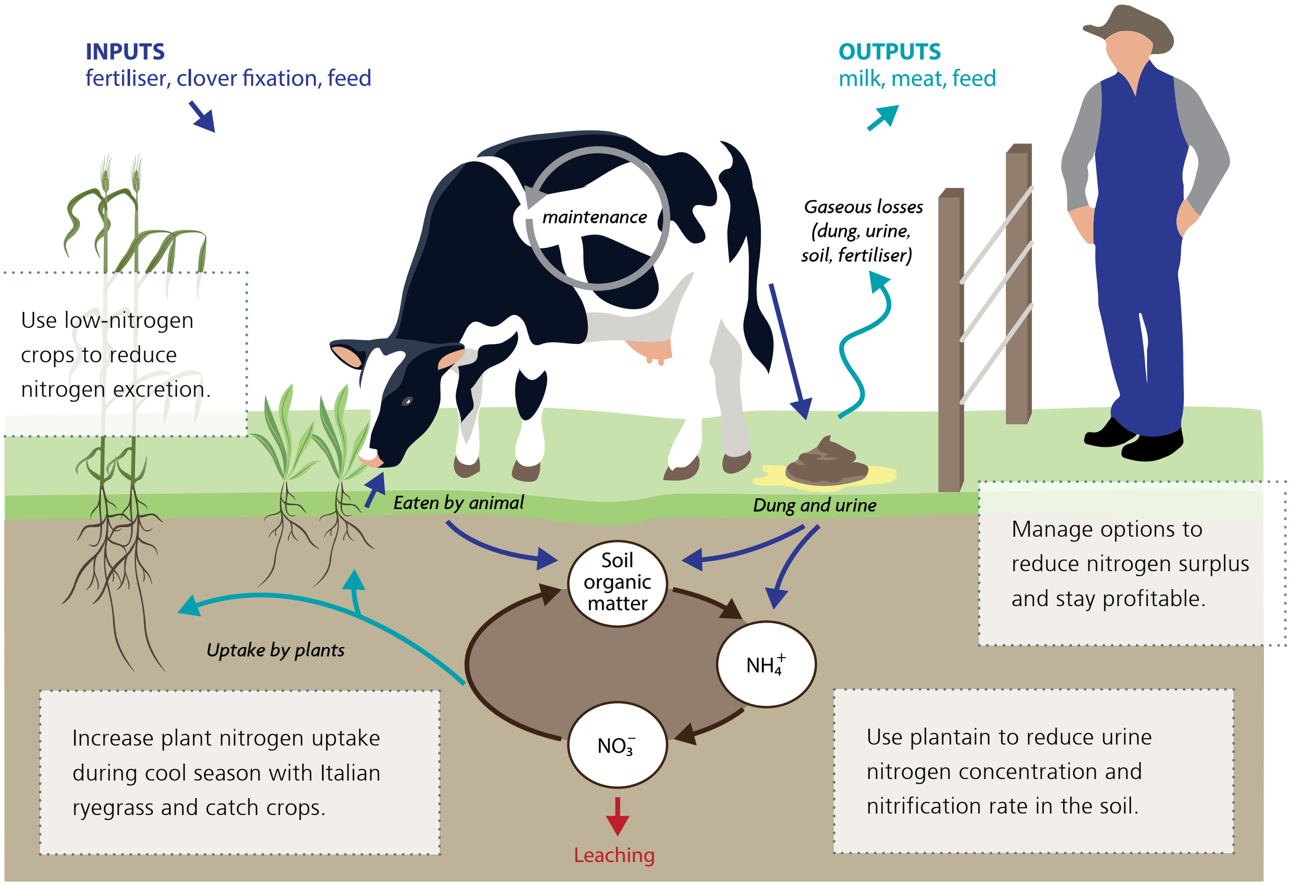
KEY POINTS

- High nitrogen (N) concentrations in cows' urine patches and high soil mineral N increase the risk of N leaching if the N is not utilised before draining below plants' root zones.
- In comparison with perennial ryegrass/clover, growing and feeding plantain reduces the N concentration of urine, it can reduce total N excreted in urine, and it can reduce nitrification rate in the soil.
- Fodder beet, maize and cereals have higher water-soluble carbohydrates to N ratios than standard pasture (which when fed reduces the total N excreted in urine).
- Italian and annual ryegrasses and winter cereals still grow at low temperatures and utilise soil N and soil moisture when the risk of drainage is high (late autumn to early spring).
- No-till establishment of winter-grazed crops can reduce soil compaction and improve the N uptake of subsequent catch crops.
- Difficulties with implementation of these options still exist. Using a mixture of mitigation options spreads risk and results in the biggest reductions of N leaching.



Overview of nitrogen cycle and options to reduce nitrate leaching

Why target forages?

Dairy farming needs to reduce its environmental footprint without losing the profitability of its business and the sector's competitive advantage on the world market.

Early (Pastoral 21) research[1] showed the substantial benefits of reducing N fertiliser and supplement inputs and keeping cows off-paddock: a 40 percent reduction in nitrate leaching compared with common practice. However, the research also showed that milk production per hectare could fall due to the lower inputs, and that costs are higher when using off-paddock infrastructure.

The Forages for Reduced Nitrate Leaching programme (FRNL) set out to find mitigation options that would maintain or improve production and profit.

Our research targeted the problem of excess N in the animals' diet, by either reducing the feed's N content or increasing plant N uptake before the excreted N leaches below the root zone. This is also relevant to mixed livestock farms and arable farms grazing stock. Growing crops has its own challenges with N leaching, and cross-sector solutions might be beneficial. For that reason, the programme was a collaboration across dairy, mixed livestock and arable farming.

What we did

FRNL used a range of field trials, lysimeter studies and animal trials to define viable options. Collaboration with 10 FRNL monitor farms ensured the research was applicable and adoptable. The monitor farmers provided feedback throughout the programme, and we adjusted our research questions and experiments accordingly. They also tested and demonstrated the researched mitigation options on their farms.

Following a mid-term review of research results, FRNL focused on the most promising mitigation options: fodder beet, catch crops and plantain in pasture. These have been proven successful, validating the key FRNL mechanisms for reducing N leaching.

Overseer software plays an important role in New Zealand farming, for nutrient management on-farm and in regulations aimed at water quality. FRNL is collaborating with Overseer Limited to ensure the model reflects the research results, so farmers and regulators can assess the benefits of on-farm change.

Key results

1. Plantain

Various studies confirmed that plantain in the diet reduces urinary N concentration. For example, urinary N concentration was 20 percent less for cows fed diets containing 30 percent plantain. It was 41 percent less in cows fed diets with 45 percent plantain, compared with cows fed ryegrass/white clover pasture only[2].

Despite similar dietary N intake (on average 545g N/cow/day),

Plantain in pasture reduces N leaching in multiple ways

urinary N excretion was 43 percent and 39 percent of N intake for cows fed 30 percent or 45 percent of the diet as plantain, respectively, compared with 50 percent of N intake for cows fed ryegrass only. This was a result of plantain's higher water-soluble carbohydrate to N ratio and lower soluble and degradable protein content, which favoured N partitioning to milk and faeces[3].

Plantain also manipulates short-term N processes controlling plant N availability. For example, in a lysimeter study, N leaching from a perennial ryegrass/white clover/plantain mixed sward was 82 percent and 74 percent lower when urine with a standardised N content was applied in December and February, respectively, compared with a standard perennial ryegrass/white clover sward.

Growth of ammonia-oxidising bacteria was significantly reduced with plantain in the mixture, indicating a biological nitrification inhibiting (BNI) effect of plantain[4], i.e. reducing the conversion rate of ammonia to nitrate. This delays the risk of N leaching because ammonia is held more by the soil than nitrate.

The BNI effect of plantain was confirmed in laboratory soil incubation studies: urine applied to ryegrass or plantain soil showed that plantain inhibits nitrification of urinary-N over a short period (<28 days) with the level of inhibitory effect decreasing over time[5].

Furthermore, a study in collaboration with the New Zealand Agricultural Greenhouse Gas Research Centre (NZAGRC) demonstrated that methane production per unit of DM eaten also declined as the percentage of plantain in the diet increased[6]. This suggests plantain might also be beneficial in achieving methane reduction targets set for agriculture.

Other studies progressed establishment and management approaches to achieve a high proportion of plantain in pasture[7]. These studies showed plantain establishment was more successful when direct drilling was used, rather than broadcasting. Early grass defoliation after sowing was preferable over delayed defoliation (mowing or grazing) to avoid grazing the new plantain plants and to reduce light competition from grass.

Pasture with Italian ryegrass can be more winter-active, taking up N.

2. Low-N crops

Fodder beet, maize and cereals are crop types that achieve high animal production and reduce urinary N excretion when fed, compared with feeding pasture only[8]. This is because they have less N and a higher water-soluble carbohydrate to N ratio than pasture.

When comparing maize silage and fodder beet at the same DM intake, urinary N concentrations were similar. However, fodder beet increased milksolids production of cows in late lactation[9]. Feeding these crops can only reduce N leaching if they replace higher-N supplements or N fertiliser-boosted pasture with a higher N content.

Crop type is more important than crop management in achieving the desired crop quality characteristics. For any crop type, N fertiliser rate was the only agronomic management intervention that consistently altered animal feed quality and potentially changed N excretion[10].

N fertiliser rate in excess of crop requirements also increased N leaching of the crop itself. Other factors that increased N leaching from cropping were mineralisation of N-rich crop residues and prolonged fallow periods[11].

3. Winter-active plant species, catch crops

Some plant species reduce N leaching by increasing the uptake of N and water during growth in the cool season, when risk of drainage is higher. In a lysimeter trial, N leaching from a urine patch was 25 to 35 percent lower under Italian ryegrass-based pastures than under other types of pastures for this reason[12]. In field trials, a winter-sown cereal catch crop reduced soil mineral N and N leaching from urine patches by 22 to 40 percent[13]. We found that establishing the catch crop earlier after winter grazing is more effective, but this isn't always possible due to weather and soil conditions.

The field trials showed that a wide range of cereals (oats, triticale, ryecorn, wheat and barley) can be effective catch crops, offering a suite of potential end-uses for farmers (e.g. green feed, green-chop silage, whole-crop silage or grain). Overall, a forage oats crop is the preferred option, considering its production potential at green-chop, crop quality, and environmental performance.

Lysimeter results suggest that autumn grazing of crop increases the risk of N leaching by allowing more time to convert urine-N to nitrate (hydrolysis and nitrification), with more rainfall and drainage facilitating leaching. Oats were still effective at reducing N leaching from autumn-deposited urine, but to a lesser extent (17 percent on a shallow, free-draining Balmoral and 15 percent on a much deeper Templeton soil) than for winter-deposited urine (33 to 44 percent and 12 to 59 percent, respectively)[14]. More than half the N leached from winter-deposited urine (55 to 74 percent) occurred during the spring months, coinciding with

The low N content of fodder beet reduces urine N excretion compared with high-N kale.

Low-N crops only reduce N leaching if they replace higher-N crop or pasture.

peak nitrate concentrations, and active crop N uptake. Without active crop growth, leaching would have been higher.

4. No-tillage forage crop establishment

Winter grazing of forage crops can result in high levels of soil compaction, affecting the storage and loss of N and the performance of subsequent crops or pasture. Cultivation of soils to establish forage crops increases the risk of soil compaction during grazing, particularly under winter wet conditions. Soil compaction is associated with a higher risk of run-off and nitrous oxide (N_2O) emissions (a potent greenhouse gas). Field trials showed direct-drilling (no-tillage) can be used to successfully establish autumn-sown crops (e.g. forage rape, forage oats, Italian or annual ryegrass), with a reduced risk of soil compaction, compared with conventional tillage practices[15].

No-tillage can also be used to establish high-producing, spring-sown crops like fodder beet and kale. No-tillage produced slightly less (nine percent) fodder beet but more (19 percent) kale than conventional tillage, and utilisation during grazing was improved by no-tillage.

The soils under fodder beet and kale crops established with no-tillage were less susceptible to compaction during grazing and allowed better establishment and N uptake of a subsequent catch crop[16]. Previous studies have shown this reduction in soil compaction contributes to a marked reduction in N_2O emissions following winter grazing[17].

These studies showed that soil water content at the time of grazing also strongly affects the fate of N in soil. The lysimeter experiment with ^{15}N-enriched urine (^{15}N is a rare, stable isotope of N) showed that compaction from livestock treading on cultivated soils under wet conditions (typical of winter) reduced soil aeration. This in turn increased N_2O emissions and consequently reduced nitrate leaching. No-tillage soils under similar conditions have much lower N_2O emissions, but no obvious increased risk of N leaching[17].

Implementation challenges

National surveys and input from the FRNL monitor farmers identified challenges when adopting plantain, fodder beet and catch crops on-farm.

Plantain declines within a few years of sowing in new pastures and is difficult to establish in high-producing pastures. To maintain an effective proportion of plantain in the sward, it is crucial to find ways to introduce plantain successfully in existing swards. In experiments and on monitor farms, direct drilling generally resulted in better establishment of plantain than broadcasting seed, but broadcasting is an easily repeated and cheaper option (e.g. every two or three years)[7]. It will be necessary to investigate management options to improve the persistence of plantain, and this is planned in future research.

It is also worth noting that there are a range of plantain cultivars in the market that may have different effects on leaching. We used the cultivar Ceres Tonic in our research. Farmers planning on using plantain as part of their N management programme should discuss this with their seed supplier and advisers.

Feeding high levels of fodder beet remains a risk for animal health due to acidosis and mineral deficiencies. The risk of acidosis can be minimised by careful transitioning. Nutrient imbalances can be minimised by feeding 40 percent or less of DM intake as fodder beet to cows in mid- to late lactation, and 70 percent or less to non-lactating cows. Risks and effects of

A crop of winter-active oats utilises soil N and water when risk of leaching is highest.

mineral deficiencies are being explored further in DairyNZ-funded and co-funded projects.

Overall, combining no-tillage forage crop establishment with controlled grazing and early establishment of catch crops provides the best option to reduce the risk of soil compaction and N losses from winter grazing.

An online survey among dairy, beef, mixed livestock, graziers and arable farmers on the use of catch crops confirmed that adverse weather conditions were usually the reason for delayed sowing or unsuccessful crops. A Sustainable Farming Fund project is investigating alternative sowing methods to improve the success of establishment under wet conditions.

Farm scale N leaching reductions

Across all FRNL monitor farms, N fertiliser use was an important management factor in driving model estimates of N leaching. The arable monitor farmers improved alignment of N fertiliser applications to crop demand and took into account the amount of N becoming available from mineralisation of crop residues and soil. All pastoral farmers implemented plantain and catch crops on their farms.

The five dairy farms also used fodder beet for autumn feed and winter grazing. Three reduced their use of N fertiliser and supplementary feed. The two mixed livestock farmers intensified over the years, grazing more stock (also over winter) and used more fertiliser for higher pasture production or growing more crop.

Over the five years the farms were monitored, the three dairy farms that lowered their fertiliser and supplement use reduced their purchased N surplus. Overseer estimated their N leaching was reduced by 35, 31 and nine percent. Overseer-estimated N leaching remained similar or increased for the remaining two dairy farms and the mixed livestock farms, but the benefits of plantain, fodder beet and catch crops are not yet fully reflected by the model. The two arable farms reduced their N leaching by 40 and 50 percent, as assessed with the Agricultural Production Systems sIMulator (APSIM).

Scenario modelling with DairyNZ's Whole Farm Model, using data from the FRNL monitor farms, showed the predicted reductions in N leaching depend on soil type, climate, how the mitigation options were implemented, and if other associated management measures were taken.

For example, implementing plantain on 28 percent of the milking platform of an FRNL monitor dairy farm on a free-draining, stony soil in Canterbury resulted in a five percent reduction in N leaching[18]. Imported supplements negated some of the benefits of plantain. For another dairy farm and a mixed dairy-beef monitor farm, incorporating plantain on 30 percent of the farm and using fodder beet and catch crops, resulted in a 19 percent reduction in N leaching, with similar or improved production and profit[19, 20].

APSIM modelling showed that the lower N concentration in urine from animals grazing plantain-rich pasture (>30 percent plantain) reduced N leaching by six percent on a 'typical' Canterbury farm on a free-draining soil and by 21 percent on a 'typical' Waikato farm on a free-draining deeper soil. Although the effect of plantain on urine N concentration reduced the N load in urine patches, it also led to a larger area of the paddock covered by urine and a greater occurrence of overlapping urine patches. When combined with an increased pasture regrowth period (which reduces N content and increases carbon to N ratio of the pasture) and a lower annual N fertiliser rate, N leaching reduced by 31 percent in Canterbury and 59 percent in the Waikato[21].

Direct-drilling of crops reduces compaction from grazing

FRNL acknowledgements

The Forages for Reduced Nitrate Leaching programme combined the expertise and resources of 10 commercial monitor farms that included Māori agribusinesses, three Crown Research Institutes (AgResearch, Plant & Food Research, Manaaki Whenua – Landcare Research), one university (Lincoln University), and two industry-good bodies (DairyNZ and the Foundation for Arable Research). The main funder of the programme was the Ministry of Business, Innovation and Employment (MBIE) with the six programme partners providing co-funding.

For more information, go to **dairynz.co.nz/FRNL**

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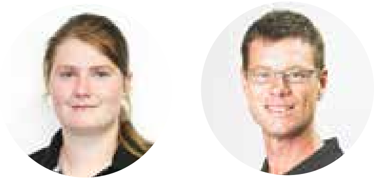
Better oocytes in our sights

DairyNZ researchers have been investigating ways to improve oocyte quality, with the end goal of lifting conception rates in New Zealand dairy herds. Find out what we've discovered and what's next.



Charlotte Reed, post-doc scientist, DairyNZ

Chris Burke, senior scientist, DairyNZ

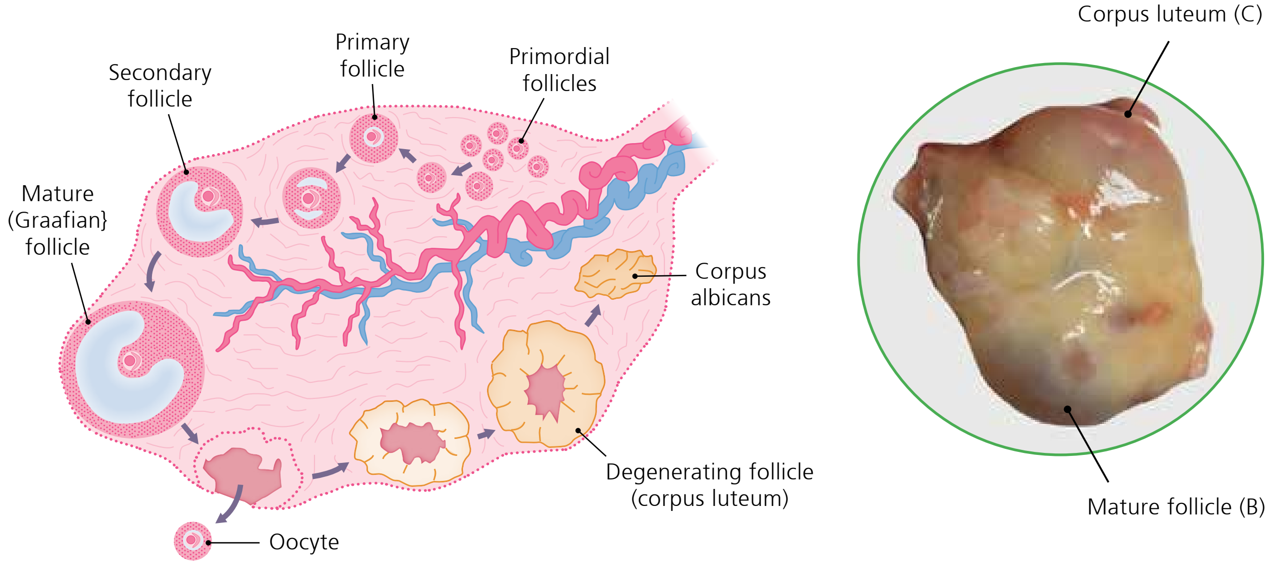
KEY POINTS

- Dairy cows experience a high rate of embryonic loss in the first week of pregnancy. Oocyte (egg) quality is an important determinant of embryo survival through this period.
- The developing oocyte is sensitive to changes within the follicle that nurtures it.
- Lactating cows with a high Fertility Breeding Value (BV) produce better oocytes and have a different follicular environment than cows with low Fertility BV.
- Improved oocyte quality and conception rate are features of cows with higher genetic fertility.
- DairyNZ's aim is to find practical solutions for New Zealand dairy farmers to increase oocyte quality, and therefore conception rates, in their dairy cows

What is an oocyte?

An oocyte is the egg which is fertilised by a sperm cell to produce offspring. Oocytes mature within follicles on the ovary. As shown in *Figure 1*, these grow from small follicles (A) to large, mature follicles with a central fluid-filled cavity (B). During each reproductive cycle, cows will typically ovulate one mature follicle following oestrus. The ovarian follicle ruptures, releasing the oocyte, which passes into the oviduct to meet with sperm. Following fertilisation, nutrient stores within the oocyte are

Figure 1. On the left, a diagram showing the progressive growth of the ovarian follicle and the formation of the corpus luteum from its remains following ovulation. On the right, a cow ovary with a large follicle and corpus luteum (note: the corpus luteum is large and mostly hidden within the ovary).



essential to support the early pregnancy, until the embryo can assume control over its own development. The remains of the ruptured follicle form the corpus luteum (C) which secretes progesterone, the hormone required to maintain the pregnancy.

Why is oocyte quality important?

Dairy cows experience a high rate of embryonic loss in the first week of pregnancy. While 80 percent to 90 percent of cows have a fertilised oocyte following insemination, almost a third of these fertilised oocytes are not viable seven days later[1]. This very early stage of pregnancy relies on nutrient stores within the oocyte to support early development. Therefore, oocyte quality is an important determinant of embryo survival through this period[2].

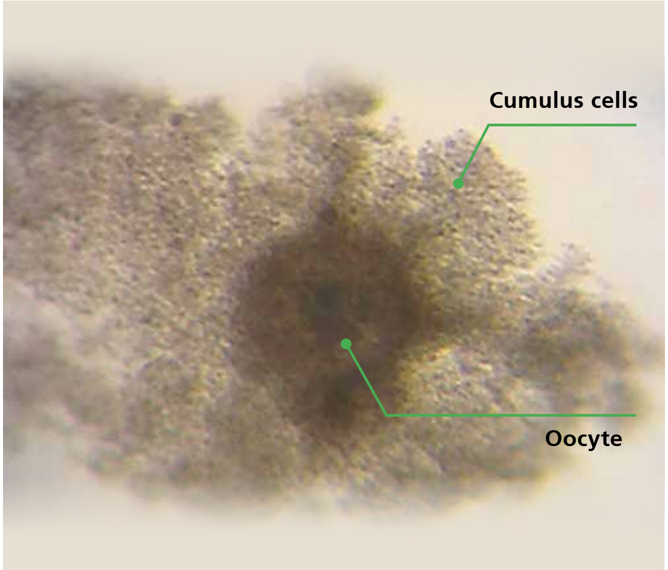
The high incidence of embryonic loss in New Zealand dairy cows during the first week after insemination is likely to be due, at least in part, to oocytes of poor quality. These oocytes are unable to sustain the embryo through this critical phase.

While it may appear that the ovarian follicle isolates and protects the oocyte from the external world, the oocyte is in fact very sensitive to environmental changes[3]. Alterations in blood metabolites and hormones, due to changes in the environment, health and nutrition, are generally reflected in the follicular fluid within developing follicles[4]. These changes in follicular environment affect the quality of the oocyte within.

What affects oocyte quality?

Dairy cows are routinely exposed to factors – notably negative energy balance in early lactation, when body tissue is mobilised to meet energy demand, and metabolic or inflammatory diseases, such as mastitis or uterine infection – that reduce oocyte quality.

The oocyte is the largest cell in the female body and contains enough nutrients to support the embryo through the first week of pregnancy



A cow oocyte and cumulus cells. Cumulus cells provide the oocyte with nutrients and coordinate its maturation.

Furthermore, these conditions may affect not only the oocytes within the larger follicles, but also those in smaller primary and secondary follicles[5] (*Figure 1*).

Bovine follicles take 80 to 100 days to develop to the ovulatory stage, once activated to grow[5]. This means the reproductive consequence of negative energy balance or disease may still be seen months later, when oocytes exposed to detrimental conditions early in their development reach ovulation[6]. Therefore, during mating, most cows will be ovulating oocytes that were exposed to relatively poor metabolic conditions in early lactation. This may affect their fertility.

Research to improve oocyte quality

At DairyNZ, we've been investing farmers' levy in research[*] to explore ways in which oocyte quality, and therefore conception rates, could be improved. Our first task was to characterise follicular environments that can support the development of a high-quality oocyte. We compared oocyte quality and the corresponding follicular environment between dairy cattle with very high (+5) or very low (-5) Fertility BV, as non-lactating heifers, and again during the first lactation. We recovered the oocyte, their supporting cumulus cells and a sample of the fluid within the ovarian follicle from cows and heifers in heat, just before ovulation.

High-fertility cows have better oocyte quality

To assess oocyte quality, we measured the expression of genes, in the oocyte and its supporting cumulus cells, that are associated with good or poor oocyte quality. High-fertility lactating cows had greater expression of genes (*VCAN* and *PDE8A*) associated with higher oocyte competency and that have been linked to a greater proportion of live births in humans[7, 8]. This indicates that oocytes from high-fertility cows are of better quality and have a greater chance of establishing a successful pregnancy than those from low-fertility cows.

Heifers generally have better fertility and higher-quality oocytes than lactating cows[9]. There was no difference in oocyte quality between high-fertility and low-fertility non-lactating heifers. So, oocyte quality may not limit the fertility of yearling heifers with low genetic fertility.

High-fertility cows have a better follicular environment

Our research found differences between high- and low-fertility cows, but not non-lactating heifers, in the composition of fluid taken from within the follicle. Compared with low-fertility cows, high-fertility cows had lower non-esterified fatty acids (NEFA) and amino acid concentrations, and altered hormone concentrations in their follicular fluid. These differences were not apparent between the high- and low-fertility heifers.

NEFA are produced when fat stores are broken down for energy. While they provide a valuable source of energy, NEFA impair cell function at high concentrations[10]. NEFA concentration in the bloodstream is reflected in the follicular fluid, where it is particularly harmful to the follicle and oocyte within, affecting hormone production, metabolism and maturation. High-fertility cows had lower NEFA concentrations within their follicles, creating a better environment for the oocyte. This may partially explain the high quality of their oocytes, compared to those from the low-fertility cows.

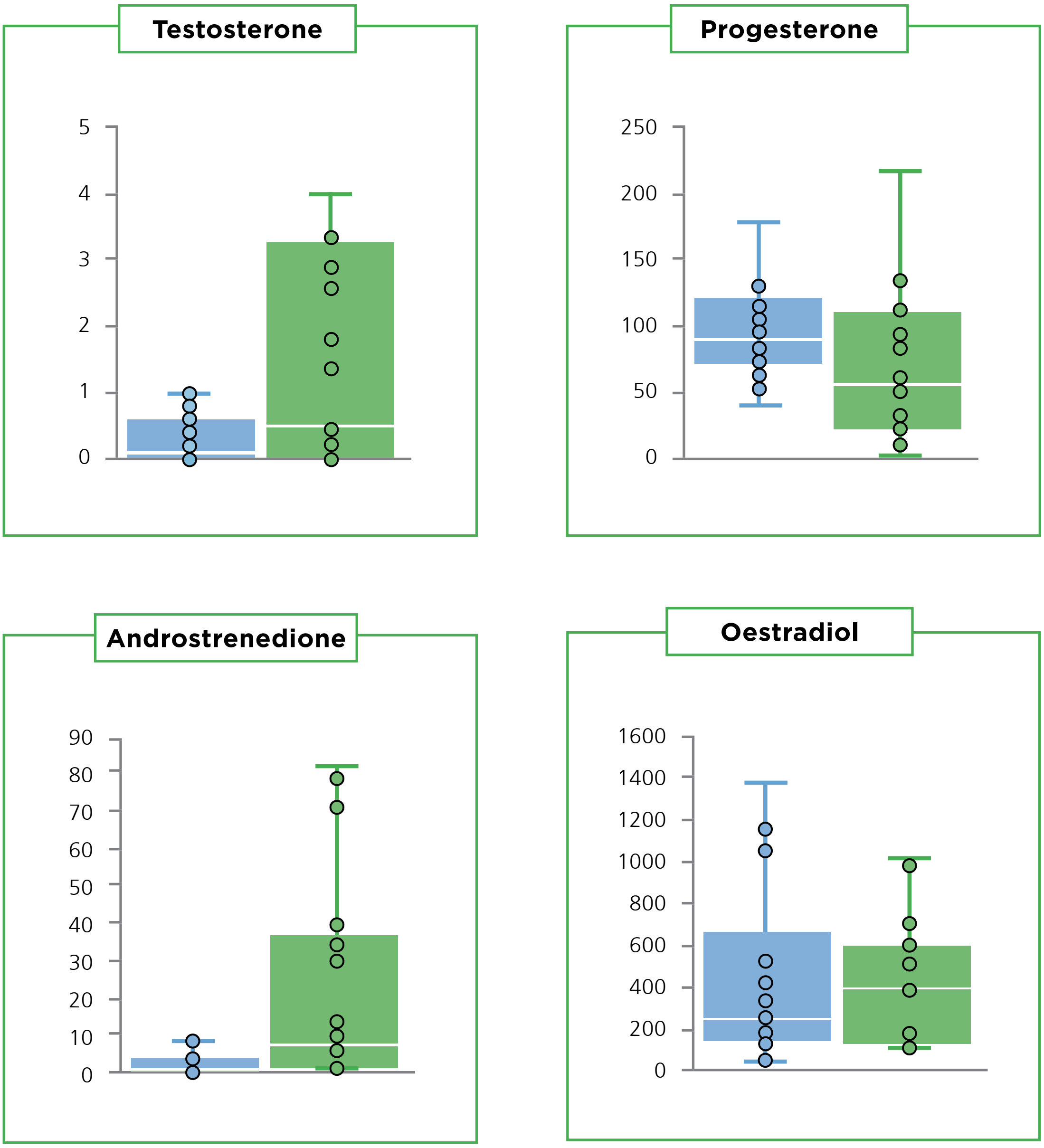
A partially dissected ovarian follicle.

The elevated follicular NEFA concentrations in the low-fertility group don't appear to reflect a greater breakdown of bodyfat, as there was no difference in blood concentrations of NEFA between the low- and high-fertility cows. Cows are thought to have some ability to protect their follicles and oocytes against rises in circulating NEFA, as follicular NEFA concentrations are typically lower than those in blood[11]. The high-fertility group had a lower ratio of follicular NEFA concentrations relative to their plasma concentrations. This tells us that the mechanisms protecting the oocyte from high-circulating NEFA may be more effective in these cows.

Amino acids in the follicular fluid are used by the oocyte and follicular cells for a wide range of processes, including energy production, cell signalling and protein synthesis[12]. Follicular concentrations of several amino acids were higher in low-fertility cows, which may indicate they have a reduced ability to use these amino acids. This may be associated with the high NEFA concentrations in their follicles, as this can interfere with cellular metabolism.

Differences in follicular hormone concentrations between the high- and low-fertility cows may indicate that low-fertility cows have a delayed response to the signal to ovulate. The ovulation process is associated with coordinated changes in hormone production, whereby the concentrations of oestradiol and androgens decrease and progesterone increases. In our study, although follicles were sampled shortly before ovulation, the low-fertility cows still had high androgen (testosterone and androstenedione) and lower progesterone concentrations (*Figure 2*). As increased follicular progesterone indicates healthy advancement of the ovulatory process, the low-fertility cows may take longer to ovulate relative to the onset of oestrus. Delayed ovulation relative to oestrus and insemination is less likely to result in a pregnancy.

Figure 2. Hormone concentrations (nanograms per millilitre ± interquartile range) in the follicular fluid of cows with high (blue boxes) or low (green boxes) Fertility Breeding Value



Where to from here?

The differences we've identified in the follicular environment are now being used to design artificial environments to mature oocytes in the laboratory. We will then assess how oocyte function is affected by the differences we observed in amino acids, hormone or NEFA concentrations. Our aim is to understand how changes in the follicular environment have an impact on oocyte function. Ultimately, we want to find practical solutions for New Zealand dairy farmers to increase oocyte quality, and therefore conception rates, in their dairy cows.

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DairyNZ post-doc scientist Charlotte Reed (left) and senior research technician Olivia Jordan at work during the first oocyte trial.

NZAEL to deliver improved BVs

Improved Breeding Values (BVs) are here, after New Zealand Animal Evaluation Limited's February upgrade to new tools for computing genetic evaluations. Further upgrades are expected in February 2021, when NZAEL will incorporate genomic data into BVs.

Brian Wickham, manager, New Zealand Animal Evaluation Limited (NZAEL)

Melissa Stephen, genetic evaluation developer, DairyNZ

KEY POINTS

- NZAEL updated its genetic evaluation system in February 2020. This coincided with the launch of the new LIC evaluation system which includes genomic data.
- NZAEL is planning to extend its evaluation system to include genomic data in February 2021.
- Farmers should consult with their breeding service provider to take account of inbreeding and hybrid vigour in their sire selection decisions.

Why do we have a genetic evaluation system?

The New Zealand genetic evaluation system for dairy cattle provides estimations of an animal's genetic merit across a wide range of production and fitness traits. This enables NZAEL to generate the selection index Breeding Worth (BW). BW gives bull breeders and dairy farmers a tool for identifying bulls and cows with the greatest genetic potential for improving future farm profits.

The value of genetic improvement accumulates over time, and it's estimated that genetic selection has generated over $3 billion in additional profits for New Zealand dairy farmers over the past 10 years. Further increasing the rate of genetic gain across the national herd will deliver larger profit gains for farmers.

EFFECT OF GENETIC IMPROVEMENT ON FARM PROFIT

Genetic gain is set to deliver

↑ $11 PROFIT per cow per year

Which equates to

↑ $4600 OF PROFIT on-farm

based on the average herd size of 419 cows

THE VALUE of genetic gain compounds over time

ACCUMULATED OVER 10 YEARS EQUATES TO

$250k per herd

$3 billion across the dairy sector

How does it work?

A cow's performance is determined by a combination of her genetic merit and her environment. The genetic evaluation system separates these two factors. The model is often expressed in the form of an equation. Typically, and in its simplest form:

$$P = G + E$$

- P is the phenotype (her observable characteristics, e.g. her milk production).
- G is the effect of the cow's genotype (her DNA).
- E is the effect of the cow's environment (the herd she's in, how she was reared etc.).

In other words, phenotype, e.g. kilograms of milk fat on the day of the herd test) equals the effects of her genotype plus the effects of her environment.

The model is called a mixed model because it's a mix of fixed and random factors affecting the phenotype. Fixed factors affect different cows, or groups of cows, in the same way, e.g. breed. Random factors are different for every cow. For example, the parts of the animal's genotype that are unique to that animal and its relatives.

To isolate the temporary effect of the environment, e.g. feeding levels, the model uses information about the herd itself and the average performance of herd mates.

Calculation

The underlying assumption is that cows of the same age, and at the same location, are exposed to the same environment. In short, we take the average of that group of animals as a baseline, adjusting for additional fixed effects like date of birth and stage of lactation when tested.

A cow's performance above or below that baseline is assumed to be the result of both genetic and permanent non-genetic effects (environmental factors, such as a difficult birth or disease at a young age) that affect the animal for its life and are not controlled by its genetics. We rely on large numbers of daughters per bull to ensure that the permanent environmental effects are appropriately separated from genetic effects.

Research has established how much G and E vary for any trait and, importantly, how similar G is for related animals. So, even though bulls don't produce milk, we can determine the effect of their G for milk yield from a knowledge of how much their female relatives produce (typically, daughters). Animals are also grouped based on their demographics to form genetic groups, which allows breeding values to be inferred for animals with no known pedigree, based on the group they have the most in common with.

Challenges

A complexity of the $P = G + E$ equation is that not all genetic merit can be passed onto future generations. In reality, the G component must be separated into genetic effects that can be directly and independently inherited by progeny (additive genetic effects) and those that cannot (non-additive genetic effects). Some examples of non-additive genetic effects include hybrid vigour, where cross-bred animals perform better than the average of their pure-bred parents.

BVs are a measure of additive genetic merit, and so under ideal conditions, they shouldn't be influenced by non-additive genetic effects. The separation of additive and non-additive genetic effects is achieved by defining factors associated with non-additive genetic effects as fixed effects in the model equation. For example, the performance of cross-bred animals is influenced by non-additive effects. To separate the effect of hybrid vigour from the breeding value, the model equation becomes:

$$P = \text{hybrid vigour} + G + E$$

The technical challenge in deciding on the mixed model for each trait is to find a model that accounts for the most variation in the phenotype, while still being readily solvable using current computers. The size of the task has increased by orders of magnitude with the availability of genomics, where detailed information on the DNA of an animal is used. Fortunately, computer technology has improved such that increasingly complex models have become viable.

How can it be improved?

The rate of genetic gain is determined by the accuracy of genetic evaluations, and age at which an animal's genetic merit can be evaluated. In recent years, there's been a substantial research effort in New Zealand and worldwide to find ways of improving the accuracy of genetic evaluations across all animals, including bulls without daughter-performance information.

This research effort has identified a number of enhancements that will improve the performance of the New Zealand animal evaluation system, including optimised evaluation models, improved computer systems and methods for including genomic data in national evaluations.

What improvements have been made?

In February 2020, several enhancements were implemented within the national genetic evaluation system, including replacing outdated 2006 software. NZAEL, a wholly owned subsidiary of DairyNZ Inc., has been responsible for operating the animal evaluation system for the New Zealand dairy sector since 2017, when the latest version of animal evaluation software was transferred from LIC to NZAEL. A substantial upgrade, including the latest advancements in technology and industry knowledge, has created a second version, NZAEL 2.0.

Model improvements

The models used for NZAEL 2.0 are similar to those used for NZAEL 1.0, but they differ in three important ways:

1. Accounting for inbreeding as a factor responsible for non-additive genetic effects

Inbreeding is present in animals whose sire and dam are related through common ancestors. The more common ancestors there are, and the closer they are in the pedigree, the greater the level of inbreeding. It is well known that inbreeding has a depressing effect on many traits. Accounting for inbreeding in the model improves the separation of additive and non-additive genetic effects, resulting in more accurate breeding values.

Herd testing is an invaluable tool for improving genetic performance and ensuring good farm management. Photo: LIC

2. Accounting for differences between Holsteins and Friesians

NZAEL 1.0 accounted for differences between major breeds, but Holsteins and Friesians were grouped as one breed. Recent research confirms there are differences between Holsteins and Friesians for a wide range of traits – so it's important to treat them separately within the genetic evaluation system. Also, there is a measurable hybrid vigour effect in Friesian cross Holstein animals (Friesian-Holstein), which the new model accounts for, resulting in more accurate BVs.

3. Drastically reducing the number of genetic groups

Genetic groups are formed so that animals with unknown ancestors can be more fairly compared. This is particularly important in New Zealand, where the unknown ancestors can be from different breeds, e.g. Friesian or Jersey.

Genetic groups are a vital component of the genetic evaluation system, but they can be difficult to implement. Animals must be assigned to the correct genetic groups while ensuring each group contains enough animals to yield sensible solutions.

The old system's grouping method had become very complex, whereas NZAEL 2.0 simplifies the grouping of animals. This optimises equations and better targets the number of genetic groups. This improvement will likely contribute to greater stability in BVs over time.

These model improvements are also incorporated in LIC's Single Step Animal Model (SSAM), which will be fitting identical models (with the addition of genomic information).

New software

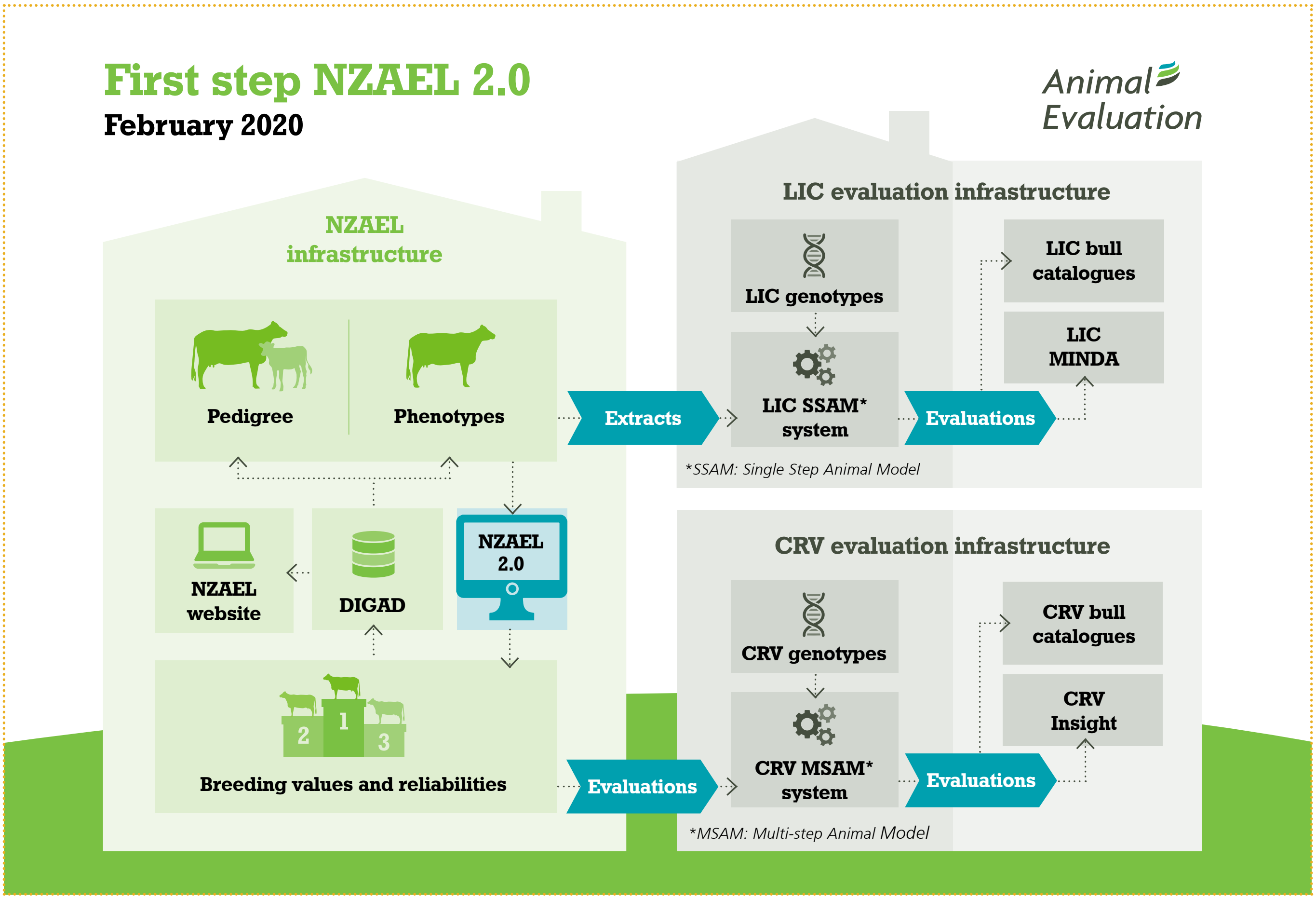
At the core of a genetic evaluation system are computer programs which fit the mixed models by forming and solving the model equations. In other words, the programs work with what we know, (performance and pedigree information, variances, and the mixed model equation) to predict the additive genetic merit of every animal.

For example, milk fat BVs are produced using performance information from herd-tested cows, which is extended across the rest of the animals in the pedigree, based on recorded relationships.

Evaluations are computed for 27 traits, including the eight economically important traits that contribute to BW: somatic cell score (which is the log transform of somatic cell count), milk fat, milk protein, milk litres, live weight, survival, body condition score and fertility.

Every animal in the pedigree increases the size of the mixed model equation. The current pedigree file has 30 million animals, and so solving these equations is a large computational task. The complexity of this task increases with every new animal that is included, and the national herd has grown by approximately 25 percent since the NZAEL 1.0 software was developed.

NZAEL 2.0 uses state-of-the-art computing software, which



Improving the genetic evaluation systems will help bull breeders and dairy farmers to increase the genetic merit of their herds and, ultimately, improve profits.

incorporates the last 13 years' worth of technological advances. These improvements enable the hugely complex system of equations to be solved quickly and reliably. The new software is much faster, with evaluations completing in less than 15 hours, roughly a quarter of the time taken by the NZAEL 1.0 software.

Adjustments – removal and updating

Over the years, several adjustments have been applied to the evaluations to increase their accuracy. These included the reproof adjustment, the parent average adjustment and the heterogeneous variance adjustment.

A reproof adjustment introduced to counteract a systematic drop in the BV of progeny-tested sires as they attain daughters in the wider national herd (the reproof effect) has now been removed, as it's no longer needed by the improved model.

The parent average adjustment addresses a systematic drop in the BV of young sires gaining their first daughter proof (progeny test proof). It's likely that the parent averages of animal evaluation (AE) enrolled sires are overestimated, due to sub-optimal partitioning of additive and non-additive genetic effects, and permanent environmental effects in their highly selected elite mothers. This adjustment is still required, and the factors applied to reduce the parent average breeding values for AE-enrolled sires have been updated.

The heterogeneous variance adjustment was originally designed to adjust the performance of herds of cows to a common variance, to give more accurate evaluations. The new system no longer needs this adjustment.

Standardisation

New standards for the pedigree and performance data used in genetic evaluations have been introduced for all trait sets. This standardisation extends to the data used by LIC in their SSAM evaluation system. NZAEL 2.0 and LIC's SSAM will use the same phenotypes and pedigree data for all traits. These standards will be most beneficial as we work towards NZAEL 3.0, which will be an independent national genetic evaluation system incorporating genomic data. It's due to be introduced in February 2021.

What improvements are still to come?

The February 2020 upgrade, the first of two stages, coincided with a similar upgrade to the LIC genomic evaluation system. The model equations and computing systems are now aligned across LIC and NZAEL. However, LIC evaluations benefit from the inclusion of genomic information. NZAEL will make use of genomic information to improve the accuracy of BW in the second stage of this upgrade, planned for February 2021.

The ongoing development of these systems will enable bull breeders and dairy farmers to increase the genetic merit of their herds and ultimately, improve their profits.

Find out more about this research, NZAEL and interpreting BVs at **dairynz.co.nz/animalevaluation**

SCIENCE SNAPSHOT

Tools for methane mitigation

What tools are being investigated to help farmers meet future methane emission targets? DairyNZ scientist Elena Minnee explores.

Methane is produced by bacteria during normal digestion of feed in the cow's rumen and hindgut. As such, there is a strong relationship between the amount of feed eaten and methane produced. However, there is evidence to suggest that this relationship can be altered by improving efficiency – that is, reducing emissions per unit of feed eaten.

Below, we look at key areas of research being conducted in New Zealand to improve emissions efficiency.

Low-methane ruminants

AgResearch's sheep-breeding programme has confirmed that some animals emit less methane than others, and the trait is heritable. The research has developed two sheep lines that differ in methane yield (g CH_4/kg DM eaten) by 11 percent[1].

The research is now being extended to dairy cattle, with the establishment of a NZ Dairy Genetics collaborative working group, including DairyNZ researchers, to develop breeding options for low-methane-emitting cattle.

Low-methane feeds

Diets of forage rape and fodder beet yield 20 and 30 percent less methane per kg of dry matter intake (DMI) than ryegrass pastures[2]. Research is extending to other forages.

Preliminary studies indicate methane yield is reduced when plantain is included at about 45 percent of a perennial ryegrass dominant diet[3]. Upcoming DairyNZ and AgResearch experiments will test these results.

Vaccines

Two species of methanogenic bacteria are responsible for 70 percent of methane produced. An AgResearch-led programme is aiming to develop a vaccine that targets and supresses the activity of these species to reduce methane emissions by at least 30 percent.

Inhibitors

A collaborative project funded by PGgRc[4] is investigating chemical inhibitors that suppress growth of methanogens and methane production in sheep and cattle by at least 30 percent. DairyNZ is involved in evaluating potential inhibitors for methane emissions and product quality.

Meanwhile, Dutch company DSM Nutritional Products has developed a feed additive, Bovaer®, that contains the methane inhibitor (3-NOP). Bovaer® successfully reduces methane emissions from livestock fed a total mixed ration. Research continues with this product to evaluate its applicability and efficacy in a pasture-based system.

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