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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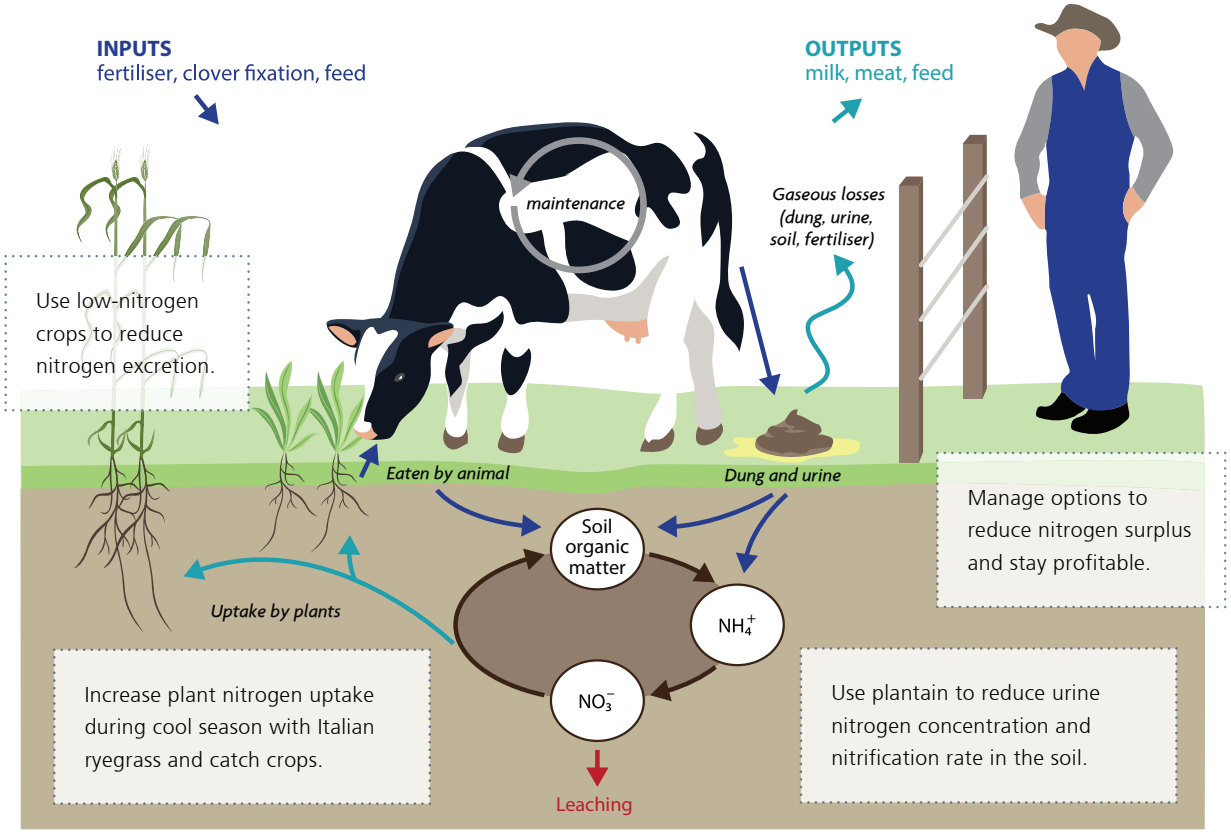
KEY POINTS

- 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].

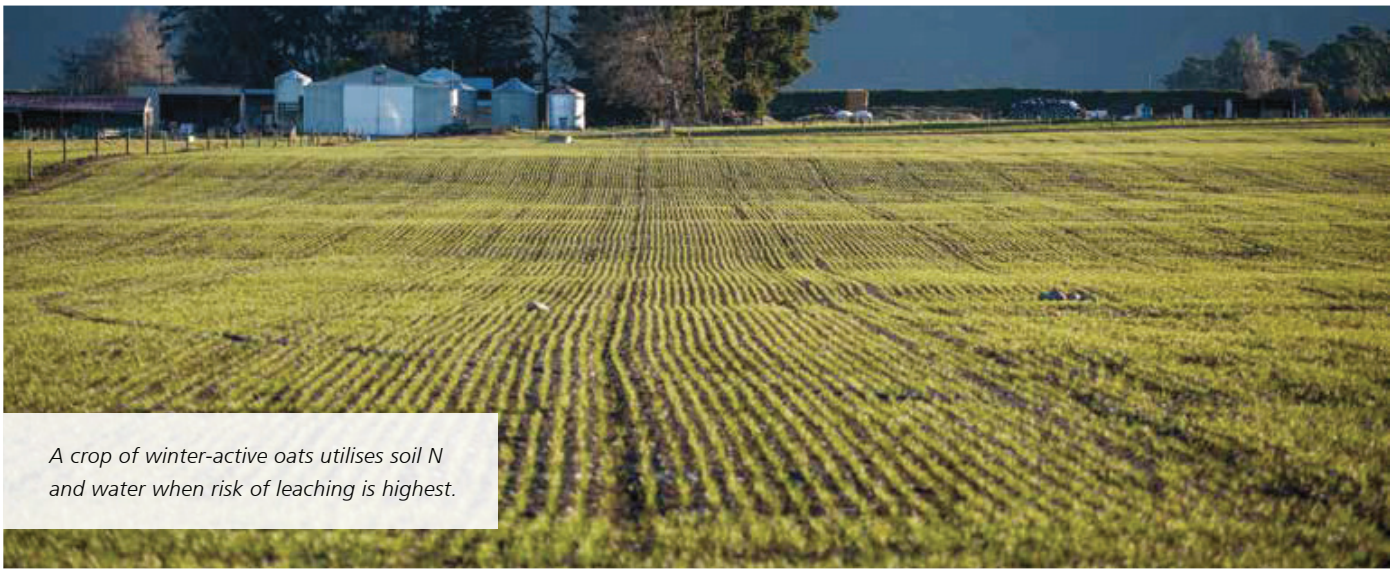
Implementation challenges

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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