Using plantain (*Plantago lanceolata*) with other on-farm strategies to meet N loss reduction targets while maintaining profit in Rotorua Lake catchment

Kate FRANSEN[1], Lydia FARRELL[1], Nicole WHEADON[2], Stephanie FRASER[3], Richard FOWLER[4], Clare BEUTH[5], Steve HOLDEM[6], Doug DIBLEY[7], Felix RODRIGUEZ-FIRPO[8], Jaimin BENTON[9], Christophe THIANGE[1]and Ina PINXTERHUIS[2]

[1]DairyNZ Ltd., Private Bag 3221 Hamilton, 3240, New Zealand
[2]DairyNZ Ltd., Lincoln, 24 Millpond Lane, Lincoln, 7608, New Zealand
[3]Bay of Plenty Regional Council, Level 2, 1118 Fenton Street, Rotorua, 3010 New Zealand
[4]Cholorfield Ltd., 310A Dalbeth Road, RD 2, Rotorua, 3072, New Zealand
[5]DA & CM Beuth, 202 Maraeroa Road, RD 2, Rotorua, 3072, New Zealand
[6]Holdem Farm, 1286 State Highway 5, RD 2, Rotorua, 3072, New Zealand
[7]Fernview Farm Ltd., 435 Oturoa Road, RD 2, Rotorua, 3072, New Zealand
[8]DairyNZ Ltd., Massey University, Tennent Drive, Palmerston North, 4474, New Zealand
[9]Agricom, C/O AgResearch, 10 Bisley Avenue, Ruakura, 3214, New Zealand.
*Corresponding author: Kate.Fransen@dairynz.co.nz

Abstract

Dairy farmers in the Rotorua Lake catchment need to make significant reductions in nitrogen (N) leaching to improve freshwater quality. One option is the inclusion of plantain (*Plantago lanceolata* L.) in pastures, which has been shown to reduce N leaching without compromising pasture or milk production. From 2022-2025, we worked with five Rotorua partner dairy farmers to develop strategies to establish and maintain plantain in pastures as part of a whole-farm approach to reducing N loss to water while limiting impacts on profitability. Modelling and benchmarking were used to determine the impact on N leaching and profitability at farm and catchment scale. Farms on well-drained pumice or podzol soils achieved up to 20% plantain (%DM) by broadcasting 4-6 kg/ha of coated plantain seed (2-3 kg/ha bare seed) across the whole farm each year, costing $45-$68/ha per year. Plantain content in pasture DM varied from 1-65% depending on establishment method, management, soil type and contour. Including 20% plantain in pastures was estimated to lower N leaching by 8-14% with a 1-2% reduction in profit. Using plantain in a modelled mitigation stack to meet the 2032 N loss reduction targets (27-30% reduction from 2021-22 N loss), resulted in 4.7-7.5% higher profit/ha/year compared to meeting the same targets without plantain. At catchment scale, implementing plantain at 20% DM content of pasture was estimated to reduce N entering Lake Rotorua by 39 t N/year. A case study using benchmarking data demonstrated high profitability with low N loss by maintaining a low-cost structure, strategic use of mitigations including plantain, and tactical management of low N fertiliser inputs.

Keywords: case study, modelling, benchmarking, overseer, partner farm

Background

Farmers in the Rotorua Lake catchment are working under regulatory requirements to reduce nitrogen (N) losses and meet a catchment-wide target of decreasing N discharge into Lake Rotorua from 755 to 435 tonnes per year. The OverseerFM (hereafter referred to as Overseer; Overseer 2024) model has been used to benchmark N loss and monitor progress toward N discharge allocations (NDAs). Individual farm targets step down over time - key milestones are set for 2022, 2027, and final targets by 2032/33, relative to their 2017 leaching (baseline). For the 26 dairy farmers in the catchment, an average 31% reduction in N leaching is required by 2032 (Bay of Plenty Regional Council; BOPRC 2016).

One mitigation option is the inclusion of plantain (*Plantago lanceolata* L.) in pastures, which has been shown to reduce urinary N concentrations and Nitrate leaching without compromising dry matter (DM) production (Hintz et al. In Press; MPI 2025; Navarette et al. 2023, Pinxterhuis et al. 2024). Overseer accounts for the effect of plantain on urinary N by adjusting the urine patch equations (Overseer 2020). The model currently does not account for further effects on N leaching that may be driven by soil mechanisms (Carlton et al. 2019; Egan et al. 2025; Talbot et al. 2020; Woods et al. 2018).

Since 2022, farmers in the catchment have partnered with the DairyNZ-led 'Plantain Potency and Practice Programme' (DairyNZ 2024a) to explore the practical

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Table 1 Rotorua Plantain partner farm details (2024-25 season) sourced from DairyBase (DairyNZ 2024c, Farms 1, 2 and 4) and from farmer-supplied data (Farms 3 and 5).

	Farm 1	Farm 2	Farm 3	Farm 4	Farm 5
Elevation (masl)	400	500	400	600	400
Soil order	Pumice (well drained)	Pumice (well drained)	Pumice (well drained)	Podzol with cemented tephra layer at varying depth.	Pumice (well drained)
Contour	Rolling	Rolling-steep	Rolling	Rolling-flat	Rolling
Stocking rate (cows/ha) on milking platform	2.6	2.8	3.0	3.2	2.9
Wintering	1/3 of herd wintered off	All cows wintered off	All cows wintered off	Wintering barn, swedes	23% of cows wintered off
Young stock	Support block off farm	Support block within farm	Support block off farm	Support block within farm	Support block off farm
Imported Supplement (t DM/ha)	0.4	2.2	5.2	3.7	4.8
Nitrogen fertiliser (kg/ha/year)	0	103	150	77	92
Milking frequency	Twice daily	Twice daily	Twice daily	Once daily	Twice daily
Milk solids production (kg/ha)	1082	1163	1407	1007	1037
Pasture and crop eaten (t DM/ha/year)	11.8	12.6	11.5	10.1	9.8
Plantain (% of total DM, effective area)	21	18	18	12	8
*Nitrogen leaching (kg/ha)	42	58	57	43	38
*2032 NDA (kg/ha)	41	42	42	31	**N/A

*Overseer leaching and NDA targets (Overseer v. 6.5.10) include support blocks for Farms 1 and 4.
**NDA for Farm 5 includes areas of forestry and excludes an area of the farm not inside the catchment boundary. For these reasons, it has not been included here.

use of plantain in meeting their NDAs. There is an approximate linear relationship between the proportion of plantain in the pasture and the reduction in N leaching as modelled in Overseer (MPI 2025). A key challenge associated with use of plantain is achieving and maintaining sufficient levels across whole farms to make a material difference to N leaching (Dodd et al. 2019; Dodd et al. 2025). From 2022-2025, the Programme worked with farmers in five catchments across New Zealand to address this challenge - developing strategies for successful plantain establishment and management, identifying realistic amounts of plantain that can be achieved across farms, and assessing the potential economic and environmental impact of plantain for meeting N loss targets. Here, we discuss dairy farmer case studies in Rotorua Lake catchment and the wider implications for farmers in the catchment in terms of:

a) The amount of plantain that can be successfully established and maintained, and the corresponding influence of landscape and management practices.
b) Modelled N load and economic impact of plantain as part of a mitigation stack at farm scale.
c) Other on-farm strategies that are important for achieving low N loss while maintaining high profitability.
d) Potential contribution of plantain for meeting N load reduction targets at catchment scale.

A companion paper (Farrell et al. 2025) provides the results of catchment-scale economic modelling.

Approach

Farm details

Five partner farms were selected based on land class and the collaborative nature of the farmers. All are located on the Mamaku Plateau on pumice or podzol soils 400-600m above sea level. According to the landform classifications of the Mamaku Plateau described by Bakker et al. (1996), Farm 1 is located in the East Landscape (E1), Farms 2 and 4 are in the Middle Landscape (M1), Farm 3 is in the south end of the North Landscape (N3) and Farm 5 is on the northeast shore of Rotorua Lake. Mean minimum and maximum temperatures are 4 and 11ºC in mid-winter (July) and 12 and 23ºC in mid-summer (January). Annual average rainfall ranges from 1900-2200mm. Specific details of each farm are described in Table 1.

Classification of land area

Within each farm, land was classified into areas according to blocks set up in their Overseer files, with

key variables including soil order, contour, effluent application, and land use (dairy herd, dry stock, crop or forestry). These variables were then considered in the analysis of plantain establishment and persistence. Within farms, the key points of differentiation included effluent application, land use, and contour.

Plantain establishment and management

All farms used Ecotain plantain, a blend of cv. Agritonic and Tonic. Four plantain establishment methods (Table 2) were used. These are described as follows.

Over-sowing/broadcasting plantain seed into existing pastures (all farms)

Over-sowing was the main method of establishment (Table 2). Large proportions of Farms 1-4 (92-100% by Year 3) were over-sown with plantain annually, while on Farm 5, a single over-sowing of 28% of the farm area (the Effluent block) occurred in 2023. The approach varied as follows.

a) Bare plantain and clover seed broadcast with a tow-behind seed spreader in autumn (Farm 4)
b) Prillcote® seed with N fertiliser broadcast from a tow-behind fertiliser spreader in spring (Farm 3)
c) Prillcote® seed with phosphorus fertiliser spread from a fertiliser truck in spring (Farms 1, 2 and 5).
d) Prillcote® seed spread from a drone on steep areas at 2 kg/ha in spring (Farm 1, 2023)

Coated seed was used to increase the weight of the seed, enabling a more even spread. Prillcote® is applied at double the rate (kg/ha) of bare seed to achieve the same sowing rate (# seeds/ha). In 2023, seeding rates of 0, 1 and 2 kg/ha (BSE) were over-sown on 10, 14 and 23 paddocks respectively on Farm 1. Visual assessments in 2023 and 2024 were compared to determine effectiveness, accounting for interactions with Overseer block description and management.

Drilling with ryegrass and clover following crop (Farm 3)

On Farm 3, a new pasture mixture of diploid perennial ryegrass (19-21 kg/ha), white clover (3-5 kg/ha) and plantain (3 kg/ha) was sown following summer crops in March 2023 (four paddocks) and March 2024 (two paddocks).

Over-sowing into new ryegrass monocultures (Farm 2 and 4)

On Farm 4, 6% of the farm was used for winter swedes crop. Following the crop, some paddocks were returned to crop while others were sown with ryegrass monocultures in late spring (November) or summer (February), providing opportunity to control broadleaf weeds before over-sowing with plantain and clover in March or April.

On Farm 2, 8% of the farm was sown to new grass without plantain in autumn 2024 following maize crops and was oversown with plantain following broadleaf weed control in spring.

Under-sowing with grass and clover (Farm 2)

On Farm 2, a seed mix of hybrid ryegrass (cv. Mohaka, 18 kg/ha), plantain (2 kg/ha) and white clover (1 kg/ha) was drilled into existing pastures on 50% of the farm in autumn 2024. The whole farm, including those paddocks, were over-sown with plantain at 2 kg/ha in spring 2024.

Grazing and weed management

All partner farmers used rotational grazing with round lengths set to achieve a pre-grazing target of 2-3 leaves on ryegrass and to meet seasonally determined target covers. No adjustments to round lengths or residual covers were made to account for plantain presence. There is currently no published evidence of any benefit to changing grazing management for maintaining plantain content in grass-based swards.

There are limited options for controlling mature broadleaf weeds in plantain-mixed swards. While bentazone can be effective in young swards, Hintz et al. (2025) found it was ineffective for controlling mature dock weed (*Rumexobtusifolius*) in older swards. All five partner farmers used spot spraying or a boom spray to control clusters of broadleaf weeds (predominately thistles).

Assessment of plantain

The DairyNZ Visual Assessment Guide (DairyNZ 2024b) was used to conduct an annual estimate of plantain content in mixed species pastures across whole farms, including paddocks not sown to plantain, in autumn (March-May) each year from 2023 to 2025. In total, 346 paddocks were assessed each autumn. Content was defined as the percentage contribution to available herbage dry matter within a week of grazing. Estimates of clover content were made at the same time. Assessors walked diagonally across each paddock and at regular intervals estimated the percentage of plantain and clover in the pasture and, on completion, an average estimate for the whole paddock. A weighted average was then calculated for the effective grazing area, including paddocks without plantain, to give the average whole farm content. Autumn was chosen as the most appropriate time to assess plantain content given that this is an important time for N loss, as risk of drainage increases and plant N uptake reduces due to reduced growth (Di et al. 2002, Shepherd et al. 2011). On a subset of 59 paddocks in Rotorua and 163 paddocks in the wider partner farm network during Year 1 (2023), pasture snip cuts (a handful of herbage

each) were taken to 4-5cm stubble height every 10-20m as assessors walked their transect. Samples were bulked for each paddock and a 40g sub-sample divided into ryegrass, plantain, clover, dead and other before drying at 60ºC for 48 hours. Composition was then calculated as a proportion of dry matter. The resulting plantain percentage was then compared with the visual assessment to verify its accuracy.

Statistical analysis

The analysis tested relationships between plantain content and paddock management variables. There were many combinations of seeding rates, timing of establishment, soil, slope, effluent use, fertiliser application, and grazing management, which hindered analysis of the full data set. However, repeated measures ANOVA was used to test, depending on the farm, for the effects of all or a subset of: Overseer block (accounting for soil type, slope, effluent input, and cropping history), plantain seeding rate, seeding method, year of seeding, and their interactions within farms. Analyses were performed using R version 4.4.1 (R Core Team, 2024) and the nlme package (3.1-164, 2023).

Farm-level modelling and benchmarking analysis

Benchmarking against DairyBase (DairyNZ 2024c) data and Overseer modelling were used to assess the potential impact of plantain in the farm system. Each of the partner farms were modelled in Overseer with and without 20% plantain across the pasture areas of the farm as an achievable level for farms in the catchment. Dairy support block areas were included for Farms 2 and 4, as these areas are included in the farm NDA targets.

Farmax (Farmax, 2025) modelling on Farms 2 and 4, using DairyBase data for the 2021-22 season (milk price $9.30/kg milksolids), determined the potential economic impact of mitigation stacks which reach the 2032 NDA target with and without plantain.

DairyBase data were used to populate farm parameters in Farmax baseline models. A detailed case study was developed for Farm 1, based on a 6-year DairyBase analysis, to demonstrate the effects of implementation of plantain and other farm management strategies on N leaching reduction targets and profitability.

Catchment-level modelling

The DairyNZ Catchment Accounting Framework (CAF) was used to assess impact of plantain sown at 20% (PL20) on N loading in the catchment for both dairy and sheep and beef (S&B) farms. For S&B farms, areas of plantain were applied to flat land only. The CAF is a spatial inventory of land cover, land use, and associated nutrient yields across New Zealand. It can be queried to provide a breakdown of N or phosphorus losses by land use/cover within an area of interest (e.g., Rotorua Lake catchment), for a reference scenario (baseline), or after adoption of specific mitigations. The CAF combines land cover data from the Land Cover Data Base (LCDB) with land use data from AgriBase (AsureQuality 2023).

Pastoral properties from AgriBase are used to define a coverage of drystock and dairy land use. For other areas not part of this coverage, the CAF falls back on LCDB data. Annual N loss rates (kg/ha/year) for LCDB classes were gleaned from the literature. For dairy polygons from AgriBase, the CAF implements a typology approach (Monaghan et al. 2021) providing spatially varying annual loss rates. A similar dataset was provided by AgResearch for S&B properties, using region-specific S&B farm classes as described in Monaghan et al. (2021). The nutrient loss reductions from plantain modelled for partner farms in Overseer were applied to typical loss rates relating to the targeted land uses and typologies, and then scaled to assess their impact on overall nutrient losses in the study area.

Results and Discussion

Plantain visual assessment and botanical composition

Visual assessment of plantain was closely related with the botanical measurements (Figure1). Fifty eight percent of visual assessments were within +/-5% of the botanical measurements and 80% were within 10% (Figure 1). A similar result was found across the national partner farm network (Figure 1). Where variation occurred, the visual assessment tended to estimate higher plantain content than the botanical measure (Figure 1). Both methods have inherent limitations. Visual assessment is subjective and reliant on the calibrated eye of the assessor, while gathering a representative botanical measure by walking a diagonal line can be difficult, especially in undulating landscapes and with inconsistency of plantain across paddocks. Additionally, botanical sample collection can inadvertently select against large plants, such as mature plantain. Ongoing research aims to improve the visual assessment method using photographs, drones, and artificial intelligence.

Farm-level plantain content

Farms 1-3 achieved 16-22% plantain across the pasture area (excluding areas used for crop) in Years 1-3, predominantly through over-sowing annually at rates between 2-4 kg/ha BSE (Table 2). Similar results (17% by 2025) were achieved on Farm 5 in the area sown. Farmer 4 was less successful in establishing plantain via over-sowing, achieving 9% from sowing 2-2.5 kg/ha bare seed in 2022, increasing to 12-14% with a lift in

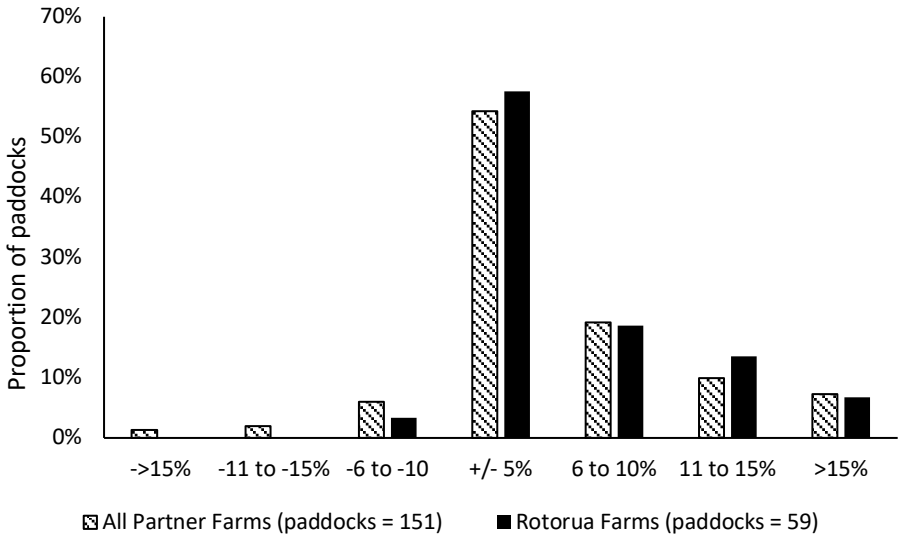

Figure 1 A comparison of visual assessment of plantain abundance in paddocks expressed as variation from the botanical measurement recorded for the same paddock (visual assessment minus botanical composition measure as DM%).

Table 2 Plantain seeding rates and resulting whole farm plantain % (based on individual paddock visual assessments) as a proportion of total pasture herbage dry matter (DM) for five Rotorua Lake catchment partner farms (total 346 paddocks). N/A = not assessed.

Farm	Year	% farm broadcast	Ecotain rate (kg/ha*)	Autumn whole farm plantain visual assessment (% of total DM)	Additional interventions
1	2022/23	100 (Nov)	2	19	2023 broadcast seed rate trial: 10 paddocks 0 kg/ha 14 paddocks 1 kg/ha 20 paddocks 2 kg/ha
	2023/24	80 (Nov)	1 & 2	22	
	2024/25	100 (Nov)	2	21	
2	2019/20, 2021/22	100 (Oct)	3-4	N/A	2 kg/ha undersown with Hybrid (cv. Mohaka) ryegrass and clover on 50% of farm in Autumn 2024 (in addition to broadcast). 6% & 8% of farm area in maize crop/new grass (without plantain) rotation in 2024 & 2025. Plantain over-sown in spring.
	2022/23	100 (Oct)	2	16	
	2023/24	100 (Oct)	2	22% (exc. crops)	
	2024/25	95 (Oct)	2	20% (exc. crops)	
3	2022/23	44 (Oct)	4	N/A	10% and 4% of farm area sown with new pasture in 2023 and 2024 respectively at 4 kg/ha Ecotain
	2023/24	52 (Oct)	4	19	
	2024/25	100 (Oct)	2	18	
4	2021/22	51 (Sep)	2.5	N/A	4-7% of farm area in swedes crop/ new grass (sown without plantain) rotation each year. Oversown with plantain in autumn.
	2022/23	94 (Mar)	2	9 (exc crop)	
	2023/24	88 (Apr)	3	14% (exc crop)	
	2024/25	94 (Apr)	4	12 (exc crop)	
5	2023/24	28 (Nov)	4	7 (15% in area sown)	20% of farm outside broadcasted area with plantain content >5% from historical sowings.
	2024/25	0	0	8 (17% in area sown)	

*Seed rates are presented as the bare seed equivalent (BSE); coated seed (Prillcote®) weighs double the weight of bare seed. All farms used Prillcote® seed except Farm 4 which used bare seed.

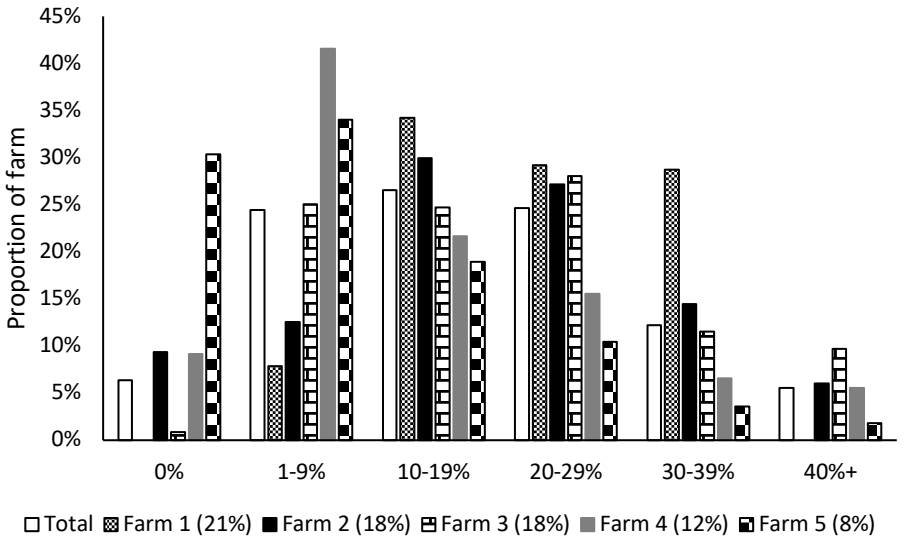

Figure 2 Proportion of total area across Rotorua Lake Partner Farms 1-5 in 2025 with varying levels of visually assessed plantain as a % of total dry matter. Bracketed numbers are the average percentage of plantain across the whole farm.

seeding rate to 3 kg/ha and 4 kg/ha in 2023 and 2024.

There was a range of plantain content within farms (Figure 2). At the 2025 measurement, 57% of farm area (118 paddocks) on Farms 1-3 had 10-29% plantain content, with 22% of farm area (43 paddocks) at >30%, 15% of farm area (33 paddocks) with 1-9% and 5% (10 paddocks) with 0%. Farm 4 had a higher proportion of the farm with 1-9% plantain while Farm 5 had a higher proportion with 0% plantain. Areas with 0% plantain on Farms 2 and 4 were due to cropping and pasture renewal. On Farm 5, the area with no plantain had not been sown to plantain.

Achieving up to 20% plantain content via broadcasting alone is a strong result. Bryant et al. (2019) found over-sowing on six paddocks on two irrigated Canterbury farms achieved <5% plantain content; on one farm in the Waikato, 17-45% was achieved. Dodd et al. (2022) found 14-16% plantain was achieved via broadcasting in the Tararua district of the lower North Island; whereas in a survey of paddocks across New Zealand, Dodd et al. (2019) reported an average of 8% plantain content on over-sown paddocks.

Method of establishment and other drivers of plantain content

Over-sowing seeding rate and frequency

Similar levels of plantain (15-20%) were achieved on Farms 1, 2, 3 and 5 regardless of the seed rate used (2, 3 or 4 kg/ha BSE). In other studies, proportion of plantain in pastures has also been poorly correlated with seeding rate (Dodd et al. 2019, Dodd et al. 2022).

Results from Farm 1 using variable seeding rate (0, 1 or 2 kg/ha BSE) during 2023 did not significantly affect plantain proportions in the following years (P>0.05). Results from Farm 5 also indicate a degree of persistence. In addition to the area oversown in 2023, a further 20% of Farm 5 contained levels of plantain between 5 and 30% (average 13%), resulting from previous inclusion of plantain in seed mixes before the onset of this programme. Similarly, the lack of decline in the area not broadcast to plantain in 2023 on Farm 1 may indicate that levels could be maintained with less frequent applications on some farms. Persistence on Farms 1 and 5 contrast to the experience of Farmer 2, where visual decline in plantain content occurred in 2021 after missing a year of broadcasting in 2020. Other studies have found that plantain generally persists for two years, declining in Year 3 (Dodd et al. 2025).

Oversowing into ryegrass monocultures (Farms 2 and 4)

On Farm 4, oversowing plantain into ryegrass monocultures in late spring (November) or summer (February) following broadleaf weed control resulted in 15-45% plantain (n = 4 paddocks), the following autumn. On Farm 2, spring oversowing of plantain into autumn sown ryegrass monocultures saw mixed success; five of seven paddocks assessed had <5% plantain content the following autumn and the remaining two paddocks had 10% and 30% plantain content. This may have resulted from the spring/summer competitiveness of the new grass.

Drilling with ryegrass and clover following crop (Farm 3)

Six paddocks sown to a diploid perennial ryegrass,

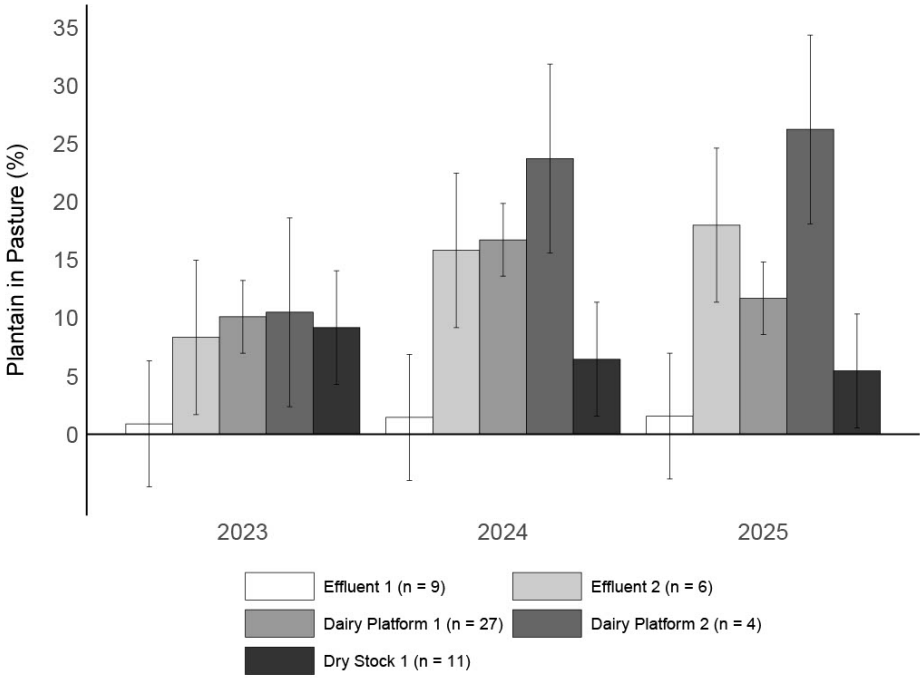

Figure 3 Plantain content (% of available herbage mass) on different areas of Farm 4 with the same seeding rate over three years. Number of paddocks per block in brackets. Bars are standard errors of the mean.

white clover and plantain mix following summer crops (Farm 3) had an average plantain content of 41% (range 25-65%). The higher plantain levels achieved when sowing with new grass is consistent with other studies (Dodd et al. 2019, Bryant et al. 2019, Dodd et al. 2022). The disadvantage of this approach is the limitations on broadleaf weed control options following establishment. On-label use of bentazone with or without flumetsulum provides good control of small broadleaf weeds in young pastures containing plantain (Gawn et al. 2012). However, these chemicals are more expensive than less selective options.

Undersowing with hybrid ryegrass and clover (Farm 2)
Broadcasting plantain in the spring, following direct drilling of hybrid ryegrass, plantain and white clover mix in autumn 2024, did not significantly change autumn (2025) plantain contribution compared with paddocks receiving spring 2024 broadcasting of plantain only. A next step would be to test whether plantain content could be maintained by either spring broadcasting or including plantain in the autumn seed mix (rather than both) in areas direct drilled with the more competitive hybrid ryegrass.

Land class and management as defined by Overseer block
Overseer blocks, as defined by differences in effluent input, soil type and contour, did not significantly affect plantain proportions on Farms 1-3. However, small parts of very steep areas on Farms 2 and 3, where it is difficult to spread seed, were observed to have less plantain. Spreading seed via a drone at 2 kg/ha on Farm 1 in 2023 resulted in only small proportions of plantain (5%) on these areas. Drone accuracy may have been an issue, given that higher proportions of plantain were observed in gullies adjacent to the steep slopes. Other explanations could include higher proportions of grass weeds and thatch in unutilised areas taking up space; or pests such as slugs harboured in less palatable forage.

Overseer block type significantly affected plantain proportion on Farm 4 (Figure 3). The five main blocks have the same soil type - pumice with an impenetrable layer of volcanic tephra, at varying depths across the farm. Four blocks (Dairy Platform 1 and 2, Effluent 2 and Drystock 1) are gently undulating and slightly elevated compared with Effluent 1, which is flat. This block is susceptible to waterlogging and pugging during winter and is located at the lowest point on the farm and close to the dairy shed.

Plantain was sown at the same rate within each year—2 kg/ha in 2022, 3 kg/ha in 2023, and 3 kg/ha in 2024—over three consecutive years in the blocks represented in Figure 3. Differences in plantain proportion in 2023 were not significant. In 2024 and 2025, Effluent 1 had less plantain than both Dairy Platform blocks ($P<0.05$).

Dry Stock 1 had less plantain than Dairy Platform 2 ($P<0.05$) and numerically had the second lowest plantain proportions in both years. Low proportions in Effluent 1 may be related to the very wet soils and pugging in the winter and spring following spreading seed in autumn. The Dry Stock block contained a higher proportion of annual and perennial grass weeds, which may be occupying space required for plantain germination. A full botanical composition assessment on these paddocks, along with control of the grass weeds prior to establishment may assist in improving plantain content.

Farm-scale modelling

There were several limitations of the Farmax/Overseer analysis which may have influenced the outcome. These include use of a single year of benchmarking data, expenses and milk price with no sensitivity analysis; use of only 2 of 26 farms in the catchment; and assumptions that 20% plantain would be achieved through over-sowing 3 kg/ha/year. Mitigations included in the stack and the corresponding impact on N leaching were also limited to those available in the Overseer model. However, useful insights were gained.

Modelled effect of plantain on leaching

Incorporating 20% plantain into pasture (P20) was estimated to reduce N leaching on Farms 1–5 by 8–14%, with an average reduction of 11% (Table 3). Actual impact of plantain on leaching may be higher than the modelled estimate when soil mechanisms are accounted for in addition to the effect on urinary N concentration. Preliminary results from farmlet trial research show a N leaching reduction of 26% over three years from swards with average 17% plantain (MPI, 2025).

Table 3 Summary of farm-scale N leaching reductions and impact on annual farm operating profit at 20% (P20) plantain compared with 0% plantain modelled in Overseer V 6.5.4 for five partner farms using DairyBase data from the year 2021-2022 (milk price $9.30/kg MS). N/A = not assessed.

Farm	N leaching reduction at P20	Profit reduction
Farm 1	14%	1%
Farm 2	11%	2%
Farm 3	10%	N/A
Farm 4	9%	2%
*Farm 5	4%	N/A

*Includes area of forestry. Subsequent modelling of 2024-25 season on the dairy platform only indicates a 8% reduction in leaching from P20.

Effect of plantain on operating profit

The effects of incorporating plantain on operating profit were estimated for Farms 1, 2, and 4 using DairyBase data for the 2021–22 season (milk price $9.30/kg MS). The additional cost was that of Prillcote® Ecotain seed, priced at $11.40/kg applied at 6 kg/ha (3 kg/ha BSE) with annual phosphorus fertiliser in spring. This cost of $68.40/ha reduced annual farm operating profit by 1-2% (Table 3). No changes to farm revenue were made.

Modelled value of plantain as part of a mitigation stack to reach the 2032 NDA

In reaching the 2032 NDA targets, Rotorua farmers will need to stack a combination of mitigations together. Comparing the cost of mitigation stacks with and without plantain helps to estimate the value of plantain to the business (Table 4).

One strategy to reach the Farm 2 2032 NDA of 41 kg N/ ha would require a 20% plantain content, limiting imported feed to 500 kg DM/cow (removing soyabean meal and feeding only maize silage), removing autumn N fertiliser and bringing culling forward from 20th May to 31st March. The reduction in annual farm operating profit was estimated at 8% (Table 4). Without plantain, Farm 2 would also need to remove all N fertiliser with corresponding reductions in stocking rate and milk production, resulting in a 12% reduction in farm profit. Overall, the scenario with plantain was 4.7% more profitable than the scenario without plantain.

One strategy to reach the Farm 4 2032 NDA of 33 kg N/ha, would require a 20% plantain content, reduced feed inputs by 10% (mostly in late spring), and a lowering of annual N fertiliser to 55 kg/ha by removing the autumn application. The reduction in farm profit was estimated at 10%. Without plantain, Farm 4 would also need to limit imported feed to 500 kg DM/ha and reduce stocking rate by c. 10%, replace PKE with maize silage, and remove all N fertiliser. The resulting reduction in farm profit was 16%. Overall, the scenario with plantain was 7.5% more profitable than the scenario without plantain.

Catchment scale modelling

Using CAF modelling, we estimated that plantain implemented at 20% (P20) of pastures on all dairy farms and on flat S&B land would achieve 7.4% (39 t N) reduction in the total annual N load from the catchment (Table 5). For the 26 dairy farms, P20 would achieve 36% (35 t N) of the dairy target of a reduction of 96 t N/year; whereas, for S&B farms, implementing P20 on flat land would achieve 9% (4 t N) of the S&B target of a reduction of 44 t N/yr. Economic modelling (Farrell et al. 2025) indicates that the 26 dairy farms in the catchment would retain $0.5M per year in farm

Table 4 Farmax and OverseerFM V 6.5.4 outputs from implementing a mitigation stack in the 2021-22 season ($9.30/kg MS milk price) to achieve NDA targets of Farm 2 and 4 with and without use of 20% plantain content as a mitigation.

	Farm 2			Farm 4		
	Starting point (2021-22)	With 20% plantain	Without plantain	Starting point (2021-22)	With 20% plantain	Without plantain
*N leaching (kg/ha)	58	41	41	45	33	33
Peak milking cows (head)	705	597	567	460	460	420
Stocking rate (cows/ha)	2.7	2.3	2.1	3.3	3.3	3.0
Culling date	20th May	20th May	31st Mar	31 May	15 Feb	15 Feb
Production (kg MS/ha)	1,115	917	870	998	947	866
Imported feed (kg DM/cow)	1,182 (Maize, Soyabean meal, DDG)	500 (Maize)	500 (Maize)	741 (PKE, molasses, tapioca)	726 (PKE, molasses, tapioca)	500 (Maize silage, PKE, molasses)
N fertiliser (kg/ha)	68	60	0	83	55	0
Operating profit ($/ha)	4,207	3,880 (-8%)	3,701 (-12%)	3,452	3,120 (-10%)	2,891 (-16%)

*N leaching per hectare is calculated using the total farm area including a support block, while stocking rate, production and operating profit per hectare are divided by the size of the milking platform.

Table 5 Target N load reductions from all dairy and all sheep and beef (S&B) farms in Rotorua Lake catchment (from BOPRC 2016) and estimated reductions in N load at catchment scale from implementing plantain at 20% of pasture herbage dry matter (P20)

Sector	2011 N load (t N/yr)	Target reduction (t N/yr)	Proportional reductions from sector as % of sector load	Estimated reduction from P20 (% N loss)	Estimated reduction from P20 (t N/yr)
Dairy	273	96	35.3	9.8	35
S&B	253	44	17.2	1.9	4
Total	526	140	26.6	5.7	39

operating profit by using plantain compared with meeting their 2032 NDAs without plantain.

DairyBase benchmark analysis of Farm 1

The 6-year DairyBase benchmark analysis for Farm 1 (Table 6) provides an example of the actual impact of changes implemented to reduce N leaching, on financial and physical farm system performance. Knowing that N leaching limits were coming when they took over farm ownership in 2019/20, Farm 1 was set up with low imported feed and fertiliser input. The low input system led to a low-cost structure. Operating expenses in 2021-22 were 67% of the benchmark, while milksolids production was 90-98% of the benchmark in the first three years. Nitrogen leaching modelled in Overseer for 2019/20 was 52 kg N/ha, with the BOPRC nutrient discharge allowance set for the farm at 54 for 2017 (starting point), 50 in 2022, 45 in 2027 and 40 in 2032.

Nitrogen fertiliser application was 40 kg N/ha/yr in 2019/20 and was used tactically to achieve target pasture covers in late winter, and in autumn to meet target winter pasture cover. Nitrogen fertiliser was reduced to 28 kg N/ha/yr and then 25 kg N/ha/yr in 2020/21 and 2021/22 by removing the autumn application. Stocking rate and production were maintained while N leaching declined by 10%. A lower stocking rate and good pasture growth conditions coming out of winter in 2024 allowed N fertiliser to be eliminated in 2024/25 while milksolids production was maintained. Clover levels assessed via visual assessment in autumn were relatively high at 17%, possibly reflecting the low N use on the farm (Egan et al. 2018). Clover levels on the other farms were lower (12-14%) for the same period ($P<0.05$), most likely due to higher use of N fertiliser (Table 1).

Plantain was introduced to the system in 2022/23 when 8 kg/ha of Prillcote® Ecotain plantain seed (Table 2) was applied with the annual phosphate fertiliser in

Table 6 DairyBase (DB) benchmark analysis for Farm 1

	Farm 1 *2019/20	DB 2019/20	Farm 1 *2020/21	DB 2020/21	Farm 1 2021/22	DB 2021/22	Farm 1 2022/23	DB 2022/23	Farm 1 2023/24	DB 2023/24	Farm 1 *2024/25
Number of farms in the benchmark group		20		22		24		24		32	
Rainfall	1424		1752		2791		3299		1734		1596
Plantain % in pasture	0%		0%		0%		19%		22%		21%
N fertiliser applied (kg/ha)	40		28	112	25	80	24	85	30	87	0
N leached modelled in Overseer V6.5.10 (kg N/ha)	52		49		47		42		40	**53	42
Production Kg MS/ ha	1057	1165	1071	1193	1095	1111	979	1144	923	1094	1082
Gross Farm Revenue ($/kg MS)					$9.90	$9.71	$9.47	$8.97	$9.28	$9.06	
Gross Farm Revenue ($/ha)					$10,845	$10,785	$9,269	$10,264	$8,566	$9,910	
Operating expenses ($/ha)					$5,296	$7,202	$5,138	$7,669	$4,224	$6,861	
Operating expenses ($/kg MS)					$4.84	$6.48	$5.25	$6.70	$4.58	$6.27	
Operating Profit/ha					$5,549	$3,583	$4,130	$2,595	$4,342	$3,049	
Operating profit/ha as % of benchmark					155%		159%		142%		
Stocking rate (Cows/ha)	2.8	2.7	2.9	2.8	2.9	2.9	2.8	2.7	2.6	2.7	2.7
Off-farm grazing eaten (dry cows) t DM/ha	0.8		0.8	0.5	0.9	0.6	1.2	0.6	0.8	0.3	0.8
Imported Supplement Eaten (t DM/ ha)	0.5		0.4	2.6	1.4	2.7	1.4	2.6	0.4	2.1	1.1
Supplement Made (t DM)	0.3		0		0.4		0		0.2		0.3
Pasture and crop harvested t DM/ha	11.8		12.3	11.7	11.7	12.2	10.8	11.6	11.8	11.9	
Pasture cover on 31st of May	2537		2253		2281		2354		2465		2422
6 Week In Calf (%)	54		49		65	71	61	64	74	66	67
Not in calf (%)	16		22		21	15	15	17	15	15	17

*Farmer supplied data (data in other years is sourced via DairyBase).
**Average N leaching for the Rotorua Lake catchment for dairy farms. Provided by Bay of Plenty Regional Council.

spring. This initial application cost approximately $91/ha, reducing profitability by around 2%, and resulted in an average of 19% plantain content across the farm. In 2023/24, half the farm was broadcast at 2 kg/ha Prillcote® and the other half at 4 kg/ha Prillcote®, with an average cost of $34/ha (<1% impact on profit). In 2024/25, 4 kg/ha was used, costing $45/ha.

The introduction of plantain to the system in 2022/23 coincided with an extremely wet season and a small reduction in stocking rate from 2.9 to 2.8 cows/ha. Milk production and pasture eaten were lower compared to the previous season, while profitability relative to the

benchmark was maintained. Stocking rate and imported supplement were reduced in 2023/24 to 2.6 cows/ha and by 0.5 t DM/ha, respectively, which was associated with a further drop in milk production and 5% drop in N leaching, though pasture and crop harvested/ha was restored to 2021/22 levels. In 2024/25, stocking rate was increased to 2.7 cows/ha and milk production was equivalent to levels achieved prior to the wet year. Given the challenging seasonal conditions and changes to stocking rate in the first two years of plantain implementation, it is difficult to assess the effect of plantain on the farm system performance in isolation. However, the continued strong performance relative to the benchmark, together with the 2024/25 performance suggest that plantain has not had a negative effect on farm performance.

At 40 kg N/ha, the Farm 1 2023/24 N leaching levels are 25% below the average of all dairy farms in the catchment (average 53 kg N/ha/year, BOPRC unpublished data). Annual farm operating profit is 142-159% of the district average benchmark farm. Overall, Farm 1 provides an example of a farm that has been able to maintain high profitability while reducing N leaching, driven by tactical use of low supplement and N fertiliser inputs, low-cost structure, and strategic use of mitigations, including plantain.

Adoption

It is not known how many of the 26 dairy farmers are currently using plantain in the Rotorua Lake catchment. However, 7 dairy farmers are reporting use of plantain to meet their current NDA targets and a further 17 dairy farmers in the catchment have included plantain in submitted plans to meet their 2032 NDA target. The BOPRC promotes plantain as an effective N leaching mitigation and has adopted the DairyNZ Visual Assessment Guide and recommendations for use and management of plantain. The five partner farmers plan to continue using plantain as part of a suite of farm management strategies to meet their NDA targets and are providing effective examples of what can be achieved with plantain to others in the catchment.

Conclusions

Farmers on well-drained Pumice or Podzol soils in the Rotorua Lake catchment may expect to achieve 15-20% plantain across their farms by spreading 4-6 kg of Prillcote® seed/ha each year, costing $45-$68/ha. Higher levels of plantain can be achieved when plantain is also sown with new pastures, as shown on Farm 3. Results from Farm 4 indicate that autumn establishment in low-lying areas that are poorly drained and with high animal traffic may result in poor plantain establishment. Across the five farms, no changes to grazing management were made when plantain was present in the sward, and weeds were managed relatively easily.

Modelling with Overseer and Farmax indicated that 20% plantain content can reduce N leaching by 8-14% with 1-2% reduction in profit. Including plantain in a mitigation stack to meet the 2032 N loss reduction targets is projected to result in 4.7-7.5% higher annual profit/ha/year at the 2032 NDA. At the whole-catchment scale, adoption of 20% plantain across all 26 dairy farms is estimated to reduce N load to Rotorua Lake by 35 t N/yr while maintaining higher profitability than achievable otherwise. Larger benefits may be possible when the full mitigation effect of plantain (including soil mechanisms) is included in the Overseer model. The case study analysis of Farm 1 demonstrates that it is possible to run a profitable farm system with low N loss by maintaining a low-cost structure, strategic use of mitigations including plantain, and tactical management of low N fertiliser inputs. The partner farm approach has proven effective in co-developing practical management strategies for use of plantain as part of an N mitigation stack, and in achieving confidence amongst farmers and the regional council for wider adoption.

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