Incorporating plantain into ryegrass-white clover mixed sward for an economically and environmentally sustainable dairy system: Year one of a farm system study

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Abstract

The objective of this replicated farm system study was to investigate the effect of increasing proportion of plantain (*Plantago lanceolata* L. cv. Ecotain) in a perennial ryegrass/white clover (RGWC) mixed sward on farm productivity, profitability and environmental footprint over the 2021/22 production season. A total of 108 dairy cows were blocked into nine herds of 12 cows. The herds were randomly allocated into one of three replicated pasture treatments sown with an increasing plantain seed rate: (i) RGWC with nil plantain (PL0); (ii) RGWC+3 kg/ha plantain seed rate (PL3) or (iii) RGWC+6 kg/ha plantain seed rate (PL6). Farmlet milk and pasture production were measured, and data was used to estimate farm profitability and environmental footprint using FARMAX and OverseerEd software, respectively. Increasing plantain seed rate from 3 to 6 kg/ha increased sward content of plantain from 24% to 34% of DM in PL3 and PL6, respectively. Pasture production (average 12,988±473 kg DM/ha), total milksolids production (1,356±40 kg/ha) and farm profitability (4,347±354 NZ$/ha) were similar amongst treatments. Compared to PL0, estimated annual nitrogen leaching and nitrous oxide emissions were reduced by 21% and 30%, (P<0.001) and 4.3% and 6.0% (P<0.01) in PL3 and PL6, respectively. Results suggest that incorporation of plantain into dairy systems could be used as a strategy to reduce predicted environmental footprint while maintaining profitability. However, these results need to be confirmed over multiple production seasons.

Keywords: *Plantago lanceolata* L., dairy cattle, sustainability, grazing system, profitability, greenhouse gas emissions

Introduction

The environmental impacts of pastoral dairy systems have been a growing concern, with particular focus on freshwater quality degradation and greenhouse gas (GHG) emissions. Consequently, regulations have been implemented by regional authorities throughout New Zealand to maintain freshwater quality (Ministry for the Environment 2020), and farm emissions are expected to be priced through a government policy designed to reduce overall agricultural emissions (Ministry for the Environment 2022). To mitigate adverse environmental effects associated with current dairy production systems, it may be necessary to explore alternative and more sustainable farming practices.

Recent studies have shown that the environmental impact of dairy farming can be reduced by using alternative forage species to perennial ryegrass/white clover (RGWC) pasture such as plantain (*Plantago lanceolata* L., Woods et al. 2018; Simon et al. 2019; Carlton et al. 2019; Della Rosa et al. 2022). For instance, dairy cows fed plantain-containing pastures were found to have reduced urinary nitrogen (N) excretion, but an increased daily urine volume, compared to those fed RGWC pastures (Minnée et al. 2020). This, in turn, leads to a reduced N load per urine patch, and subsequently lower N leaching (Woods et al. 2018; Carlton et al. 2019) and nitrous oxide emissions (Di et al. 2016; Simon et al. 2019). In addition, Della Rosa et al. (2022) showed that methane emissions per kg dry matter (DM) intake were reduced by feeding non-lactating dairy cows pure plantain compared to ryegrass. Thus, plantain could be used as a natural mitigation strategy for nitrate leaching and GHG emissions. However, long term studies are still required to confirm environmental benefits of plantain at scale.

Very few farm system trials have been carried out at scale to assess the efficacy of plantain in reducing N leaching from pastoral dairy systems, as well as its effect on farm productivity and profitability. Farm system studies require a significant investment of resources and labour, and replication is often sacrificed in favour of long-term monitoring. For example, in a non-replicated farm trial comparing performance of dairy systems based on either Italian ryegrass + plantain or a conventional RGWC pasture, Al-Marashdeh et al. (2021) reported similar farm productivity and profitibility but lower predicted N leaching and nitrous oxide emissions by implementing the Italian ryegrass

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and plantain into the conventional dairy system. To date, however, effects of plantain on farm productivity, profitability and environmental footprint have not yet been investigated in a replicated farm system trial. Such studies would build confidence in the use of plantain by farmers and increase the rate and extent of adoption. Further, although a minimum level of 30% plantain in cows' diet has been reported to be necessary for reducing their urinary N output (Minnée et al., 2020), it remains a significant challenge for farmers to maintain such levels under grazing conditions (Dodd et al., 2020). To address this challenge, there is a need to investigate the impact of different sowing rates on plantain content in a mixed pasture and their ability to maintain target levels under a dairy grazing system. Therefore, the objective of this study was to investigate the effect of increasing the level of plantain in a RGWC mixed sward on farm productivity, profitability and environmental footprint in a replicated farm system study over a full production season.

Materials and Methods

The farm system study was carried out under irrigation at the Lincoln University Research Dairy Farm (LURDF; 43°38'20.6"S 172°27'26.8"E), Canterbury, New Zealand, over the period from August 2021 to July 2022. This data represents a single production season of a multi-year farm system study that aims to examine the long-term effects of plantain on farm productivity, profitability, and nitrate leaching.

The study area (32 ha) had flat topography, and the imperfectly to well-drained silt loam soil types included Wakanui, Templeton and Barrhill (Landcare Research 2023). Total irrigation applied was 226 mm between late October and March with an application rate of 4-6 mm via pivot irrigation. During the study period, the cumulative rainfall was 770 mm from a total of 149 rain events. The daily maximum air temperature ranged between 8.1 to 29.6°C and the minimum temperature between -4.2 to 17.8°C. The experimental procedures were approved by Lincoln University Animal Ethics committee (AEC2021-07).

Farm systems design

In late July 2021, 108 Jersey × Friesian dairy cows were blocked into nine herds (12 cows per farmlet herd) by age (4.2±2.0 years; average ± SD), live weight (489±44.2 kg), body condition score (4.9±0.4), calving date (17/08/2021±14 days) breeding worth (133±53) and production worth (166±91). Herds were then randomly allocated into one of three pasture treatments (n=3) sown with an increasing plantain seed rate: (i) RGWC without plantain (PL0); (ii) RGWC + 3 kg/ha plantain seed rate (PL3) or (iii) RGWC + 6 kg/ha plantain seed rate (PL6). A total of 32 ha of approximately 0.3-ha paddocks were allocated to the farmlets, with 12 paddocks per farmlet and a resulting stocking rate of 3.3 cows/ha. Paddocks were randomly allocated into farmlets but were balanced for soil type, sowing method, and distance to milking shed.

The treatment pastures were established in March 2021, when all paddocks were sprayed with glyphosate-based herbicide including broad-leaf weed control. Seed mixtures were then sown via cultivation (15 ha) or direct drilling (17 ha), depending on level of broad-leaf weed contamination (especially dock *Rumex* species) and/or the possibility of damage to emerging plantain seedlings caused by slugs. The PL0 paddocks were sown with a seed mixture of perennial ryegrass (*Lolium perenne* L.; cv. Legion AR37 20 kg/ha) and white clover (*Trifolium repens* L. cv. Tribute; 2 kg/ha). The sown seed mixture for PL3 was the same cultivars of perennial ryegrass (18 kg/ha) and white clover (2 kg/ha) plus plantain (cv. Ecotain; 3 kg/ha), and PL6 consisted of perennial ryegrass (15 kg/ha) and white clover (2 kg/ha) plus plantain (6 kg/ha). To achieve early control of persistent weeds, a broad-leaf herbicide, namely Kamba (Kamba 750 at 0.4 l/ha), was applied on all PL3 and PL6 paddocks during spring 2021, while Pasture-Kleen Xtra (3 l/ha) herbicide was used on all PL0 paddocks. However, the use of both herbicides likely had a negative impact on the establishment of white clover. Therefore, white clover seed was re-sown into all treatment paddocks by broadcasting at a rate of 5 kg/ha from late spring to early summer of 2021.

Management

The farmlets were managed individually following decision rules and common management practices in the region as explained by Al-Marashdeh et al. (2021). Nitrogen fertiliser (150 kg N/ha/y) was applied as urea in eight to nine applications to each paddock annually. The dairy farm effluent was exported off farm and none was applied to the farmlet areas.

Herbage mass was determined weekly for each paddock based on pasture compressed height measured with a rising plate meter (RPM; Jenquip Electronic Pasture Meter, Feilding, New Zealand), and using the manufacturers prediction equation of mass (kg/DM/ha) = 140 × height reading + 500 for all pasture types. Paddocks were then ranked based on herbage mass which was used, in addition to days since grazing, to determine the order of rotational grazing. The annual pasture production of all paddocks in each farmlet was calculated as summation of differences of pre- and post-grazing pasture mass between each grazing event over the production season and was averaged for each treatment. Daily DM requirement of cows was estimated based on their requirements for metabolisable energy (megajoules, MJ ME) for maintenance and production (AFRC, 1993). The pre-grazing herbage mass was calculated as [Pre-grazing herbage mass = (cow intake kg DM/day × stocking rate × rotation length) + post-grazing residual target], with target post-grazing compressed pasture height of 4-5 cm (7-8 RPM or approximately 1500 kg DM/ha). During periods of surplus, pasture was conserved as silage and fed out to cows during periods when pasture supply was in deficit. After drying off in May, all cows were shifted off farm to graze on a winter crop (kale; *Brassica oleracea* L.) during June and most of July 2022.

Measurement

During the months from September 2021 to May 2022, pre-grazing pasture samples were collected weekly from paddocks (taken from 20 different points along a zigzag walking path) due to be grazed by each farmlet herd to determine botanical and chemical composition. The herbage was cut with shears at expected grazing height (5 cm above ground level) along a zigzag transect through the paddock. A sub-sample of pasture was dried at 60°C for 48 hours, ground and analysed for chemical composition at Lincoln University Analytical Laboratory using a near infrared spectrophotometer (DS 2500 F, Foss, Maryland, USA). Pasture ME was estimated based on the equation [ME (MJ/kg) = digestible organic matter content × 0.016 (g/kg of DM); AFRC, 1993]. A second pasture sub-sample was dissected into perennial ryegrass, plantain and white clover, dried at 60°C for 48 hours, and the dry weight of each component recorded. The proportion of each species was determined as a percentage of the whole harvested DM.

Pasture RPM estimates were calibrated against quadrat cuts collected weekly from one paddock per farmlet (four 0.259 m^2 quadrats per paddock). Pasture height was measured with the RPM at the site of the quadrat, and pasture within quadrat was cut to ground level. The cut pasture was then washed and oven-dried at 60°C for 48 hours to determine the DM in each quadrat. The pasture mass (kg DM/ha) was then calculated as [dry weight (g) × (10000 m^2/0.259)]/ 1000 g/kg. The regression equations were derived for each treatment considering pasture RPM compressed height and the pasture mass (kg DM/ha). The goodness of fit of regression equations were on average 0.69.

Cows were milked twice a day (at 0600 and 1400 h) from calving until 1 February 2022, and once a day (at 0700 h) from 1 February 2022 until dry off on 10 May 2022. Individual cow milk volume was automatically measured at each milking (Del Pro, DeLaval) and milk composition (fat and protein content) was determined fortnightly (CRV Ambreed, Hamilton, New Zealand) using milk samples collected at consecutive afternoon and morning milkings.

Modelling

FARMAX

The actual data collected from each farmlet were used to estimate the economics using FARMAX Dairy commercial modelling tool (FARMAX DairyPro, Version 8.1.0.54, Hamilton, New Zealand). The economic analysis did not include the actual cost of establishing the pasture, but it did consider the cost differences associated with plantain establishment. The additional expenses were factored into the total farm expenses, including the prices of the seed mixture (NZ $300, $340 and $360 for PL0, PL3 and PL6; Agricom) and herbicides (NZ $62.0 vs $15.0 per L for Kamba and Pasture Kleen Xtra). Database implemented in FARMAX for dairy farm operational cost and farm expenditure in the Canterbury area in 2020/2021 was used to estimate farm working expenses. Total farm working expenses include labour/wage expenses, livestock and feed expenses (NZ $210.0 per t DM of pasture silage), costs for grazing livestock replacements (NZ $24.0 and $40.0 per head/month for heifer calves and rising two-year-old heifers, respectively), and wintering cows off the farm (NZ $94.0 per cow/month). Additionally, expenses such as fertilizer (NZ $661.0 per t urea plus $12.0 per ha spreading cost), irrigation, weed and pest control, vehicle expenses, repairs and maintenance, as well as overhead expenses including administration, insurance, and depreciation were taken into account.

The average milk price per kg of milksolids by Fonterra Co-operative Group Limited across the season was NZ $7.92 and was used as the milk price to estimate farm revenue. The “Simple” milk price option was selected in FARMAX using the DairyNZ Levey of 3.60 c/kg milksolids. This choice of “Simple” option for milk price aimed to eliminate uncertainties regarding the timing of milk price payments between seasons and exclude any deferred payments from previous seasons. The farm revenue was predicted by FARMAX based on the net milk sales to a milk company, livestock sales and net change in feed inventory (Bryant et al. 2010). Surplus silage by the end of production season was sold at NZ $210.0 per t DM. Farm profitability before tax was calculated as total revenue minus total farm working expenses.

OverseerEd

Individual farmlet N surplus, nitrate leaching, and GHGs were estimated using OverseerEd (version 6.5.0; Wellington, New Zealand) (Science Advisory Panel 2021). The predictions were based on the applied inputs and outputs for production, soil type and climate

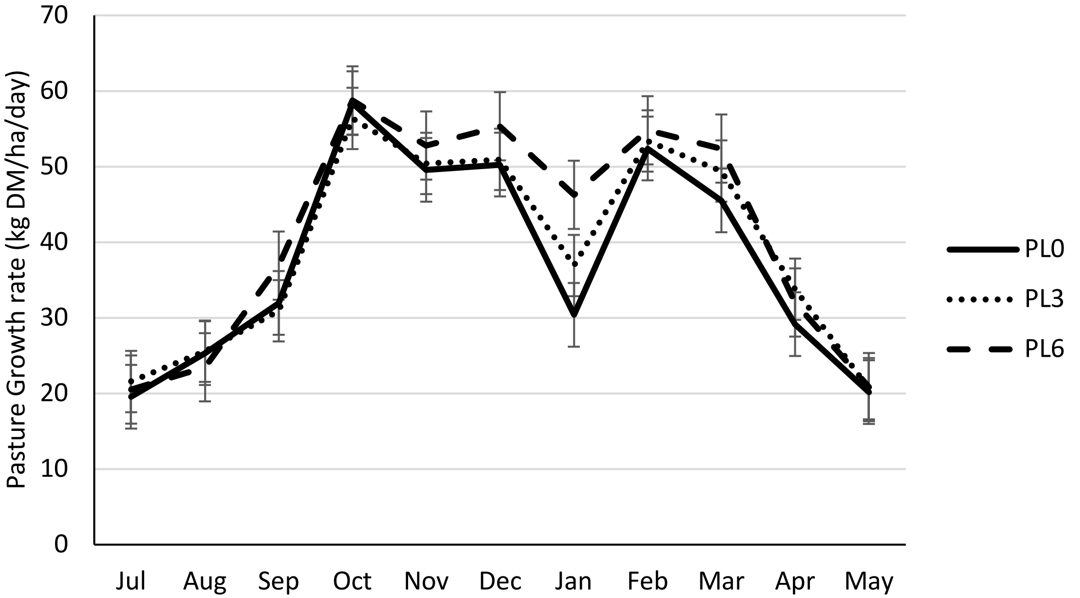

Figure 1 Average daily growth rate (kg DM/ha/d) of mixed pastures sown with an increasing plantain seed rate: perennial ryegrass and white clover (RGWC) without plantain (PL0); RGWC + 3 kg/ha plantain seed rate (PL3) or RGWC + 6 kg/ha plantain seed rate (PL6) during 2021/22 production season.

(Wheeler et al. 2006). The proportion of plantain in the sward was accounted for in the prediction of urinary N excretion and subsequent N load (Shepherd 2020).

Statistical Analysis

All statistical analyses were performed using Genstat statistical software (19th edition, VSN International Ltd., Hemel Hempstead, UK). Botanical and chemical composition data were analysed by two-way ANOVA considering treatment and season of the year and their interactions as fixed factors. Productive, economics and environmental footprints data were analysed by one-way ANOVA with pasture type as treatment and the mean value for each farmlet being the experimental unit (three experimental units per treatment). Net feed inventory data had skewed distributions and were transformed before being analysed, but actual means were presented. Results were declared significant at $P<0.05$.

Results

The number of days in milk (average 257 days) was similar between treatments (Table 1). Milksolids production on a per cow and per ha basis were similar between treatments, averaging 407 and 1356 kg, respectively. Total pasture production (average 13 t DM/ha), total pasture conserved (average 1.2 t DM/ha), total silage fed (average 163 kg DM/cow over August to December and February to May) and total imported silage (84 kg DM/cow) were similar across the treatments (Table 1). The total amount of N fertiliser applied was not different amongst treatments with an average annual rate of 148 kg N/ha (Table 1). Pasture growth rate was similar between treatments in all months, except January where growth was greater in PL6 than PL0 and PL3 (Figure 1).

The chemical and botanical composition of pasture treatments are presented in Table 2. The botanical content of perennial ryegrass, plantain, and white clover were different between treatments ($P<0.001$) and across different seasons of the year ($P<0.001$). Overall, the content of plantain was lower in PL3 (average 24%) than in PL6 (average 34%, $P<0.001$). In comparison to spring (13% and 18%), content of plantain increased in summer (26% and 38%) and further increased in autumn (33.4% and 46.0 %) in both PL3 and PL6, respectively. The average content of white clover was greater in PL0 (5.5%) than PL3 (1.8%) and PL6 (2.2%, $P<0.001$), but similar between PL3 and PL6. The content of crude protein (CP) in pasture was similar between treatments but different between seasons, where it was lower in summer (average 18.3%) than spring (19.7%) and autumn (20.9%, $P<0.05$). Average content of neutral detergent fibre (NDF) was greater in PL0 (43.5%) than PL3 (40.8%) and PL6 (39.8%, $P<0.001$), but similar between PL3 and PL6. Average pasture ME was greatest in spring (12.5 MJ/kg DM), lowest in summer (11.4 MJ/kg DM) and intermediate in autumn (11.8 MJ/kg DM, $P<0.001$). Overall, average pasture ME was greatest ($P=0.018$) in PL0 (12.1 MJ/kg DM), lowest in PL6 (11.7 MJ/kg DM) and intermediate in PL3 (11.9 MJ/kg DM).

Table 1 Physical and production summary of dairy systems based on mixed pastures sown with an increasing plantain seed rate: perennial ryegrass and white clover (RGWC) without plantain (PL0); RGWC + 3 kg/ha plantain seed rate (PL3) or RGWC + 6 kg/ha plantain seed rate (PL6) during 2021/22 production season.

	Treatment			**SEM**	**P value**
	PL0	**PL3**	**PL6**		
Days in milk	256	257	258	1.8	NS
Milksolids production					
kg/cow	410	401	410	11.9	NS
kg/ha	1,367	1,335	1,367	39.8	NS
Pasture production (t DM/ha)	12.4	12.9	13.6	0.47	NS
Total pasture conserved (t DM)	0.61	1.07	1.88	0.67	NS
Total silage fed (t DM)	1.99	1.95	1.95	0.48	NS
Imported silage (t DM)	1.38	0.93	0.32	0.61	NS
Net feed inventory (t DM)	0.00	0.06	0.26	0.238	NS
Nitrogen fertiliser applied (kg N/ha)	151.9	149.7	143.4	3.34	NS

Table 2 Botanical and chemical compositions (% of DM) by season of mixed pastures sown with an increasing plantain seed rate: perennial ryegrass and white clover (RGWC) without plantain (PL0); RGWC + 3 kg/ha plantain seed rate (PL3) or RGWC + 6 kg/ha plantain seed rate (PL6) during Spring 2021, Summer and Autumn 2022.

	Perennial ryegrass	**Plantain**	**White Clover**	**Crude Protein**	**Neutral detergent fibre**	**Metabolisable energy**
Spring						
PL0	87.2	0.0	0.2	19.0	40.4	12.5
PL3	78.1	13.0	0.2	20.7	39.0	12.5
PL6	70.7	18.0	0.1	19.5	39.7	12.4
Summer						
PL0	89.7	0.0	5.3	19.0	45.5	11.6
PL3	71.9	25.3	1.6	19.0	44.5	11.4
PL6	59.8	37.3	2.6	16.9	42.3	11.1
Autumn						
PL0	82.8	0.2	11.0	22.7	44.5	12.0
PL3	59.5	33.4	3.7	20.2	38.8	11.8
PL6	46.9	46.1	3.9	19.8	37.5	11.7
SEM						
Treatment	0.90	0.87	0.48	0.80	0.51	0.10
Season	0.90	0.87	0.48	0.80	0.51	0.10
P value						
Treatment	<0.001	<0.001	<0.001	NS	<0.001	0.018
Season	<0.001	<0.001	<0.001	0.016	<0.001	<0.001
Treatment × Season	<0.001	<0.001	0.002	NS	<0.001	NS

Farm revenue, working expenses and profit (before tax) are shown in Table 3. All financial outputs were similar amongst treatments, with an average farm revenue of NZ $11,213 per ha, farm working expenses of NZ $6,111 per ha, and farm profit of NZ $4,347 per ha.

Table 3 FARMAX economic outputs for dairy systems based on mixed pastures sown with an increasing plantain seed rate: perennial ryegrass and white clover (RGWC) without plantain (PL0); RGWC + 3 kg/ha plantain seed rate (PL3) or RGWC + 6 kg/ha plantain seed rate (PL6) during 2021/22 production season, and at milk price of NZ $7.92/kg of milksolids.

Unit	Treatment			SEM	P value
	PL0	PL3	PL6		
Farm Revenue					
NZ $/ha	11,282	11,023	11,333	348	NS
NZ $/cow	3,385	3,307	3,400	104	NS
NZ $/kg MS	8.45	8.47	8.50	0.02	NS
Farm Working Expenses					
NZ $/ha	6,101	6,114	6,117	10	NS
NZ $/cow	1,830	1,834	1,835	12	NS
NZ $/kg MS	4.58	4.70	4.59	0.14	NS
Farm Profit					
NZ $/ha	4,426	4,153	4,461	354	NS
NZ $/cow	1,328	1,246	1,338	106	NS
NZ $/kg MS	3.3	3.2	3.3	0.2	NS

Table 4 Farm environmental footprint as predicted by OverseerEd model (version 6.5.0) for dairy systems based on mixed pastures sown with an increasing plantain seed rate: perennial ryegrass and white clover (RGWC) without plantain (PL0); RGWC + 3 kg/ha plantain seed rate (PL3) or RGWC + 6 kg/ha plantain seed rate (PL6) during 2021/22 (August 2021 to July 2022).

		Treatment				
Variable	**Units**	**PL0**	**PL3**	**PL6**	**SEM**	**P-value**
N surplus	kg N/ha/year	201.7	200.0	201.3	2.0	NS
N leached	kg N/ha/year	23.3[c]	18.3[b]	16.3[a]	0.7	<0.001
GHG emitted[1]	kg CO_2-equivalents/ha/year	13,162	12,944	13,047	171	NS
Nitrous oxide emitted	kg CO_2 equivalents/ha/year	3,075[b]	2,944[a]	2,892[a]	39	0.008

[1] Total predicted GHG (Greenhouse gas) emissions as methane, carbon dioxide and nitrous oxide.

[a-c]Means within a row with different superscripts differ (P<0.05).

Annual N surplus (average 201 kg N/ha) was similar amongst treatments, but nitrate leached (kg N/ha/year) was 21.5 and 30.0 % lower in PL3 and PL6 than PL0 treatment, respectively (<0.001), and 12% lower in PL6 than PL3 (Table 4, <0.001). Total GHG emissions (methane, carbon dioxide and nitrous oxide) were similar across treatments, but nitrous oxide emissions were reduced by 4.3 % and 6.0% in PL3 and PL6 treatments compared to PL0, respectively (P<0.01, Table 4).

Discussion

Annual pasture production was similar amongst treatments, averaging 13 t DM/ha, but was lower than the 16.5 t DM/ha reported by Chapman et al. (2021) on the same site. Although the annual rainfall was relatively similar between the two studies (with an average of 612 mm) and the rainfall patterns were comparable, 44% more irrigation was applied in the Chapman et al. (2021) study compared to this study (327 vs. 227 mm). Black and Murdoch (2013) demonstrated a water use efficiency of 27 kg DM/ha per mm of water applied for irrigated and N fertilised pasture on a similar soil type to this study. This suggests that a lower moisture level may have resulted in a yield loss of 2.7 t DM/ha in this study compared with the Chapman et al. (2021) study. Due to mechanical issues experienced during the summer months, irrigation could not be applied on several occasions throughout the current study. As a result, there was a decline in the pasture growth rate in January, which led to a lower pasture yield compared to the regional benchmark.

The botanical content of the two plantain farmlets showed that despite doubling the seed rate in PL6 compared with PL3, the average plantain content differed by only 10% across the year. The gradual increase in content of plantain after sowing and across seasons has been observed in previous studies which, under dairy grazing conditions, showed a peak in plantain content at about 15 months after sowing followed by a gradual decline (Nguyen et al. 2022). Plantain has previously been shown to have similar N response to perennial ryegrass (Martin et al. 2017), and pasture growth rates were not affected when plantain was incorporated in a mixed RGWC sward by Nguyen et al. (2022). Thus, the similarity in pasture production amongst treatments in the current study was not surprising. Overall, our results showed that, under grazing conditions, inclusion of plantain in a RGWC mixed sward either at 3 or 6 kg/hg seed rate did not affect pasture DM yield.

In this study there was no difference in milk production amongst treatments. The effect of plantain on cow's milk production in previous research has been variable. For example, in a short-term study, plantain was shown to increase milksolids production when cows were grazing pasture containing 50% or 100% plantain compared to those grazing RGWC during autumn (Box et al. 2016). On the other hand, Navarrete et al. (2022) reported similar milksolids production between cows grazing RGWC or plantain containing pastures. Similarly, in a long-term farm system study, Al-Marashdeh et al. (2021) reported similar level of milksolids production between plantain-based and RGWC-based dairy system. Interestingly, the similar production level amongst treatments in this study was despite a reduced average ME content of pasture with the increasing level of plantain in the sward (average across all seasons 12.1, 11.9 and 11.7 MJ/kg DM for PL0, PL3, and PL6, respectively). It is possible that the lower NDF content in the plantain-based pasture, compared to RGWC (average across all seasons 43.5%, 40.8% and 39.8% for PL0, PL3, and PL6, respectively), resulted in a higher DM intake for cows in the plantain-based treatments. This, in turn, may have compensated for the lower pasture ME content.

Farm profitability was similar amongst farm systems tested in this study (average NZ \$4,347 per ha and NZ \$3.3 per kg of milksolids), suggesting that plantain incorporation into the dairy system did not affect farm profitability. Al-Marashdeh et al. (2021) also demonstrated that farm profitability did not differ between dairy systems based on either plantain or RGWC when compared at a similar farm input level. However, it is important to note that the content of plantain in the mixed swards has been shown to decline rapidly after approximately two years after sowing date (Cranston et al. 2016; Nguyen et al. 2022). As such, maintaining plantain proportion targets, particularly under grazing conditions, is one of the biggest challenges for farmers (Dodd et al. 2020). Thus, it is important to consider the long-term additional costs associated with re-establishing plantain into mixed swards when comparing farm profitability. For example, re-establishing plantain at 3 kg/ha seed rate would approximately cost NZ \$60 per ha via broadcasting, and up to NZ \$250 per ha (depends on scale of job and type of drill) via direct drilling. The findings of the current study, based on one production season, suggest that incorporation of increasing level of plantain in a mixed RGWC sward does not affect farm profitability, although these findings need to be confirmed over multiple years.

Reducing farm N surplus by reducing N imported as supplement and fertiliser, and increasing N exported in milk, stock and feed, is the major driver for reducing farm N loss into the environment (Di and Cameron 2002; Chapman et al. 2021). However, in the current study N surplus was similar amongst treatments, but predicted annual N leaching and nitrous oxide emissions were reduced by including plantain in the mixed pasture. The impact of plantain on nitrate leaching has been incorporated into Overseer based on scientific evidence supporting the effect of plantain on reducing urinary N excretion in dairy cattle, as explained by Shepherd (2020). Under the condition of current study, annual N leaching predicted by OverseerEd was, on average, reduced by 9% with every 10% increase in plantain in the mixed pasture DM. In addition, doubling plantain seed rate in PL6 compared to PL3, did not significantly affect predicted nitrous oxide emissions, but led to an 11% decrease (mainly due to 10% difference in plantain content) in predicted annual N leaching. Results of our study showed that integration of plantain into the dairy system potentially presents a viable solution for mitigating adverse environmental effects. However, the environmental benefits of plantain in reducing nitrate leaching, as suggested by model predictions in this study, will be confirmed through an ongoing direct measurement at paddock scale. These measurements involve the implementation of suction cups and lysimeters within the farmlets of this study, spanning across multiple years.

Conclusions

Incorporating an increasing level of plantain into a RGWC mixed sward (0, 3 or 6 kg/ha sowing rate) reduced predicted nitrate leaching and nitrous oxide emissions while maintaining farm productivity and profitability of the dairy system in the first production year. These results suggest that plantain could contribute to an economically and environmentally sustainable dairy system, although economic performance needs to be further tested over a sequence of climatic years and through a range of milk prices received and expenses incurred. Additionally, environmental benefits of plantain also need to be confirmed through direct measurements at paddock/farm scale.

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