PRACTICAL OPTIONS FOR REDUCING THE ENVIRONMENTAL IMPACTS OF INTENSIVE, FORAGE-BASED DAIRY SYSTEMS

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Introduction

Reducing the environmental impacts of the dairy industry in New Zealand has become a key focus with increasing interest surrounding nitrogen (N) leaching issues (Bryant et al., 2007, Woodward et al., 2013). Regional Councils throughout New Zealand have been developing regulations that place a limit on the amount of nitrate-N (NO_3^--N) leached from agricultural land. Nitrogen from urine patches is a major contributor to N leaching, due to the high loading rate of N in urine patches compared with the capacity of many plant species to take up N (Cameron et al., 2013). There are several ways in which plants and management strategies can be used to reduce nitrate leaching losses without impinging production. The Forages for Reduced Nitrate Leaching (FRNL) programme is investigating several strategies including:

- using forages to increase N uptake from the urine patch once the urine is deposited on the soil surface
- using efficient irrigation to optimise pasture production and N uptake from the soil
- identifying forage types and N fertiliser rates which optimise production whilst reducing plant N concentration
- growing forages that lead to livestock excreting urine with a lower concentration of N, and
- identifying management practices which optimise production from alternative pasture types which reduce urinary N.

Effects of forage type on N leaching losses

Roshean Woods

One approach to mitigation of N leaching losses is to increase the uptake of N by forage plants, particularly during the cooler seasons when the risk of leaching is greatest. In grazed systems, if plants can utilize urine-N more efficiently at these times of the year, the N lost to

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drainage water could be reduced. Using lysimeters we measured N leaching losses from urine patches deposited onto the commonly used perennial ryegrass-white clover forage mixture, and some alternative forages: Italian ryegrass, lucerne, and an Italian ryegrass-plantain-white clover mixture.

Results showed N leaching losses for control (non-urine) lysimeters were minimal (<2.2 kg N/ha). When urine was applied, total N leaching losses were 35% lower ($P < 0.1$) from Italian ryegrass (133 kg N/ha) and 99% greater ($P < 0.001$) from lucerne (407 kg N/ha), when compared with perennial ryegrass-white clover (205 kg N/ha) (Fig 1) (Woods et al., 2016). The reduction in N leaching for Italian ryegrass, was attributed to it having taken up more N during the winter with 2.1 kg N/ha/day taken up on average, compared with 1.6 kg N/ha/day for perennial ryegrass-white clover, and 0.3 kg N/ha/day for lucerne. Herbage dry matter (DM) yields for the 17-month experimental period were 24 T DM/ha for perennial ryegrass-white clover, 21 T DM/ha for Italian ryegrass and 25 T DM/ha for lucerne (Woods et al., 2016). Please note that we have identified some limitations in the measurement technique used to determine N leaching losses from lucerne due to its deep rooting capability and further research is needed in this area for grazed lucerne stands (see Woods et al. (2016) for more detail).

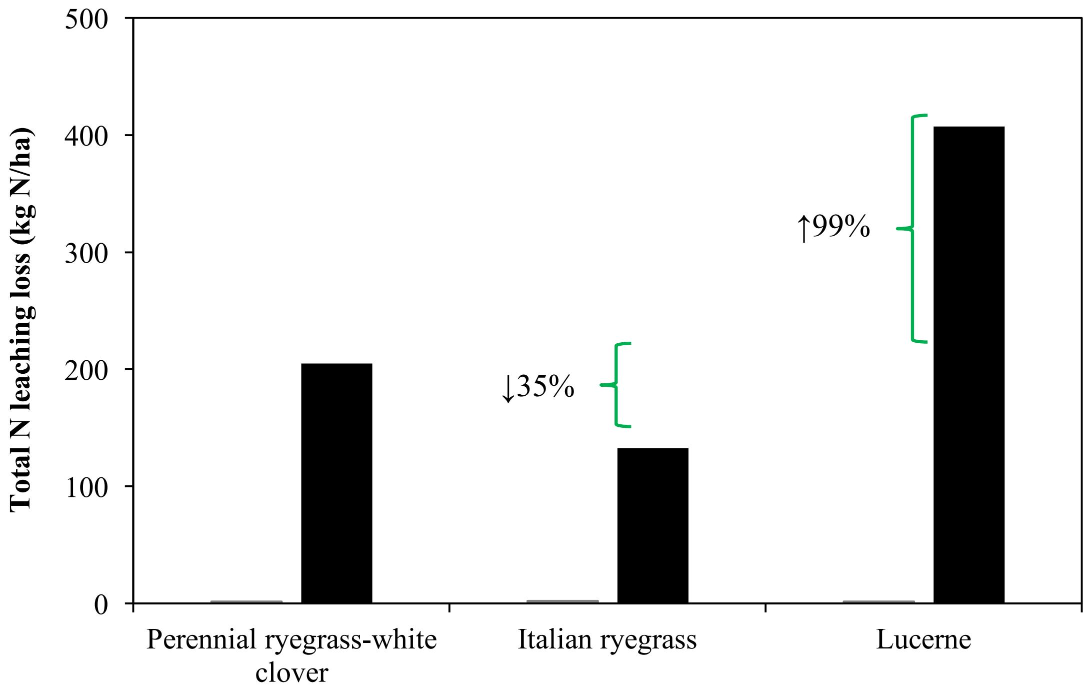

Figure 1: The grazing cycle: the quality of a pasture is the result of the previous grazing.Figure 1: Total mineral nitrogen (nitrate + ammonium) leaching loss (kg N/ha) from lysimeters for the experimental period: 7 May 2014 to 1 October 2015. Forages were treated in May 2014 with (■) or without urine (■) (at 700 kg N/ha).

Initial results of a second study, show N leaching losses to be around 45% lower from urine (700 kg N/ha) deposited onto an Italian ryegrass-plantain-white clover mixture, compared with perennial ryegrass-white clover. This appears to be again attributed to greater cool-season N uptake. In another treatment, we took into account the N concentration of the urine excreted by dairy cows grazing each of the two forages, and found this was lower for the Italian ryegrass-plantain-white clover mixture (508 kg N/ha) than the perennial ryegrass-white clover (664 kg N/ha). For this treatment, initial N leaching losses were shown to be 89% lower for the Italian ryegrass-plantain-white clover mixture, compared with perennial ryegrass-white clover. There was no difference in herbage DM yield between the two forages. These data will be confirmed once the experiment has been completed.

This research has shown that it is possible to reduce urine patch N leaching losses by optimizing forage growth and N uptake using alternative forages which are more winter-active or reduce urine-N excretion. These are potential tools which farmers could use to reduce N leaching losses into the future.

Effects of irrigation management on N leaching losses

Anna Carlton

Irrigation management is another proposed mitigation option to reduce N leaching losses through increased plant growth and thus N uptake over the summer period. Of key interest is how these diverse forages respond to irrigation and whether they can be used to reduce N leaching losses. The objective of this study was therefore to quantify the effect of 'optimum' vs. 'deficit' irrigation management regimes on N uptake by diverse and standard forages, and on N leaching losses from spring deposited urine.

Using lysimeters, we measured plant N uptake and N leaching losses from urine patches deposited onto a 'standard' perennial ryegrass and white clover forage and a 'diverse' forage containing perennial ryegrass, white clover, red clover, prairie grass, plantain and chicory. Following urine application, irrigation water was applied at optimum vs. deficit rates from November to March. Treatments are outlined in Table 1.

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Table 1: Description of lysimeter treatments.

Treatment no.	Irrigation regime	Irrigation rate (mm)	Pasture species	Treatment (kg N ha^{-1} yr^{-1})
1	Deficit	9 mm, 3 d	Standard	700
2	Deficit	9 mm, 3 d	Diverse	700
3	Deficit	9 mm, 3 d	Standard	500
4	Deficit	9 mm, 3 d	Diverse	500
5	Optimum	18 mm, 3 d	Standard	700
6	Optimum	18 mm, 3 d	Diverse	700
7	Optimum	18 mm, 3 d	Standard	500
8	Optimum	18 mm, 3 d	Diverse	500

Initial results suggest that low N leaching losses occur from urine deposited in late spring. At a N loading rate of 700 kg N/ha, initial N leaching losses under optimum irrigation were shown to be approximately 88-97% lower than those from deficit irrigation. This appears to be attributed to greater herbage growth and N uptake during the summer period by forages receiving optimum irrigation. There was no apparent difference in N leaching losses between diverse and standard pastures. These data will be confirmed once the trial has been completed. The results from this trial demonstrate that adequate moisture over summer improves soil N use by plants and reduces N leaching from spring deposited urine in grazed pastures.

Effects of N fertiliser on yield and plant N content

Kirsty Martin

An approach to increase pasture production while achieving environmental targets associated with lower N leaching is to identify forages that grow more at a reduced annual application of N fertiliser. While N fertiliser responses have been well described for grasses (Hill et al., 2005, Mills et al., 2009), less information is available for alternative legume and herb species. A field study was conducted on the Canterbury Plains, New Zealand over 12 months. Six species (perennial ryegrass, Italian ryegrass, white clover, lucerne, chicory and plantain) were grown under irrigation and cut and carry management at six annual N-fertiliser rates ranging from 0 to 450 kg N/ha/year.

Results indicated that, at all N fertiliser rates, Italian ryegrass and plantain were higher yielding than perennial ryegrass (9.9 and 10 T DM/ha/year vs 7.7 T DM/ha/year, Fig 2(Martin et al., In press). Above application rates of 180 kg N/ha/year, N content increased significantly in both grasses and herbs, (2.4 – 2.8 % of DM in grasses, 2.9 – 3.3 % of DM in herbs, Fig 3). Forages with high N content often result in higher N intake and increased risk of urinary N loss. A higher N content in white clover and lucerne (4.3 % of DM) compared to herbs and grasses (3.1 and 2.6 % of DM) suggest legumes in pastures are likely to be a contributor to high N in the diet (Fig 3) however, it is important to note that most dairy pastures contain less than 20 % clover content.

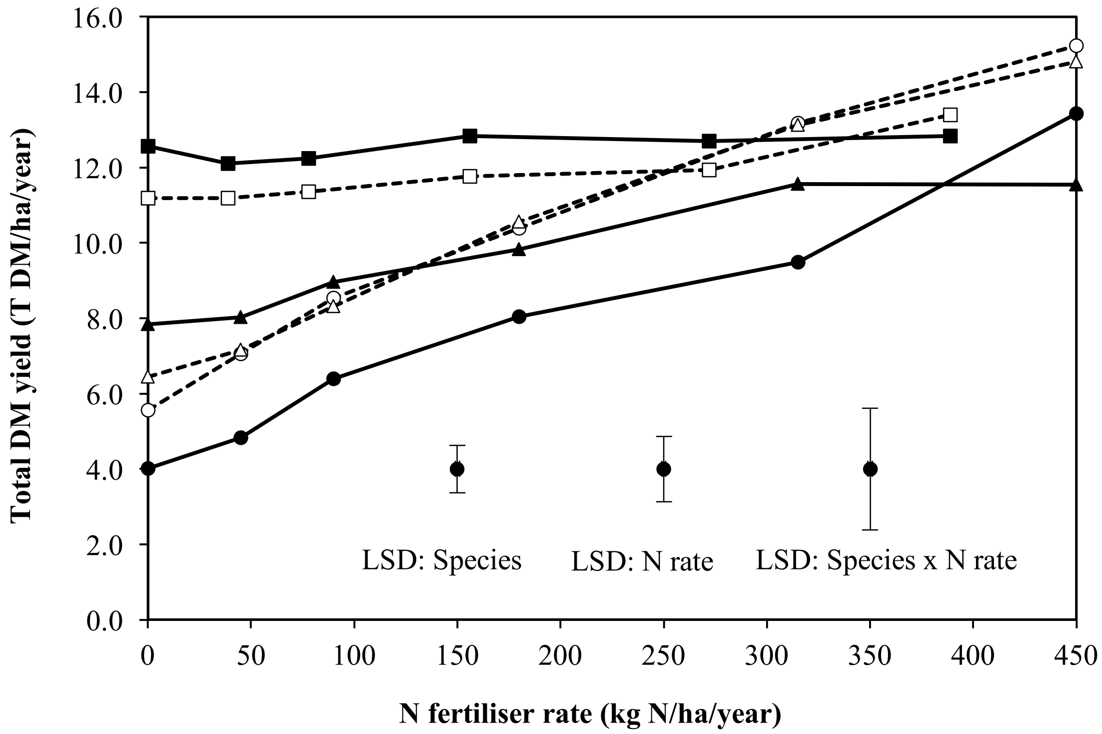

Figure 2: Total annual yield (T DM/ha/year) of perennial ryegrass (—●—), Italian ryegrass (--○--), white clover (—■—), lucerne (--□--), chicory (—▲—) and plantain (--Δ--) at six N fertiliser rates ranging from 0 to 350 kg N/ha/year. LSDs from ANOVA for main effects species, N fertiliser rate and the interaction are shown as error bars. LSD = least significant difference (α=0.05).

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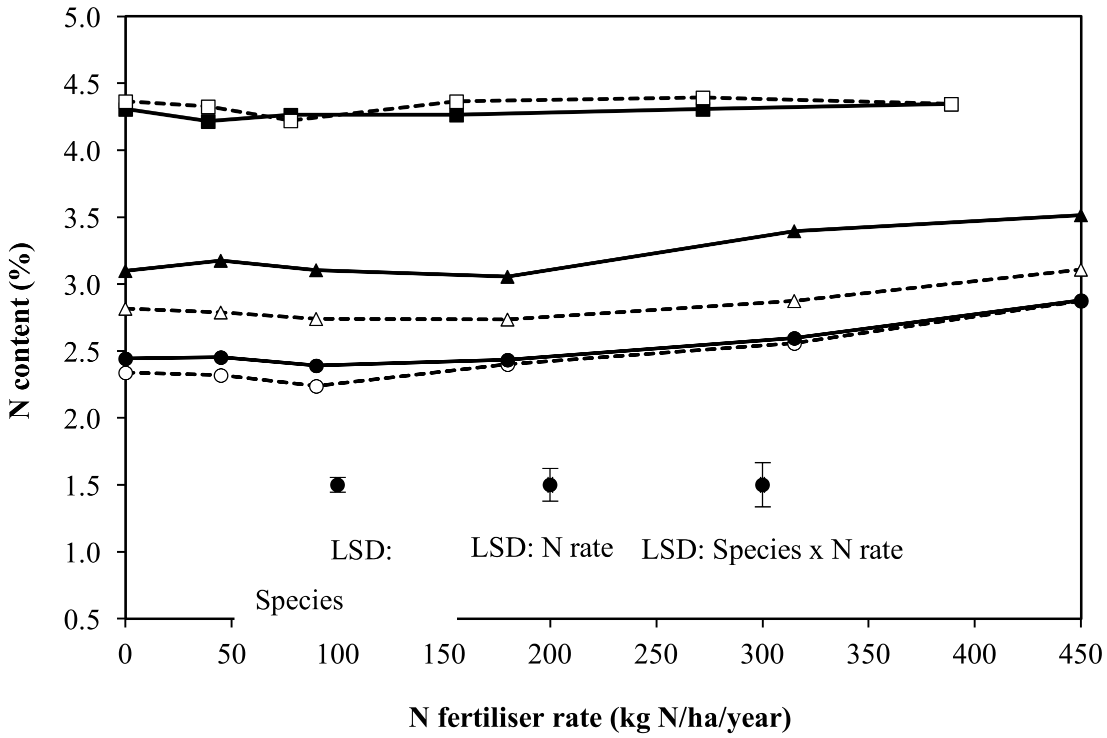

Figure 3: Average annual N concentration (% of DM) of perennial ryegrass (—●—), Italian ryegrass (--○--), white clover (—■—), lucerne (--□--), chicory (—▲—) and plantain (--Δ--) at six N fertiliser rates ranging from 0 to 350 kg N/ha/year. LSDs from ANOVA for main effects species, N fertiliser rate and the interaction are shown as error bars. LSD = least significant difference (α=0.05).

Plantain for reduced N loading in the urine patch

Lisa Box

Previous studies have demonstrated that cows grazing 'diverse' pastures containing herbs (plantain and chicory) excrete urine which has lower N concentrations compared with cows grazing standard perennial ryegrass-white clover pastures (Bryant et al., 2017, Totty et al., 2013). More recent experiments have focussed specifically on feeding plantain as a strategy to reduce nitrogen excretion (Box et al., 2016). At Lincoln University, milk production and urinary N concentration were measured in two experiments in early and late lactation dairy cows grazing a perennial ryegrass-white clover pasture, pure plantain, or a pasture comprised of 50% perennial ryegrass-white clover and 50% pure plantain by ground area. All cows were offered a similar herbage allowance.

In late lactation daily milksolids production per cow was 0.17 kg MS greater for cows grazing plantain than cows grazing pasture, with cows grazing 50-50 pasture-plantain intermediate (Table). A striking result was that the urine-N concentration was over 55% lower for plantain and about 33% lower for 50-50 pasture-plantain than pasture in both experiments (

Table). Previous studies have shown that the excretion of N in urine is linearly related to N intake (Tas et al., 2006). However, in this experiment there was no difference in apparent N intake between pasture and plantain. Despite some indication of increased urine volume for cows with plantain included in their diet, there was a reduction in total N output. Using an average urination volume and assuming a patch size of 0.2 m^2, the urine N loading from cows on pasture was about 700 kg N/ha in autumn and 670 kg N/ha in spring. With the same assumptions a urine patch from cows grazing plantain would have a N loading of about 450 kg N/ha in autumn and 320 kg N/ha in spring. Applications rates above 500 kg N/ha will likely increase leaching and nitrous oxide emission potential (Groenigen et al., 2010). This shows the potential of plantain to reduce N losses from grazing dairy systems.

Table 2: Mean milk yield and composition of dairy cows grazing perennial ryegrass-white clover pasture, plantain or 50-50 pasture-plantain. LSD = least significant difference (α = 0.05). Means followed by different letters denote that values are significantly different at the 5% level

	Pasture	**50-50 pasture-plantain**	**Plantain**	**LSD**	**P value**
Late lactation (autumn 2015)					
Milk solids (kg/d)	1.50^{a}	1.60^{ab}	1.67^{b}	0.08	0.012
Milk protein (%)	4.28	4.29	4.34	0.09	0.512
Milk fat (%)	6.16^{a}	5.52^{b}	5.80^{ab}	0.23	<0.001
Urea N (mmol/L)	11.2^{a}	10.9^{a}	9.96^{b}	0.54	0.005
Early lactation (spring 2015)					
Milk solids (kg/d)	2.42	2.43	2.39	0.01012	0.772
Milk protein (%)	3.75a	3.67b	3.72ab	0.0602	<0.001
Milk fat (%)	5.48	5.32	5.38	0.2299	0.394

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Table 3: Mean urine N characteristics, volume and total N output of dairy cows grazing perennial ryegrass-white clover pasture, plantain or 50-50 pasture-plantain. LSD = least significant difference (α = 0.05). Means followed by different letters denote that values are significantly different at the 5% level.

	Pasture	50-50 pasture-plantain	Plantain	LSD	P value
Late lactation (autumn 2015)					
N concentration (g N/L)	5.4[a]	3.6[b]	2.4[c]	0.06	<0.001
Total volume/day (L/d)[1]	46.5 (3)	59.1 (3)	73.8 (3)	23.65	0.079
Average volume/urination (L)[2]	3.23 (95)	2.87 (88)	3.34 (86)	0.552	0.228
N output/d	251	213	177		
Early lactation (spring 2015)					
N concentration (g N/L)	4.7[a]	3.4[b]	2.2[c]	0.046	<0.001
Total volume/day (L/d)[1]	43.6 (2)	33.6 (2)	54.1 (3)	33.31	0.331
Average volume/urination (L)[2]	2.75 (67)	2.82 (51)	3.09 (66)	0.491	0.325
N output (g N/d)	205	114	119		

Grazing management of diverse pastures to support milk yield

Grace Cun

Diverse pastures containing additional legumes and herbs have shown to reduce urinary N concentration of dairy cows (Bryant et al., 2017; Totty et al., 2013) and improve pasture production (Nobilly et al., 2013). However, compared with perennial ryegrass, the alternative species in diverse pastures have different grazing requirements which can affect regrowth, persistence and nutritive value. In this research, options to manage diverse pastures for improved pasture production and animal production were investigated using normal grazing (3.5 cm or 7-8 clicks on the plate meter) or lax grazing (5 cm or 10-11 clicks on the plate meter). A lax defoliation regime allows the parent grass tiller to reach anthesis prior to mowing or grazing, and has shown to aid daughter tiller survival and improved dry matter yield and persistence ("late control"; Matthew, 1991, Matthew et al., 1989). However, it is also recognised that leaving behind a high pasture residual in spring may reduce herbage quality and decrease milk yield. A lactation study was used to investigate whether a combination of lax grazing in one rotation followed by pre-graze mowing in the next rotation could improve both pasture production and milk yield of cows grazing diverse pastures (Table 4).

Results show a lax grazing management in spring, coupled with a longer rotation length (22 versus 27 days), increased pre-graze mass (>1000 kg DM/ha) and this contributed to a lower milk yield in November. Incorporating pre-graze mowing wasn't enough to offset the milk yield reduction in November or during the following rotation in December (Table 5). In this study, lax grazing didn't improve herbage growth rates compared with normal grazing. Although mowing improved ME in December compared to lax grazing it wasn't enough to improve milk yield.

These results further demonstrate the negative impact of high pre-graze herbage mass on milk yield. At high herbage mass, pre-graze mowing didn't improve milk yield in the current rotation but can improve pasture quality in the subsequent rotation.

Table 4: An initial set-up phase (Sep-Oct) in the experimental area was grazed by dairy cows to create different pasture masses to allow the area to be grazed at the same time during the trial period in Nov. Then in Dec, an experiment was designed to determine the effects of pre-graze mowing in the subsequent grazing rotation. Grazing pasture heights shown are target heights.

Treatment	10-Sep	30-Sep	17-Oct	22-Oct	10-17 Nov	14-21 Dec
Norm	Graze to 3.5 cm	Graze to 3.5 cm	----	Graze to 3.5 cm	Graze to 3.5 cm	Graze to 3.5 cm
Lax	Graze to 3.5 cm	Graze to 5 cm	Graze to 5 cm	---	Graze to 3.5 cm	Graze to 3.5 cm
Mow	Graze to 3.5 cm	Graze to 5 cm	Graze to 5 cm	---	Pre-mown to 3.5 cm	Graze to 3.5 cm

Table 5: Pasture regrowth from Nov-Dec, pre-grazing herbage mass, forage metabolisable energy (ME), total milksolids of Norm, Lax and Mow treatments. Values followed by different superscript statistically significant ($P \leq 0.05$).

	Norm	Lax	Mow	*Significant?*
Pasture regrowth (kg DM/ha/d)	40.8	38.5	36.8	*No*
Pre-graze yield (kg DM/ha)-November	3105^{a}	4190^{b}	4108^{b}	*Yes*
Metabolisable energy (MJ ME/kg DM)	12.23	12.14	12.30	*Slightly*
Milksolids (kg MS/cow/d)	2.43	2.34	2.25	*Slightly*
Pre-graze yield (kg DM/ha)-December	3614	3582	3401	*No*
Metabolisable energy (MJ ME/kg DM)	11.4	11.3	11.7	*No*
Milksolids (kg MS/cow/d)	1.80	1.87	1.87	*No*

Notes:

Key messages

- By optimizing forage growth and N uptake, N leaching loss can be reduced using:
  - Forages which are more winter-active e.g. Italian ryegrass
  - Forages which reduced urine-N excretion e.g. Italian-plantain-white clover mixture.
- Good irrigation management could reduce NO_3^- leaching losses from spring deposited urine in grazed pastures.
- Applying N fertiliser rates above 180 kg N/ha/year increases the risk of higher N urinary outputs because of increased N intake.
- At similar N fertiliser rates, Italian ryegrass and plantain are higher yielding than perennial ryegrass.
- Plantain pastures can be used to reduce N loading at the urine patch while maintaining or improving milk production.
- Using lax grazing to manage diverse pastures in spring is unlikely to provide DM production and milk yield benefits.

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References

Box, LA, Edwards, GR & Bryant, RH 2016. Milk production and urinary nitrogen excretion of dairy cows grazing perennial ryegrass-white clover and pure plantain pastures. *Proceedings of the New Zealand Society of Animal Production,* 76, 18-21.

Bryant, JR, Hoogendoorn, CJ & Snow, VO 2007. Simulation of mitigation strategies to reduce nitrogen leaching from grazed pasture. *Proceedings of the New Zealand Grassland Association,* 69, 145-151.

Bryant, RH, Miller, LA, Greenwood, SL & Edwards, GR 2017. Milk yield and nitrogen excretion of dairy cows grazing binaryand multispecies pastures. *Grass and Forage Science*, 1-12.

Cameron, KC, Di, HJ & Moir, J 2013. Nitrogen losses from the soil/plant system: a review. *Annals of Applied Biology,* 162, 145-173.

Groenigen, JW, Velthof, GL, Oenema, O, Groenigen, KJ & Kessel, C 2010. Towards an agronomic assessment of N2O emissions: a case study for arable crops. *European Journal of Soil Science* 61, 909-913.

Hill, JO, Simpson, RJ, Wood, JT, Moore, AD & Chapman, DF 2005. The phosphorus and nitrogen requirements of temperate pasture species and their influence on grassland botanical composition. *Australian Journal of Agricultural Research,* 56, 1027-1039.

Martin, K, Edwards, G, Bryant, R, Hodge, M, Chapman, D, Moir, J & Cameron, K In press. Herbage dry matter (DM) yield and nitrogen concentration of grass, legume and herb species grown at different nitrogen fertiliser rates under irrigation *Animal Production Science*.

Matthew, C 1991. *"Late Control"-what is it and why should it work?,* Massey University, Palmerston, New Zealand.

Matthew, C, Xia, J, Hodgson, J & Chu, A 1989. Effect of late spring grazing management on tiller age profiles and summer-autumn pasture growth rates in a perennial ryegrass (Lolium perenne L.) sward. *Proceedings of XVI International Grassland Congress*.

Mills, A, Moot, DJ & Jamieson, PD 2009. Quantifying the effect of nitrogen on productivity of cocksfoot (Dactylis glomerata L.) pastures. *European journal of agronomy,* 30(2), 63-69.

Nobilly, F, Bryant, R, McKenzie, B & Edwards, G. Productivity of rotationally grazed simple and diverse pasture mixtures under irrigation in Canterbury. Proceedings of the New Zealand Grassland Association, 2013. 165-172.

Tas, BM, Taweel, HZ, Smit, HJ, Elgersma, A, Dijkstra, J & Tamminga, S 2006. Utilisation of N in perennial ryegrass cultivars by stall-fed lactating dairy cows. *Livestock Science,* 100, 159-168.

Totty, VK, Greenwood, SL, Bryant, RH & Edwards, GR 2013. Nitrogen partitioning and milk production of dairy cows grazing simple and diverse pastures. *Journal of Dairy Science,* 96, 141-149.

Woods, RR, Cameron, KC, Edwards, GR, Di, HJ, Clough, TJ, Clough., aTJ, . & press)., i 2016. Effects of forage type and gibberellic acid on nitrate leaching losses. *Soil Use and Management,* 32(4), 565–572.

Woodward, SL, Waugh, CD, Roach, CG, Fynn, D & Phillips, J 2013. Are diverse species mixtures better pastures for dairy farming? *Proceedings of the New Zealand Grassland Association,* 75, 79-84.

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