The effect of perennial ryegrass sowing rate and companion grass on the establishment of plantain in mixed pastures

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Abstract

Managing the content of plantain in grass-based swards has become an important consideration for farmers intending to use this species to support seasonal forage supply and nitrogen loss mitigation. Changes in companion perennial ryegrass sowing rate and companion grass species were investigated to understand their impact on initial sward yield and the success of plantain establishment in grass-based pastures. In 2021, an agronomic experiment involving six large-plot trial sites was established in Northland, the Waikato, Manawatū, Canterbury and Southland. This paper reports the sward yield and botanical composition results of the establishment phase, defined as the first two harvests at each site after sowing. Adjusting the diploid perennial ryegrass sowing rate from 8 to 20 kg/ha increased establishment phase yield but reduced mean plantain content across sites from 25% down to 20%. Fast establishing grass species (Italian and Hybrid ryegrass), which achieved the highest early yields, also had the lowest plantain botanical composition at the second harvest (mean across sites 8-13% compared to 21-23% for perennial grasses). Regional and soil type differences in the success of plantain establishment were evident, with the best results on the Waikato Allophanic soil and the poorest on the Canterbury Pallic soil. Competition during the establishment phase, whether from different grass species or varying sowing rates, can affect plantain percentage. Farmers and advisors need to consider this when establishing multi-species pastures.

Keywords: hybrid ryegrass, Italian ryegrass, *Plantago lanceolata* L., tall fescue, tetraploid ryegrass

Introduction

Perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.) based pastures have been the basis for the majority of New Zealand pastoral systems, providing easy management, reliable dry matter production, high quality pasture and the ability to fix atmospheric nitrogen. However, excessive losses of nitrogen (N) to air and water present a growing issue for the sustainability of these systems (Monaghan et al. 2007). Considerable effort has gone into developing forage-based mitigations that would have minimal impact on pastoral productivity and profitability. Narrow-leaved plantain (*Plantago lanceolata* L., hereafter referred to as 'plantain') has been shown to reduce N losses when used in ryegrass-based pastures in grazing systems (Pinxterhuis et al. 2024; Egan et al. 2025).

The scale of the effect that plantain has on reducing nitrogen loss from pastoral systems appears to be relative to the proportion of plantain in a pasture sward (Box et al. 2023; Vi et al. 2023). This is an important consideration in New Zealand systems for which most of the consumed feed is from home-grown pasture (Mills and Neal 2021), usually comprised of a grass-legume mixture. Therefore, there is considerable interest in understanding how best to achieve the desired ratio of plantain in the herbage available for animal consumption and how it can be maintained. Field surveys indicate that plantain content (i.e. the proportion of plantain in harvested herbage dry matter) in grass-dominant pastures declines within 3-4 years of establishment (Dodd et al. 2019; Dodd et al. 2022). While a plantain content threshold for mitigating N losses has not been clearly determined, achieving and sustaining substantive proportions in a mixed pasture presents an agronomic challenge to adoption (Dodd et al. 2024).

Initial establishment success, interspecies competition, and grazing management all could influence the ability of plantain to establish and persist in mixtures (Black et al. 2017). In terms of establishment, the best way to maximise plantain content appears to be from sowing with new grass (Dodd et al. 2022), yet there are currently insufficient data to advise on optimal plantain sowing rates. In a recent Irish study, McGrane et al. (2025) report on the effectiveness of simultaneously increasing plantain sowing rate and reducing perennial ryegrass sowing rate as an approach to optimising plantain content.

A further possibility relates to the potential for selection of a companion grass species and/or cultivar that is more conducive to the establishment of sufficient plantain content in swards. The seasonal

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Table 1 Study site descriptions, including soil type, drainage classification, long term mean (LTM, 1991-2020) rainfall and temperature, starting soil tests (to 150mm depth), and site management details (including sowing dates, the first two harvest dates and nitrogen inputs for that period) from the six trial site locations: Northland, Waikato – Allophanic; Waikato – Gley; Manawatū; Canterbury and Southland. Soil data source Manaaki Whenua/BSI. Climate data source NIWA/ESNZ.

	Northland	Waikato (A)	Waikato (G)	Manawatū	Canterbury	Southland
Locale	Kerikeri	Ngāhinapōuri	Ngāhinapōuri	Cheltenham	Lincoln	Edendale
Lat., Long.	35.18S, 173.94E	37.92S, 175.18E	37.92S, 175.18E	40.13S, 175.6E	43.6S, 172.46E	46.34S, 168.78E
Soil order	Oxidic	Allophanic	Gley	Pallic	Pallic	Brown
Soil drainage	Well	Well	Poor	Moderate-well	Moderate	Well
Soil profile available water (mm)	94	200	184	150	157	167
Rainfall LTM (mm/y)	1710	1387	1387	851	588	1028
Annual temperature LTM (°C)	15.3	13.5	13.5	12.3	11.5	10.1
Starting soil test						
Soil pH	5.7	5.6	5.6	6.2	5.6	5.5
Soil OlsenP (mg/L)	19	17	30	24	23	50
Management details						
Sowing date	15 Apr 2021	8 Apr 2021	8 Apr 2021	12 Apr 2021	26 Nov 2021	8 Dec 2021
First harvest date	27 Jul 2021	5 Jul 2021[1]	5 Jul 2021	25 Jun 2021	12 Jan 2022	8 Feb 2022
Second harvest date	29 Sep 2021	16 Aug 2021	21 Sep 2021	16 Aug 2021	9 Feb 2022	2 Mar 2022
Nitrogen inputs (kg N/ha)	105	125	73	82	82	54

[1] First full harvest of all treatments, an additional harvest of Italian and Hybrid ryegrass treatments occurred in June.
[2] incl. initial diammonium phosphate plus one application of urea after first harvest.

growth pattern of perennial ryegrass and plantain are strongly overlapping, and plantain has a small seed that germinates readily but establishes slowly, suggesting that inter-specific competition from grasses bred for rapid establishment will be strong (Bryant et al. 2019).

This paper reports on a study to determine whether a reduction in perennial ryegrass sowing rate (from the industry standard), or selection of an alternative grass species, would increase plantain contribution to newly established pastures. The work was conducted as a series of six plot trials across five different pastoral farming regions of New Zealand, focusing on the sward establishment phase of the trials. Further results of longer-term persistence and production measurements will be reported in subsequent papers.

Materials and Methods

Site description and design

In 2021, six regional field plot experiments were established. One at Kerikeri, Northland, two at Ngāhinapōuri, Waikato (on the same farm but on two soil orders), and one at Cheltenham, Manawatū were all established in Autumn 2021; and one at Lincoln, Canterbury and one at Edendale, Southland were established in late Spring 2021 (Table 1). With the exception of the Canterbury site at Kimihia Research Centre, all were within paddocks on commercial farms.

The plot trials were established with 4 replicates (Northland, Manawatū, Canterbury, Southland) or 5 replicates (Waikato) in a randomised complete block design. Plots were sown as 6 m long by 3 m wide (Northland, Manawatū, Canterbury, Southland) or 6 m wide (Waikato). Prior to sowing, resident pastures on the sites were sprayed with Roundup at 5 L/ha and cultivated. The plots were sown using an '*Oyjord'* belted cone plot drill with a 15 cm row spacing (www.oyjord.com). Site-based soil samples were taken prior to sowing and analysed for soil pH and Olsen P (Table 1) to verify and correct any key soil fertility limitations. Diammonium Phosphate at 200 kg/ha was applied to all sites at sowing.

Treatments

There were ten sward type treatments in the experiment, summarised in Table 2, showing the treatment codes used subsequently in the text. The sowing rates of all sward type treatments were the same across the regional sites. Sward type mixes that include plantain are shown with a '+PL' in the code, and one that included white clover is shown with a '+WC' in the code. The plantain

Table 2 Summarised treatments and main comparison groups in this study, including the sward type treatment codes, sowing rates (kg/ha) and seed number ratios (%). Treatment codes are shown with species code, and sowing rate for varied diploid perennial ryegrass sowing rate treatments. Species codes: Plantain, PL; Diploid perennial ryegrass, PRD; white clover, WC; Tetraploid perennial ryegrass, PRT; Tall Fescue, TF; Tetraploid hybrid ryegrass, HR; Italian ryegrass, IR.

	Comparison groups		Sowing rate			Seed ratio
Sward type treatment code	**Sowing rate**	**Companion species**	**Grass**	**Plantain**	**White clover**	**Grass: Plantain: Clover**
PL	X		0	12	0	0:100:0
8PRD+PL	X		8	3	0	73:27:0
16PRD+PL	X	X	16	3	0	84:16:0
20PRD+PL	X		20	3	0	87:13:0
PRD	X		20	0	0	100:0:0
IR+PL		X	20	3	0	87:13:0
HR+PL		X	24	3	0	81:19:0
PRT+PL		X	24	3	0	81:19:0
PRD+PL+WC		X	16	3	5	49:9:42
TF+PL		X	24	1	0	95:5:0

cultivar used in all swards was Ecotain® environmental plantain, which is a blend of the Agritonic and Tonic plantain cultivars. White clover was not included in the majority of treatments due to prior experiences of difficultly controlling spread between in small plots, and the expectation that recovery of resident white clover in the plots would occur over time. The one instance where it was included was to test whether this made a material difference to the herbage accumulation and plantain composition results. Two monoculture sward type treatments were included for comparison, pure plantain (PL) sown at 12 kg/ha and pure diploid perennial ryegrass (PRD) sown at 20 kg/ha.

Two main sward type comparison groups are identified in the second and third columns of Table 2. The first group was designed to examine the effect of perennial ryegrass sowing rate, and used rates of 8, 16 and 20 kg/ha with a consistent rate of plantain (3 kg/ha). This was intended to create a range of ryegrass:plantain seed ratios and thus a range of plantain contents.

The second sward type comparison group was designed to examine the effect of companion grass species and used a range of sowing rates considered typical for those species (Table 2). A consistent plantain sowing rate of 3 kg/ha was used in all of these treatments, except for the tall fescue treatment, where a 1 kg/ha sowing rate was used. This lower rate was based on prior experience establishing plantain in tall fescue pastures, where the recognised slower establishment rates of tall fescue compared with the ryegrasses (Easton et al. 1994) have been observed to result in plantain-dominant swards (Clark et al. 2010). The varied companion grass species mixed with plantain, included appropriate commercial endophyte strains, and were: diploid perennial ryegrass (*Lolium perenne*, cultivar Legion AR37, PRD+PL); tetraploid perennial ryegrass (*Lolium perenne*, cultivar Halo AR37, PRT+PL); diploid Italian ryegrass *(Lolium multiflorum*, cultivar Asset AR37*,* IR+PL); tetraploid hybrid ryegrass (*Lolium boucheanum,* cultivar Mohaka AR37*,* HR+PL); and tall fescue (*Festuca arundinacea*, cultivar Hummer MaxP, TF+PL). The additional treatment including white clover with the diploid perennial ryegrass used cv. Tribute (PRD+PL+WC).

Yield assessment

All sites were managed using a cut and carry system. Harvests were taken when the average pasture cover (APC) of each site was between 2500 - 3000 kg DM/ha. At one site (Waikato Allophanic) an additional cut of the Italian and hybrid ryegrass plots on June 9th was required prior to the first general harvest, and the yields are included in the first harvest totals. A 45 cm wide rotary mower strip was cut along the length of each plot to a height of 4 cm (approximately 1500 kg DM/ha residual). The cut samples were weighed for fresh weight. One sub-sample of 400 g from each plot harvest was taken and oven dried at 90°C for at least 48 hours to determine dry matter concentration (%).

The yields for the first two full treatment harvests were deemed to constitute the establishment period. This reflected the lack of substantial plantain contribution observed in the first harvest for many treatments and sites. This meant that the evaluation period differed between sites (Table 1), due to different establishment rates and site conditions (e.g. severe winter wetness at the Northland site). In order to compare yields between sites and for site × treatment interactions, the average

daily herbage accumulation rate (HAR) was calculated from establishment to the first harvest, and from the first to the second harvest.

Botanical composition assessment

At each harvest a representative herbage sample of 30 cm length and of two drill rows width was cut from each plot with hand shears to the same height as the mower residual, for a botanical sample. Botanical samples were hand separated into sown species (grass; plantain leaf and scape; white clover) and unsown species, oven dried at 90°C for at least 48 hours and weighed to determine the contribution to yield of the various botanical components. The remainder of the plot was cut to 4 cm height using a mower and the surplus herbage discarded.

Trial management

Weeds were monitored, and selective herbicide was applied to control unsown broadleaf species where appropriate. Hand weeding was also used where necessary to control hard to kill species, particularly in the PRD+PL+WC treatment. An initial capital application of diammonium phosphate was applied to all plots at all sites (200 kg/ha, 18:20:0:0). Nitrogen was applied as urea after the first harvest at rates of 3% of the average amount of forage removed during harvest (Table 1).

Statistical analysis

An optimal REML spatial model was fitted to the harvest 1 herbage HAR, harvest 2 HAR, harvest 1 and harvest 2 plantain botanical composition measurements using Genstat 24 (VSN International, 2024). All sward type treatments were included in the same analysis, and a separate spatial model and error variance was fitted for each site. Fixed effects included sward type treatment, site and the sward type × site interaction. The model with the minimal Bayesian Information Coefficient (Gilmour et al. 1997) was selected as the optimal model. Duncan's post-hoc means comparison test were performed with a significance level of 0.05.

Results

Between-site differences in dry matter production and plantain botanical composition

The time to second harvest at each site varied as follows (Table 1): Northland 167 days; Waikato Allophanic 130 days; Waikato Gley 166 days; Manawatū 126 days; Canterbury 75 days; and Southland 84 days.

The mean HAR over the first two harvests (Table 3) differed between sites ($p<0.001$), being greatest at the Southland site (95 kg DM/ha/d) and least at the Manawatū site (11 kg DM/ha/d). The mean contribution of plantain to yield at the second harvest also differed between sites ($p<0.001$), being greatest at the Waikato Allophanic site (32%) and least at the Canterbury site (17%). The sward type affected mean HAR across sites, but the site × sward type interaction was comparably small, indicating while sward effects varied by site, this variation was modest relative to the main sward type effect; the interaction ratio was 5.7%.

Effect of diploid perennial ryegrass sowing rate on dry matter production and plantain botanical composition

Increasing the diploid perennial ryegrass sowing rate from 8 kg/ha (8PRD+PL) to 16 kg/ha (16PRD+PL) or 20 kg/ha (20PRD+PL) significantly increased initial dry matter production at the first harvest in a combined analysis of all sites ($p<0.05$, Table 4a). However, by the second harvest, the 8PRD+PL sward was not significantly different than the 16PRD+PL sward, and only the 20PRD+PL sward had a significantly greater HAR ($p<0.05$).

The main effects of diploid ryegrass sowing rate varied across location for individual sites across both first two harvests. At the Waikato Gley site the 8PRD+PL sward treatment had significantly lower HAR than other PRD swards ($p<0.05$), and at the Manawatū and Canterbury sites the 20PRD+PL sward had a significantly greater HAR than the 8PRD+PL sward ($p<0.05$, Table 3a). The other three sites showed no significant differences between all PRD+PL sowing rates.

Increasing the diploid perennial ryegrass sowing rates from 8 kg/ha to 16 or 20 kg/ha had a significantly negative effect on the plantain content at the first harvest, reducing it from 26.1% at 8 kg/ha ryegrass rate, to 12.4% and 12.9% respectively for the 16 and 20 kg/ha ryegrass rates (Table 4a, $p<0.05$). By the second harvest, this effect was diminished such that the plantain content was not significantly different between the 8PRD+PL and 16PRD+PL sowing rate treatments (25.2% and 23.5%) but was significantly lower in the 20PRD+PL sward (19.5%, $p<0.05$). For both harvests, the pure plantain and perennial ryegrass swards largely maintained their botanical composition with on average <3% ingress of other species.

Plantain content at the Northland and Canterbury sites was significantly reduced at the 16PRD+PL treatment compared to 8PRD+PL sward treatment (Table 5a, $p<0.05$). At the other four sites, there was no significant effect of ryegrass sowing rate on plantain content. At the Waikato and Southland sites, the original plantain content target of 30% was generally achieved at all ryegrass sowing rates. In the pure plantain sward, only at Canterbury was there was a notable unsown species contribution (>5%).

Table 3 Individual site analysis of mean herbage accumulation rate (kg DM/ha/d) of ten sward types over the first two harvests at each site. (analysed together but divided into two sward treatment comparison groups (a) perennial ryegrass sowing rate and (b) companion grass treatments). Appended letters that are the same are not significantly different within their individual site (column). PL = plantain; PRD = diploid perennial ryegrass; PRT = tetraploid perennial ryegrass; WC = white clover; IR = Italian ryegrass; HR = hybrid ryegrass; TF = tall fescue. LSD = Fisher's protected least significant difference test.

Sward type	Northland	Waikato Allophanic	Waikato Gley	Manawatū	Canterbury	Southland
(a) Ryegrass sowing rates						
PL	5.3 d	9.6 e	9.3 e	4.9 e	30.3 f	81.4 e
8PRD+PL	21.5 ac	19.0 d	10.7 e	7.2 de	46.8 de	96.5 bc
16PRD+PL[1]	18.6 c	21.1 cd	12.7 d	8.6 cd	53.1 cd	95.7 c
20PRD+PL	22.6 ac	20.4 cd	14.3 cd	11.6 c	56.6 b	97.6 bc
20PRD	19.9 bc	21.5 cd	13.3 cd	11.9 c	59.1 bc	97.0 bc
(b) Companion grasses						
IR+PL	23.1 ac	33.5 b	20.5 a	21.6 a	33.8 f	90.7 cd
HR+PL	24.2 ab	39.6 a	17.6 b	17.9 b	63.7 a	107.3 a
PRT+PL	20.0 bc	24.9 c	14.5 c	11.6 c	57.7 bc	103.8 ab
16PRD+PL[1]	18.6 c	21.1 cd	12.7 de	8.6 cd	53.1 cd	95.7 c
16PRD+PL+WC	25.4 a	18.0 d	12.6 de	9.5 cd	57.2 bc	95.5 c
TF+PL	21.4 ac	7.5 e	13.9 cd	4.5 e	45.3 e	84.1 de
Site mean[2]	20.2	21.5	13.9	10.9	50.4	95.0
Sward type p-values	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Sward type LSD (5%)	3.8	5.1	1.8	3.7	6.8	7.8

[1] 16PRD+PL data line repeated for ease of comparison within Table 2 treatment groups.

[2] Between site comparison mean HAR: $LSD_{maximum}$ = 13.0; LSD_{mean} = 6.6

Table 4 Mean cross-site herbage accumulation rates (HAR) of ten sward types for the first two harvests at each site (analysed together but divided into two sward treatment comparison groups (a) perennial ryegrass sowing rate and (b) companion grass treatments). Appended letters that are the same are not significantly different within each harvest (column). PL = plantain; PRD = diploid perennial ryegrass; PRT = tetraploid perennial ryegrass; WC = white clover; IR = Italian ryegrass; HR = hybrid ryegrass; TF = tall fescue. LSD = Fisher's protected least significant difference test.

Sward type	HAR (kg DM/ha/d)		Plantain content (% of harvested DM)	
(a) Ryegrass sowing rates	**Harvest 1**	**Harvest 2**	**Harvest 1**	**Harvest 2**
PL	7.8 f	47.4 e	99.5 a	97.6 a
8PRD+PL	17.0 e	56.6 bd	26.1 b	25.2 b
16PRD+PL[1]	20.1 d	56.0 cd	12.4 cd	23.2 bc
20PRD+PL	21.8 c	59.8 ac	12.9 cd	19.8 c
20PRD	21.0 cd	60.6 ab	1.2 f	0.0 f
(b) Companion grasses				
IR+PL	28.9 a	59.2 bc	3.1 ef	8.3 e
HR+PL	25.9 b	64.1 a	6.1 e	13.4 d
PRT+PL	22.0 c	57.2 bd	11.9 d	20.7 c
16PRD+PL[1]	20.1 d	56.0 cd	12.4 cd	23.2 bc
16PRD+PL+WC	20.0 d	58.4 bc	13.0 cd	21.7 bc
TF+PL	8.1 f	53.0 de	15.5 c	21.2 c
Sward type p-values	<0.001	<0.001	<0.001	<0.001
Sward type LSD (5%)	1.6	4.6	3.5	3.8

[1] 16PRD+PL data line repeated for ease of comparison within Table 2 treatment groups.

Table 5 Individual site analysis of plantain botanical composition at the second harvest (% of harvested dry matter) of ten sward types at each site (analysed together but divided into two sward treatment comparison groups (a) perennial ryegrass sowing rate and (b) companion grass treatments. Note differing periods since establishment (Table 1). Appended letters that are the same are not significantly different within their individual site (column). PL = plantain; PRD = diploid perennial ryegrass; PRT = tetraploid perennial ryegrass; WC = white clover; IR = Italian ryegrass; HR = hybrid ryegrass; TF = tall fescue. LSD = Fisher's protected least significant difference test.

Sward type	Northland	Waikato Allophanic	Waikato Gley	Manawatu	Canterbury	Southland
(a) Ryegrass sowing rates						
PL	100.0 a	100.0 a	100.0 a	100.0 a	94.1 a	99.7 a
8PRD+PL	24.5 bc	30.8 b	29.2 b	14.3 b	23.1 b	32.1 b
16PRD+PL[1]	14.0 de	30.6 b	31.2 b	12.9 bc	10.1 c	29.1 bc
20PRD+PL	15.3 cd	27.1 b	26.8 b	12.5 bc	8.9 c	23.4 bc
20PRD	0.0 f	0.0 d	0.0 e	0.0 d	3.8 c	0.0 e
(b) Companion grasses						
IR+PL	9.0 def	19.1 c	8.1 d	1.9 cd	3.1 c	8.3 de
HR+PL	14.9 bcd	25.2 bc	17.4 c	2.1 cd	2.9 c	11.0 de
PRT+PL	27.1 b	26.9 b	24.7 b	18.2 b	5.0 c	24.7 bc
16PRD+PL[1]	14.0 de	30.6 b	31.2 b	12.9 bc	10.1 c	29.1 bc
16PRD+PL+WC	12.0 de	29.9 b	30.4 b	17.6 b	10.2 c	22.7 bc
TF+PL	17.5 bcd	31.0 b	26.4 b	20.0 b	6.1 c	19.5 cd
Site mean[2]	23.4	32.1	29.3	19.9	16.7	27.0
Sward type p-values	<.001	<0.001	<.001	<.001	<.001	<.001
Sward type LSD (5%)	14.3	6.9	6.9	11.7	8.3	11.6

[1] 16PRD+PL data line repeated for ease of comparison within Table 2 treatment groups.
[2] Between site comparison Plantain content harvest 2: $LSD_{maximum}$ = 13.8; LSD_{mean} = 10.2.

Effect of companion grass species on dry matter production and plantain botanical composition

There was a significant effect of companion grass species on harvested yield at both harvest dates across in the combined analysis across all sites (Table 4b, $p<0.001$). At the first harvest, sward mixtures containing a faster establishing companion grass (Italian and hybrid ryegrasses) had a significantly greater HAR than PRD swards ($p<0.05$). In turn the perennial ryegrass swards (PRD and PRT) had significantly greater HAR than the TF sward ($p<0.05$), which was the slowest establishing treatment. At the second harvest, the HR+PL sward still had a significantly greater HAR than the other ryegrass swards, but the HAR of the TF sward was not significantly different to the PRT or PRD sward (without WC).

At five of the individual sites, the difference in mean HAR between IR+PL and HR+PL over the first two harvests differed significantly ($p<0.05$). At two sites (Waikato Gley and Manawatū) IR+PL was greater than HR+PL and at the other three sites, HR+PL was greater than IR+PL (Table 3b). At two of the sites (Waikato Allophanic and Manawatū), the HAR for the TF+PL sward was significantly less than other companion grass swards ($p<0.05$). At Canterbury and Southland, the HAR for the TF+PL sward was significantly less than all other companion grasses, apart from IR+PL sward. Tetraploid perennial ryegrass (PRT+PL) had numerically greater mean HAR than diploid perennial ryegrass (16PRD+PL) at all sites, but this difference was only significant at the Waikato Gley and Southland sites (Table 3b), and did not result in a significant difference in plantain composition (Table 5b)

The companion grass species also significantly impacted the plantain content of the swards ($p<0.001$), with IR+PL and HR+PL being lower on average across all sites (Table 5b). The difference between these two swards and the PRD swards was significant at the Waikato, Manawatū and Southland sites ($p<0.05$). Differences in plantain content between TF+PL and PRD+PL swards varied across sites but none were significant ($p>0.05$). Likewise, differences in plantain content between PRT+PL and PRD+PL swards varied across sites but only at the Northland site was it significantly greater (by >10%, $p<0.05$).

Single species additive effects

Comparing the monoculture of diploid perennial ryegrass (20PRD), with the grass mix treatment with the same grass sowing rate (20 kg/ha), but with the

addition of 3kg of plantain (20PRD+PL), showed no significant difference in HAR in either the individual sites (Table 3a) or the combined analysis (Table 4a).

The 16PRD+PL+WC treatment consistently had similar HAR and plantain content to the 16PRD+PL treatment in the combined analysis ($p>0.05$, Table 4b). This was also the case at most of the individual sites, with the exception of the Northland site, where the +WC sward had a significantly greater mean HAR (c. 7 kg DM/ha/d). (Table 3b). There was no significant difference between these two sward types for the proportion of plantain at the second harvest at any site ($p>0.05$), though the content of the +WC sward was numerically greater by ~4% at the Manawatū site and less by ~6% at the Southland site (Table 5b).

Yield of plantain monoculture

The monoculture of plantain (PL) had the lowest mean HAR over the first two harvests at 4 of the 6 sites (Table 3) and the lowest HAR at both harvests in the combined multi-site analysis (Table 4). This sward treatment had significantly lower mean HAR than all perennial ryegrass treatments, although it was not significantly different than the yield of the TF+PL sward at both harvests in the combined site analysis and at four of the individual sites (Table 3).

Discussion

These results highlight the significant influence of both companion grass sowing rate and companion species selection on the dry matter yield during establishment and the botanical composition of plantain in mixed pastures under a cutting regime.

Effect of diploid perennial ryegrass sowing rate

There was generally a positive relationship between initial ryegrass sowing rates and pasture production during sward establishment (Table 3a, 4a), as seen in other sowing rate trials with white clover (e.g. Lee et al. 2018). For perennial ryegrass and plantain mixes this was a clearer trend than seen in the study of McGrane et al. (2025), which manipulated botanical composition at establishment through both an increased plantain sowing rate and a reduced perennial ryegrass sowing rate (holding total sowing mass constant at 25 kg/ha). In that study, the range in the three ryegrass sowing rates used was much less (20, 21.5 and 23 kg/ha) and the intermediate rate gave the lowest establishment yield. The two studies did produce a similar result in terms of the impact of increasing the ryegrass:plantain sowing ratio (Table 2), whereby the plantain contribution to yield during establishment was reduced as ryegrass sowing rate increased. This suggests that increasing ryegrass density intensifies interspecific competition, reducing the contribution to yield of the secondary species – that is the plantain in this case. This is also consistent with observations of greater ryegrass sowing rates reducing broadleaf weed content (Lee et al. 2018) and clover content (Hurst et al. 2000).

Vi et al. (2023) also describe variable sowing rates used in a paddock-scale experiment under grazing which targeted 30% plantain, 50% plantain and 70% plantain amongst a mixed sward with diploid perennial ryegrass and white clover. In that work the proportion of plantain was manipulated successfully by both reducing diploid perennial ryegrass sowing rate and increasing plantain sowing rate. However, plantain proportions of higher than 50% were not achieved under any combination of sowing rates. This implies there is an upper threshold for plantain content in swards dominated by perennial ryegrass, consistent with plant community assembly patterns of dominant, subordinate and transient species (Grime 1998).

Effect of companion grass species on plantain botanical composition and dry matter production

Another agronomic factor that can be considered to manipulate the relative abundance of plantain in a pasture sward is grass species selection. The diploid perennial ryegrass treatment (16PRD+PL) produced significantly less dry matter by the first harvest than the comparable tetraploid perennial ryegrass (PRT+PL; Table 3b), but the plantain composition was only slightly greater, a non-significant difference ($p>0.05$). This result partly conflicts with the findings of McGrane et al. (2025), where diploid perennial ryegrass plus plantain yielded significantly higher but has significantly less plantain proportion than tetraploid perennial ryegrass plus plantain during establishment. While the treatment species could be considered comparable, in our study the plantain cultivar was different (Ecotain® *vs.* Hercules) and the sowing rate of the grasses was adjusted for seed size, with tetraploid perennial ryegrass sown at 24 kg/ha and diploid perennial ryegrass at 16 kg/ha, whereas in McGrane et al. (2025) both diploid and tetraploid grasses were sown at the same rate. With the difference in seed size between these two perennial ryegrass types there would be a higher seedling density achieved from sowing diploid perennial ryegrass at the same rate relative to tetraploid perennial ryegrass (Table 2). It is possible that the lack of significant impact on the plantain proportion in our study could be due to the HAR difference not being large enough – by the second harvest they were not significantly different for HAR (Table 4b).

Shorter lived grasses such as Italian ryegrass and hybrid ryegrass are known to be faster to establish and more winter active than perennial ryegrass and tall fescue (Easton et al. 1994). This study showed that the rapid establishment of these two grasses resulted

in greater HAR, but lower plantain composition through the establishment period (Table 4, 5). These grasses appeared to provide increased competition to the plantain compared with perennial ryegrass and tall fescue. Cid et al. (2011) also describe the poor establishment and contribution to biomass of plantain when sown with annual ryegrass, relative to when plantain was grown in mixtures with orchard grass (cocksfoot; *Dactylis glomerata*) and tall fescue, two less rapidly establishing perennial grass species. and Hurst et al. (2000) took a similar approach, noting that substituting perennial ryegrass with timothy (*Phleum pratense*, L) improved the contribution of clovers to the sward. This shows that when making decision or recommendations to maximise plantain percentage in a pasture sward, consideration needs to be given to grass species selected in a pasture mix.

In studying the longer-term yield of three species mixes that included perennial ryegrass, plantain and white or red clover, Black et al. (2017) in general show greater yield when all three were combined. Such an effect was certainly apparent in this study comparing the PL and 16PRD+PL or 16PRD+PL+WC sward treatments, but we observed no differences between the latter two with the addition of WC in this establishment period for the multi-site analysis and for 5 of the 6 sites. The observation that plantain percentage in harvested herbage was no less when white clover was added to diploid perennial ryegrass and plantain, both sown at the same rate, could suggest that 5 kg/ha of white clover could have a synergistic effect on plantain establishment when established in a mixed sward with diploid perennial ryegrass.

It is important to acknowledge this study was conducted under a cut and carry only system. Further work needs to be done on the effect of these factors on the establishment of plantain in mixed species swards under grazing, since this introduces additional selective pressures such as grazing preference (Pain et al. 2014) and sensitivity to treading damage (Wilson et al. 2024).

Finally, the sites were established for the purpose of examining the longer-term productive performance of the mixtures and the persistence of plantain within them, given that such questions have been regularly raised by farmers contemplating the adoption of forage plantain in perennial grass-based pastures. Those results will be reported in a future publication.

Conclusions

This study demonstrates that two key agronomic factors – companion grass species selection and sowing rate – significantly influence both initial dry matter production and the establishment of plantain within mixed swards. An increase in perennial ryegrass sowing rates reduced the early abundance of plantain numerically, but only at two sites was this significant (from c. 21-23% down to 9-13%). This highlights the importance of optimising sowing rates to balance early herbage yield, species competitiveness, and the desired plantain proportion. Substituting Italian or hybrid ryegrass for perennial ryegrass increased herbage yield during establishment but suppressed plantain content at all but one site. This suggests that more competitive cool-season grass species can place greater pressure on plantain during early establishment. Site-related factors such as location and soil type also appeared to influence establishment outcomes. Differences between the Waikato Allophanic and Gley sites, including time to second harvest and the additional early harvest of Italian and hybrid ryegrass treatments at the Allophanic site, indicate that soil type and associated site conditions can affect early sward development. Broader regional differences were also evident, with North Island sites established in autumn having lower HAR than South Island sites established in late spring. Overall, competition during establishment – driven by both companion species choice and sowing rate – can strongly influence plantain percentage in mixed swards. Farmers and advisors should consider these factors carefully when designing multi-species pasture mixes.

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