Effectiveness of strategies used to establish plantain in existing pastures

Racheal H. BRYANT[1*], Mike B. DODD[2], Allister J.E. MOORHEAD[3], Paul EDWARDS[4] and Ina J.B. PINXTERHUIS[4,]
[1]*Faculty of Agriculture and Life Sciences, PO Box 85084, Lincoln University, Lincoln 7647, Christchurch, New Zealand*
[2]*AgResearch, Grasslands Research Centre, Private Bag 11008, Palmerston North 4442, New Zealand*
[3]*Agricom, PO Box 3761, Christchurch, New Zealand*
[4]*DairyNZ Ltd, PO Box 85066, Lincoln University, Lincoln 7647, New Zealand*
*Corresponding author: Racheal.Bryant@lincoln.ac.nz

Abstract
In recent years plantain (*Plantago lanceolata*) has emerged as a potential forage for reducing nitrogen losses from dairy farm systems. However, achieving sufficient proportions of plantain in pastures to help meet target reductions in nitrate leaching presents on-farm challenges. To investigate sowing methods for establishing plantain into existing pasture to achieve high plantain populations, direct drilling was compared with broadcasting before and after grazing. Additionally, pre-graze mowing versus grazing only, and early versus late first defoliation after sowing were investigated to assess their effect on reducing competition from existing pasture. Botanical composition was determined in a small-plot study at Lincoln following summer sowing under irrigation, and from commercial dairy farms in Canterbury (irrigated) and Waikato (not irrigated). Generally, direct drilling was more effective than broadcast sowing for establishing plantain. The method of defoliation after sowing (pre-graze mowing or grazing) was not as important as timing of early defoliation in the resulting plantain populations. Early grazing, while seedlings were small enough to avoid defoliation, improved plantain establishment likely by reducing competition from the pre-existing pasture.

Keywords: *Plantago lanceolata*, seedling survival, broadcast, direct drill, undersow, oversow

Introduction
The leaching of nitrogen (N), mostly in the form of nitrates through groundwater into streams and waterways is an increasing environmental concern throughout New Zealand. The majority of this N stems from land intensively managed for crop and ruminant production systems. Under grazing, there is a high risk of nutrient loss from urine patches. In conventional perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*) pastures, N loading from urine patches is equivalent to 700–1000 kg N/ha, of which more than 50% can be lost through leaching (Di & Cameron 2002). Animal and lysimeter studies have demonstrated the efficacy of forages such as plantain (*Plantago lanceolata*) and Italian ryegrasses (*Lolium multiflorum*) to reduce N losses (Bryant et al. 2018; Totty et al. 2013; Woods et al. 2016). When plantain accounts for 30–50% of the diet of dairy cows, urinary N concentration and estimated N excretion is reduced by more than 20% with no compromise in milk yield per cow compared with conventional ryegrass clover pastures (Woodward et al. 2012; Box et al. 2017; Dodd et al. 2019). Ease of adoption of plantain-based pastures within farm systems is not yet known, but initial data from commercial farms indicate that high plantain contents in mixed-species pastures can be achieved in the first years after pasture renewal, but cannot be maintained (Dodd et al. 2019).

Reducing competition by spraying ryegrass with herbicide (Glassey et al. 2012; Thom et al. 2011), reducing post graze mass and growth rate of existing pasture by mowing (Bryant et al. 2016), or allowing sufficient time for phenological development of plantain before defoliation (Powell et al. 2007), have all been shown to improve establishment of pure swards of plantain. The placement of seed is one of the factors that can have a significant effect on germination (Sheldon 1974) so undersowing (direct drilling into an existing pasture without an herbicide application) or oversowing (broadcasting seed onto the soil surface of a pasture) may affect plantain establishment. The purpose of this research was to investigate sowing and defoliation strategies which might improve establishment and early survival of plantain into existing pastures.

Materials and Methods
The study consisted of a small-plot experimental site and concurrent on-farm monitoring.

Small-plot study
The experiment took place between December 2016 and May 2018 at the Lincoln University Research Dairy Farm. An established pasture, sown in April 2010 with tetraploid perennial ryegrass (cv. Bealey) and white clover (cv. Kopu II), was selected as the

ISSN 2463-2872 (Print) ISSN 2463-2880 (Online) https://doi.org/10.33584/jnzg.2019.81.406

experimental site. The design was a 3 × 2 × 2 factorial design with four blocks. Main plot treatments (67 m^2) were the three plantain-sowing methods: broadcast immediately before grazing (BCB); broadcast after grazing (BCA); and direct drilling after grazing (DDA). Strip-plot treatments (101 m^2) addressed the timing of first defoliation for the BCA and DDA methods: 21 days after sowing (21 d, 220 growing degree-days) or 42 days after sowing (42 d, 430 growing degree-days). Split-plot treatments (17 m^2) were defoliation method: grazing (G) or pre-graze mowing (M) to a stubble height of 4 cm.

The grass tiller density, as determined from 50 soil plugs (29 cm^2), prior to the start of the trial was 7499±633 tillers/m^2, predominantly perennial ryegrass and some twitch (*Elytrigia repens*) and brome (*Bromus stamineus*) grass weeds. There was minimal clover or dicotyledon weeds making up a total growing point (GP) density of 8028±603 GP/m^2. Soil test results prior to the study (November 2016) showed pH 6.2, cation exchange capacity 15 me/100g, and minerals: Olsen P, K, Ca, Mg and S 22 mg/L and 0.89, 8.6, 1.11 me/100g and 10 mg/kg respectively. Although the site was irrigated, one of the block replicates was situated outside the irrigation zone and experienced moisture deficit during summer. Results from this block were included in the analysis.

Plantain (cv. Tonic, a broad-leaved, erect and winter-active cultivar; Charlton & Stewart 2006) was sown at a rate of 8 kg/ha of bare seed for all treatments (equivalent to 380 viable seeds/m^2, based on an average seed germination of 95%), with no nitrogen fertiliser applied at sowing. The BCB treatment was applied on 5 Dec 2016, with plots then grazed on 6 Dec 2016; the BCA and DDA were applied on 7 and 8 Dec 2016 respectively. At the first grazing event (21 d after sowing), the area was grazed or mown to a target residual of 4 cm. Pre-graze plots were mown with a push mower immediately before grazing. At 21 days after sowing, the plots in the 42-d treatment were excluded from grazing using electric fencing. After 42 days, the entire experimental area was grazed, (including the 21-day treatment, which was grazed for a second time), then 30 kg N/ha was applied as urea.

Botanical composition assessment was carried out prior to each grazing using hand scissors, taking six random samples (approximately 150 g fresh weight, FW) to ground level within each plot. A 50 g FW subsample was hand-sorted into sown grass, legume, plantain and weeds and oven dried to a constant weight for dry matter determination. Plantain density counts were made two months after sowing (six quadrats of 10 × 10 cm per plot) and at the end of winter each year (August; six quadrats of 4 × 0.1 m per plot).

On-farm studies

In the South Island, three Canterbury farms participating in the Forages for Reduced Nitrate Leaching programme were monitored: Canlac near Dunsandel and Paritea near Eyrewell both on predominantly shallow free-draining Lismore soils, and Ruapuna on shallow free-draining Ruapuna soils. All sowed plantain at a rate of 4-8 kg seed/ha cv. Tonic onto established pastures, with the establishment options and sowing dates presented in Table 1.

Farmers chose not to use slug bait or herbicide to potentially aid establishment. Baseline growing point density (grass tillers, clover and weed) was 3885±342, 4896±269 and 5184±418 GP/m^2 for the Canlac, Paritea and Ruapuna farms, respectively. After establishment, plant density and botanical composition were determined on three occasions: October 2017, April 2018 and August 2018. Distinct plantain plants were counted in 30 quadrats (0.2 m^2) evenly distributed along three transects across each paddock treatment (length differed between paddocks). Herbage in all quadrats was cut to a grazing height of 3.5 cm for botanical composition. The samples were bulked per treatment, subsampled, dissected into plantain and other species, and oven dried at 60°C for 48 hours for dry matter (DM) percentage.

In the North Island, a research (DairyNZ Scott Farm near Newstead) and a demonstration farm (Owl Farm, St Peter's School near Cambridge) in the Waikato had started to integrate plantain into their pastures using a variety of methods. Details of establishment conditions in several paddocks on each of the two farms are shown in Table 2. These paddocks were surveyed in autumn 2018 and 2019 for plantain plant population density and botanical content (Table 2). The paddocks varied in soil types (Te Rapa, Te Kowhai and Bruntwood silt loams at Scott Farm; and a mixture of well-drained Allophanic and Pumice soils and poorly drained Gley soils at Owl Farm). Plant populations were measured by counting distinct plants in 40 frames (0.2 m^2) along a single 100-m transect per paddock. Botanical content was assessed by harvesting four randomly placed plots (3 m^2) per paddock just prior to grazing, dissecting the plantain from the harvested material and oven drying at 60°C for 48 hours.

Statistical analyses

Data from the Lincoln small-plot study were analysed for variance using repeated measures analysis (botanical composition) and split-split plot model (plant density) using Genstat software (Version 19; VSN International) where: sowing method, timing of grazing and defoliation were fixed terms and block the random term in the repeated measures model. Results for plant density were compared within dates using sowing

Table 1 Description of plantain establishment methods into existing perennial ryegrass and white clover pastures on three Canterbury farms and subsequent impact on plantain content (% of total dry matter).

Farm	Sowing date	Method[1]	Sowing rate (kg/ha)	Days before defoliation	Defoliation treatment[2]	Total dry matter (%)		
						October 2017	April 2018	August 2018
Canlac	Dec-16	DDA	8	21	Graze	4	19	7
Canlac	Dec-16	DDA	8	21	Mow	16	14	15
Canlac	Dec-16	DDA	8	30	Mow	4	25	16
Paritea	Feb-17	BCB	8	30	Mow	1	3	0
Paritea	Feb-17	DDA	8	30	Mow	2	4	0
Paritea	Feb-17	BCA	8	30	Mow	0	4	0
Ruapuna	Feb-17	BCA	8	30	Graze	0	0	<1
Ruapuna	Feb-17	BCA	8	30	Mow	0	1	<1
Ruapuna	Feb-17	BCA	8	21	Graze	0	5	1
Ruapuna	Feb-17	BCA	8	21	Mow	0	5	<1
Ruapuna	Dec-17	DDA	8	n/a	n/a	n/a	6	2
Ruapuna	Dec-17	DDA	4	n/a	n/a	n/a	<1	2
Ruapuna	Dec-17	DDA	8	n/a	n/a	n/a	0	<1
Ruapuna	Dec-17	DDA	4	n/a	n/a	n/a	0	<1

[1]DDA is direct drill after grazing; BCA is broadcast seed after grazing; BCB is broadcast seed before grazing
[2]defoliation either by grazing 'Graze' or pre-graze mowing 'Mow'.

Table 2 Description of plantain establishment methods for new and existing pastures on two Waikato farms (Scott Farm and Owl Farm, ordered by date of establishment) and subsequent impact on plantain content (plant population density and % of total dry matter) in April/May 2017 and 2018.

Farm*	Sowing date	Method[1]	Sowing rate (kg/ha)	2017	2018	2017	2018
New grass-clover-plantain pastures				*Plants/m²*		*% of dry matter*	
Scott (3)	Mar-17	DDS	1.5	12	13	-	24
Owl (3)	Sep-17	DDS	4	107	20	[2]>80	36
Scott (1)	Oct-17	DDC	3	27	11	-	32
Scott (2)	Mar-18	DDS	3	20	13	-	33
Owl (3)	Mar-18	DDS	4	87	22	-	25
Existing ryegrass-clover pastures							
Owl (2)	Sep-17	BCB	4	14	1	17	[2]<10
Owl (4)	Sep-17	DDA	4	22	13	47	32
Owl (2)	Oct-17	BCA	13	28	7	45	38
Scott (1)	Oct-17	Rolled, BCA	6	13	12	-	68
Scott (1)	Oct-17	DDA	6	50	4	-	2

*Number of paddocks with same method in parenthesis, values are averages.
[1]DDA is direct drill after grazing; DDC is direct drill after cultivation; DDS is direct drill after herbicide spray; BCA is broadcast seed after grazing; BCB is broadcast seed before grazing.
[2]Visually estimated. - = no data.

method as main plot, time of grazing as sub plot and defoliation method as sub-sub plot. Significance was reported at the 5% level. No statistical analyses were carried out for the on-farm data, which were collected as observational records.

Results and Discussion

The sowing rate of 8 kg plantain seed/ha, equivalent to 400 seeds/m^2 in the Lincoln small-plot study was considered high. However, initial emergence and survival of plantain within the first 80 days resulted in an average density of 62±10 plants/m^2 that was not affected by sowing or defoliation methods. This value represents 19% of the seed sown even allowing for 96% germination and competition from existing pasture. A similar study in Tasmania achieved an almost identical plant density of 63 plants/m^2 at a similar sowing rate (Raedts & Langworthy 2018). Those authors found that a high sowing rate (7.5 kg bare seed/ha) improved plantain density compared with a lower sowing rate (2.5 kg bare seed/ha) over the first 12 months. Therefore, an 8 kg/ha sowing rate was chosen for the current study to ensure there were sufficient plant numbers to test the other factors relating to seedling survival.

Pre-graze mowing or grazing to a similar target height of 4 cm did not affect plantain density, so any impact of a one-off mowing event on regrowth or post graze residual was too small to influence plantain survival. However, delaying the first defoliation treatment from 21 to 42 days reduced plant survival at day 78 from 133 to 78 plants/m^2 respectively (Figure 1). Results from a series of experiments in the Netherlands that involved sowing naturalised seeds of *P. lanceolata* into established Kentucky bluegrass (*Poa pratensis*) mixtures found plantain seedling survival, but not germination, was very sensitive to shading by competition (van der Toorn & Pons 1988; Pons & van der Toorn 1988). The upright leaves of *P. lanceolata* make light interception difficult, resulting in a low tolerance to shade. The early germinating plantain seedlings in the current small-plot study at 21 days were barely visible and small enough to remain under the mower or grazing height, which subsequently allowed more light into the base of the canopy. By contrast, visual assessment of the seedlings prior to the first grazing in the 42-d treatment revealed plantain plants with elongated leaves, competing with surrounding canopy. These new leaves were exposed to defoliation at 42 d, resulting in high mortality.

Plantain density declined over time. (Figure 1) with shading, overgrazing and treading damage likely contributing to plant mortality, and similar results have been reported previously (Labreveux et al. 2004; Stewart 1996).

The initial small size of the plants meant they made little contribution to the biomass. Over time, the continual appearance of new leaves and emergence of side rosettes resulted in larger plants, which compensated for loss of numbers, so that across all treatments the average number of days to reach a maximum plantain content of 29% DM was 432 days (a little over 14 months after sowing; Figure 2). However, half the plots took more than 470 days to reach a maximum plantain content, also half the plots reached a maximum plantain content of less than 28%. Previous studies have shown that when included in seed mixtures with other perennial species to establish new pasture, the population of plantain and subsequent botanical contribution can be higher (20 to 70%), particularly in the first season (Dhamala et al. 2017; Dodd et al. 2017; Totty et al. 2013).

Over the course of this study, the most successful sowing method was DD, resulting in the greatest maximum plantain content (36%) compared with either the pre-grazing broadcast (24%) or post-grazing broadcast (26%) methods (P<0.001), and the greatest average plantain content (13%, Figure 3) compared with either pre-grazing broadcast (8.3%) or post-grazing broadcast (8.6%) methods (P<0.007). Overcoming competition from existing species is probably the greatest challenge in establishing into existing pastures (Thom

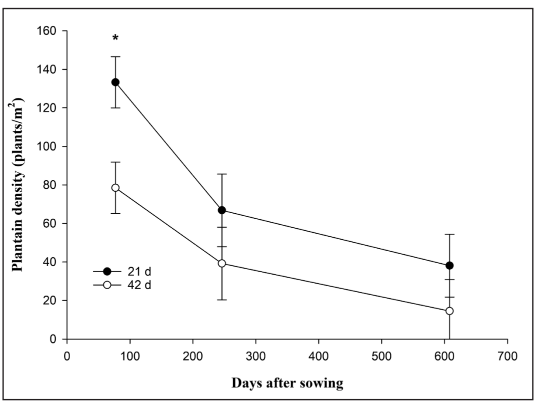

Figure 1 Average plantain density in the small-plot trial at Lincoln over 600 days following establishment into existing pastures and using grazing or pre-graze mowing 21 or 42 days after establishment. Error bars are the standard error of the difference and the asterisks denote significance at P<0.05.

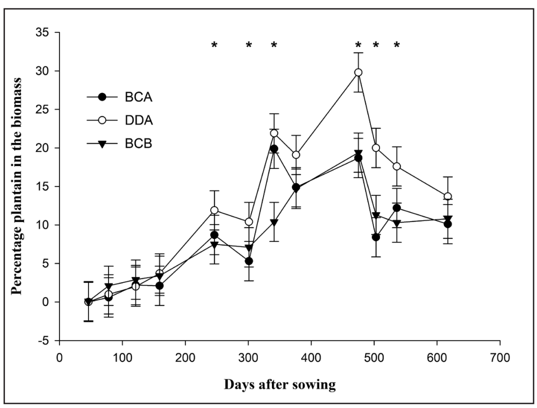

Figure 2 Plantain percentage in pasture biomass in the small-plot trial at Lincoln following establishment into existing pastures by direct drilling (DD), or broadcasting (BC) before (B) or after (A) grazing with dairy cows. Where error bars are the standard error of the difference and asterisks denote significance at P<0.05.

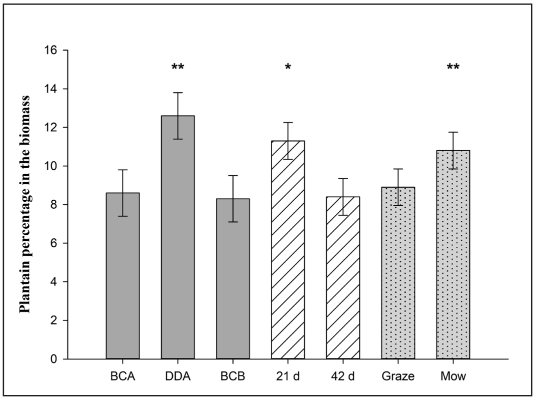

Figure 3 Average plantain content (% of dry weight of biomass) over 600 days in the small-plot trial at Lincoln following establishment into existing pastures by direct drilling (DD), or broadcasting (BC) before (B) or after (A) grazing with dairy cows and using grazing or pre-graze mowing after 21 or 42 days after establishment. Error bars are the standard error of the difference and the asterisks indicate significance to * = P<0.05; ** = P<0.01

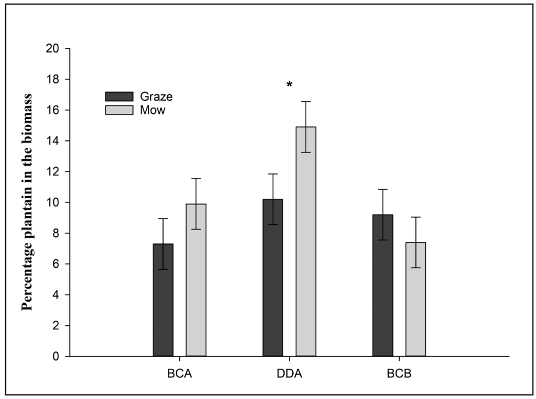

Figure 4 Plantain percentage in pasture biomass in the small-plot trial at Lincoln following establishment into existing pastures by direct drilling (DD), or broadcasting (BC) before (B) or after (A) grazing followed by grazing or pre-graze mowing at the first defoliation event. Error bars are the standard error of the difference and the asterisks indicate significance to * = P<0.05.

et al. 2011). Given the old age and high growing point density of the current pasture it is likely that existing plant populations were relatively stable, with the plantain occupying what might otherwise have been the place of an annual weed population. The extent to which DD improved plantain establishment relative to BC was not great, however, and reflects an opportunity for farmers to use the lower-cost broadcast option, especially when the chance of germination and successful establishment is improved by harrowing or rolling after broadcasting the seed. It remains to be investigated if higher plantain content can be maintained if seed is drilled or broadcast repeatedly, e.g. every second year.

The interaction between sowing method and defoliation method (P=0.04) showed that the advantage of DD was mainly realised when plots were mown prior to the first grazing after sowing (Figure 4), otherwise mean plantain content was similar among all treatments. It is not clear why pre-graze mowing aided growth or survival of plantain in the DD treatment. Plantain is known to be sensitive to trampling and compaction (Blom 1977; Kuiper & Bos 1992), which may have occurred less on mown plots as animals had less reason to target those areas when given the choice of both tall and short swards. In addition, the process of drilling loosens the soil somewhat as the coulter passes through the soil, providing a more favourable environment for emerging seedlings.

The results of the on-farm studies are shown in Tables 1 and 2. Six to sixteen months after establishment the content of plantain ranged from 1% to more than 80% of the DM biomass, highlighting the variable success in practice due to a range of establishment methods and subsequent conditions and management across various soil types and environments. The on-farm results for Canterbury revealed either poor germination or survival, or both, at two of the three farms. A small delay in grazing of 9 days (from 21 to 30 days) at Canlac did not appear to negatively impact plantain establishment (Table 1). That the other two farms failed to establish plantain (0 and 6%) highlights there is considerable risk of failure. These two farms attempted to introduce plantain in February, which may have been too late for successful establishment if considering thermal time requirements (Powell et al. 2007). Further, the paddocks used on these two farms had a considerably higher growing point density than at Canlac, likely resulting in stronger competition from the existing sward (Thom et al. 2011). Slug damage was also a problem on one of the farms.

The Waikato on-farm results showed variable plantain density after six months in both newly sown pastures and existing pastures that was likely a result of an interaction between sowing rate and sowing method (Table 2). The DD method was consistently better than BC sowing. In all cases, plant densities declined over the subsequent year. At Owl Farm, plant densities of >20 plants/m^2 were able to contribute to >40% of available DM in autumn 2018. However, lower plant densities (12–13 plants/m^2) were still able to contribute a high proportion of available DM (>30%) at Scott Farm in 2019, even in a nine-year-old paddock. These results support findings that the better performance of plantain relative to ryegrass and clover during dry late summer period was a factor (Nie et al. 2008).

Practical implications

Some factors that support establishment of plantain when introduced in existing pastures are well understood, e.g. achieving soil-seed contact, providing sufficient moisture, reducing light competition by an early first grazing or light herbicide use.

The Lincoln small-plot trial, supported by the on-farm observations, showed that the success of plantain establishment was often better under DD than BC; however, the difference with BC was not large. A low plant density can still contribute a significant proportion of herbage DM once plants are fully developed. Therefore, the lower-cost option of BC, which incurs the same seed cost as DD but avoids a drilling cost of \$100-\$150/ha (Askin & Askin 2018), may be attractive, especially when the first grazing after sowing is early enough to avoid grazing the young plants.

The on-farm observations in Canterbury and the Waikato showed that the results of sowing plantain into existing pastures are highly variable.

The study showed that establishing plantain into existing established swards can rarely be expected to result in more than 30% of DM. Stewart (1996) noted that plantain is unlikely to contribute more than 20% of DM in productive pastures. For a few months, a maximum plantain content of between 15 and 30% of the pasture DM was achieved with direct drilling and using pre-graze mowing within 3 weeks of sowing.

Further work is required to provide farmers with guidance as to how to achieve better, and particularly more consistent, results from establishing plantain into existing pastures. Some important factors to be considered are whether or not repeated drilling or broadcasting can achieve the desired plantain content, or if this approach could maintain a sufficiently high plantain content in the years after sowing new mixed-species pastures with plantain.

ACKNOWLEDGEMENTS

Research was completed as part of the *Forages for Reduced Nitrate Leaching* programme with principal funding from the New Zealand Ministry of Business, Innovation and Employment (DNZ1301) and co-funding from research partners DairyNZ Inc, AgResearch, The New Zealand Institute for Plant and Food Research Ltd, Lincoln University, the Foundation for Arable Research and Manaaki Whenua – Landcare Research. A huge thank you to FRNL monitor farmers and the management teams at Scott Farm and Owl Farm. Thanks to Agricom for seed supply. Many thanks to field staff for data collection: DairyNZ tech team Anna Clement, Natalie McMillan, Deanne Waugh and Dale Beker, Lincoln University third year students, Mancoba (Christopher) Mangwe, and Charissa Thomas. We gratefully acknowledge statistical support from Barbara Kuhn-Sherlock (DairyNZ).

REFERENCES

Askin D, Askin V. 2018. Lincoln University Financial Budget Manual. “Manual Sales” Faculty of Agribusiness and Commerce. Lincoln. ISBN 978-0-86476-432-4.

Blom CWPM. 1977. Effects of trampling and soil compaction on the occurrence of some *Plantago* species in coastal sand dunes. II. Trampling and seedling establishment. *Oecologia Plantarium 12*: 363-381.

Box LA, Edwards GR, Bryant RH. 2017. Milk production and urinary nitrogen excretion of dairy cows grazing plantain in early and late lactation. *New Zealand Journal of Agricultural Research 60*: 470-482.

Bryant RH, Kingsbury LA, Edwards GR. 2016. Does mowing before grazing increase dry matter intake and milk yield? *Proceedings of the New Zealand Society of Animal Production 76*: 73-77

Bryant RH, Welten BG, Costall D, Shorten PR, Edwards GR. 2018. Milk yield and urinary-nitrogen excretion of dairy cows grazing forb pasture mixtures designed to reduce nitrogen leaching. *Livestock Science 209*: 46-53.

Dhamala NR, Rasmussen J, Carlsson G, Soegaard K, Eriksen J. 2017. N transfer in three-species grass-clover mixtures with chicory, ribwort plantain or caraway. *Plant and Soil 413*: 217-230.

Di HJ, Cameron KC. 2002. Nitrate leaching in temperate agroecosystems: sources, factors and mitigating strategies. *Nutrient Cycling in Agroecosystems* 64: 237-256.

Dodd MB, Dalley DE, Elliott D, Wims, CM. 2017. Establishment year productivity, botanical composition and nutritive value of grass/lucerne/plantain dairy pasture mixtures. *Journal of New Zealand Grasslands 79*: 229-236.

Dodd MD, Dalley D, Wims C, Elliott D, Griffin A. 2019. Comparison of temperate pasture species mixtures selected to increase dairy cow production and reduce urinary nitrogen excretion. *New Zealand Journal of Agricultural Research 62*: 504-527.

Dodd MB, Moss RA, Pinxterhuis JB. 2019. A paddock survey of on-farm plantain use. *Journal of New Zealand Grasslands 81*: 125-130.

Glassey CB, Clark CEF, Roach CG, Lee JM. 2012. Herbicide application and direct drilling improves establishment and yield of chicory and plantain. *Grass and Forage Science 68*: 178-185.

Kuiper PJC, Bos M. 1992. Plantago: a multidisciplinary study. *Ecological Studies* No. 89. Springer-Verlag Berlin Heidelberg.

Labreveux M, Sanderson MA, Hall MH. 2006. Forage chicory and plantain: Nutritive value of herbage at variable grazing frequencies and intensities. *Agronomy Journal 98*: 231–237.

Nie ZN, Miller S, Moore GA, Hackney BF, Boschma SP, Reed KFM, Mitchell M, Albertsen TO, Clark S, Craig AD, Kearney G, Li GD, Dear BS. 2008. Field evaluation of perennial grasses and herbs in southern Australia. 2. Persistence, root characteristics and summer activity. *Australian Journal of Experimental Agriculture 48*: 424-435.

Pons TL, van der Toorn J. 1988. Establishment of *Plantago lanceolata* L. and *Plantago major* L. among grass I. Significance of light for germination. *Oecologia 75*: 394-399.

Powell AM, Kemp PD, Jaya ID, Osbourne MA. 2007 Establishment, growth and development of plantain and chicory under grazing. *Proceedings of the New Zealand Grassland Association 69*: 41-45.

Raedts P, Langworthy A. 2018. Establishing plantain in spring in existing perennial ryegrass pastures in northern Tasmania. *Animal Production Science*. doi.org/10.1071/AN18575

van der Toorn J, Pons TL. 1988. Establishment of *Plantago lanceolata* L. and *Plantago major* L. among grass. II. Shade tolerance of seedlings and selection on time of germination. *Oecologia 76*: 341-347.

Sheldon JC. 1974. The behaviour of seeds in soil: III. The influence of seed morphology and the behaviour of seedlings on the establishment of plants from surface-lying seeds. *Journal of Ecology 62*: 47-66

Thom ER, Fraser TJ, Hume DE. 2011. Sowing methods for successful pasture establishment – a review. *Pasture Persistence – Grassland Research and Practice Series 15*: 31-38

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.

Woodward SL, Waghorn GC, Bryant MA, Benton A. 2012. Can diverse mixtures reduce nitrogen losses? Proceedings of the 5th Australasian Dairy Science Symposium. Melbourne, Australia. Pp. 463-464.

Woods RR, Cameron K, Di HJ, Edwards GR, Clough TJ. 2016. Effects of forage type and gibberellic acid on nitrate leaching losses. *Soil Use and Management 32*: 565-572.