Sowing strategies to increase the plantain (*Plantago lanceolata* L.) content of Manawatu dairy pastures

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Abstract

Plantain is incorporated into New Zealand dairy pastures to reduce nitrogen loss, but poor establishment and persistence are commonplace. Four sowing strategies, involving the substitution of ryegrass with increased plantain sowing rates and repeated re-seeding of plantain and other species, were compared on No. 4 Dairy Farm at Massey University. Treatments were: 20, 15, 10, or 5 kg ryegrass with 3 kg white clover and 0, 4, 7, or 10 kg plantain/ha in autumn 2019 (Nil–High), re-seeded with 3, 6, or 9 kg plantain/ha sown in autumn 2020 (Low–High), 3 kg ryegrass, 3 kg white clover and 10 kg plantain/ha after grass herbicide in autumn 2021 (High), 4, 6, or 8 kg plantain/ha in spring 2021 (Low–High) and 4 or 6 kg plantain/ha (Low–Medium) or 12 kg Italian ryegrass/ha (High) in autumn 2023. On average, pasture growth and weed content were not different across treatments, but plantain content increased from 4% to 24%, 32% and 38% for Nil to High, which maintained the highest plantain content over 5 years. These results show that the substitution of ryegrass with increased plantain sowing rates, and repeated re-seeding of plantain can increase the plantain content of dairy pastures.

Keywords: establishment, perennial ryegrass, persistence, sowing rate, weed

Introduction

The incorporation of plantain (*Plantago lanceolata* L.) into perennial ryegrass (*Lolium perenne* L.)/white clover (*Trifolium repens* L.) dairy pastures has been shown to reduce nitrogen (N) loss to the environment (Pinxterhuis et al. 2024) and augment pasture dry matter (DM) production in summer and autumn (Moorhead and Piggot 2009; Dodd et al. 2022; Dodd et al. 2025). However, the required proportion of plantain in the total pasture DM is often variable and difficult to maintain (Dodd et al. 2025). This has contributed to scepticism about the feasibility of plantain inclusion as a N-loss mitigation tool for dairy systems (Eady et al. 2025), since the efficacy of plantain for reducing N loss from pastures is tied directly to its proportion of pasture DM (Pinxterhuis et al. 2024). Industry concern for the impact of plantain inclusion on pasture production is also reasonable with some previous studies demonstrating increases in annual pasture yield with plantain inclusion (Moorhead and Piggot 2009; Dodd et al. 2022), while others have shown reductions (Macfarlane et al. 2015; Myint et al. 2021).

Achieving an effective plantain content in a dairy pasture depends on several on-farm factors, including: sowing method, grazing management, treading damage, insect predation and limited methods for reliable weed control (Dodd et al. 2025). While some attention has been given to establishment method for plantain, little consideration has been given to its sowing rate, particularly to establish plantain in a ryegrass-based dairy pasture. Since plantain possesses a relatively limited capacity for asexual propagation (Grime et al. 1989), its persistence within a dairy pasture is likely determined by the longevity of the initially established population (Dodd et al. 2022), and/or the recruitment of new plants via natural seed dispersal (Phillips et al. 2016). Furthermore, given that the plantain content in a dairy pasture appears to decrease with age at a similar rate regardless of how many individual plantain plants establish at sowing (Dodd et al. 2022), increasing the sowing rate of plantain, and thereby increasing the initial plant density, could extend the period during which plantain contributes a desirable proportion of pasture DM.

Simply increasing the sowing rate of plantain may not be sufficient to improve its establishment in a dairy pasture. At a high sowing rate, a high population of plantain and ryegrass seedlings could be expected to cause further inter- and intraspecific competition for light against the plantain seedlings, particularly

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where conventional sowing rates of ryegrass are used (van der Toorn and Pons 1988). To mitigate this effect, a reduction in the sowing rate of ryegrass could be considered as part of the overall sowing strategy (McGrane et al. 2025). However, reducing the sowing rate of ryegrass carries with it a perception of risk for lower pasture production and greater weed ingress (Lee et al. 2018).

While plantain establishment may be improved by altering sowing rates, plantain content in a ryegrass-based pasture generally declines over time, making re-seeding by direct drilling a potential strategy for maintaining plantain content. The successful establishment of re-seeded plantain is likely to depend on competition from the pre-existing pasture, as plantain seedlings are susceptible to shading from mature plants (van der Toorn and Pons 1988). Previous research has shown that the establishment of plantain is improved where light transmission to the base of the sward is greater (Pons and van der Toorn 1988; Bryant et al. 2019). Consequently, the effectiveness of re-seeding is expected to depend largely on pasture conditions at the time of re-seeding.

The aim of this work was to develop sowing strategies to increase the proportion of plantain in dairy pastures. The strategies used were the substitution of ryegrass with increased sowing rates of plantain, and repeated re-seeding of plantain and other high-quality pasture species over successive years. Growth rates and botanical compositions of dairy pastures from an initial autumn sowing on Massey University's No. 4 Dairy Farm over 5 years are presented.

Materials and Methods

The experiment was conducted from September 2019 to May 2024 in a paddock at Massey University's No. 4 Dairy Farm, Palmerston North (40°23'26.9" S 175°36'43.5" E). The soil is a Tokomaru silt loam, characterised by a highly compacted fragipan at 0.78 m depth, which acts as a natural barrier to effective drainage (Scotter et al. 1979) and makes the soil susceptible to waterlogging and treading damage during wet periods. The mean annual rainfall was 963 mm and the mean daily air temperature was 14°C (Figure 1), recorded from a NIWA station (21936) at Palmerston North, approximately 750 m from the study site.

Prior to sowing, the paddock had a soil Olsen P of 30 mg/L and pH 5.8. The resident perennial ryegrass-based pasture was sprayed out with 4 L/ha Polaris 540 (540 g/L glyphosate) and 30 g/ha Harmony 50SG (500 g/L thifensulfuron-methyl). The paddock was direct drilled on 5 April 2019 with 20 plots of four treatments (Nil, Low, Medium and High Plantain) in a completely randomised design. Each plot was 20 m × 40 m (800 m^2). A direct drill was used to re-seed the plantain three

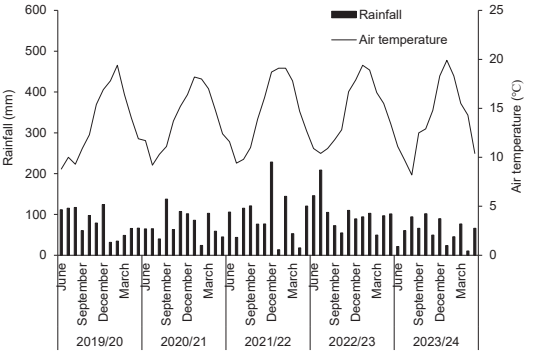


Figure 1 Monthly rainfall and mean air temperature from June 2019 to May 2024 (Years 1–5) at No. 4 Dairy Farm, Massey University.

times over 4 years in the Low and Medium treatments, and plantain and other high-quality pasture species four times over the 4 years in the High treatment. The seed was planted at a target depth of 2 cm in 15 cm-spaced rows. Treatment details and corresponding sowing rates were: 20, 15, 10, or 5 kg One^{50} perennial ryegrass with 3 kg Tribute white clover and 0, 4, 7, or 10 kg Agritonic plantain/ha on 5 April 2019 (Nil–High); re-seeded with 3, 6, or 9 kg Agritonic/ha on 30 March 2020 (Low–High), 3 kg One^{50}, 3 kg Tribute and 10 kg Agritonic/ha after 0.5 L/ha SeQuence (240 g/L clethodim) grass herbicide and Bonza Gold adjuvant on 29 April 2021 (High), 4, 6, or 8 kg Agritonic/ha on 30 November 2021 (Low–High) and 4 or 6 kg Agritonic/ha (Low–Medium) or 12 kg Manta Italian ryegrass/ha (High) on 28 March 2023.

Fertiliser was applied to all plots at 150, 60, 60 and 69 kg N/ha as Urea in total in 2019/20, 2020/21, 2021/22 and 2023/24, respectively, and at 31, 23, 50, 52 and 50 kg/ha of N, P, K, S and Ca, respectively, as Superphosphate, Potassium Chloride, Sulphur 90 and Flexi-N in December 2022.

The paddock was lightly grazed with a single herd of 100 dry cows for 4 h on 2 July 2019. From September 2019, each plot was rotationally grazed with a group of 3–4 lactating dairy cows (equal number across treatments) for 2–3 days, depending on pasture mass. The target pasture mass was 3,200 kg DM/ha pre-grazing and 1,600 kg DM/ha post-grazing. Prior to each grazing, the cows were grouped according to treatment, and each group was grazed on pastures similar in botanical composition to the treatment, in paddocks adjacent to the plots. Excess pasture mass (>2,000 kg DM/ha) was cut and removed on two or three occasions per year.

Pasture growth was measured by cutting pasture to ground level in three randomly placed 0.1 m^2 quadrats per plot with a shearing handpiece within 24 h before and after each grazing event. If necessary, the sample

was washed with cold water to remove soil and faeces. The sample was dried in a forced convection oven at 75ºC for at least 48 h for DM determination. Pasture growth rate was calculated by subtracting the post-grazing (or post-mowing) mass of the previous grazing from the pre-grazing mass of the current grazing and dividing the difference by the number of days within the regrowth period.

Pasture botanical composition was measured by hand-plucking pasture to grazing height (5–7 cm above ground level) at 15–20 random sites per plot within 24 h before each grazing event. The whole sample was thoroughly mixed, divided into quarters, two random quarters were discarded, and the remaining quarters were mixed and quartered again until the sample to be sorted was down to about 400–500 pieces. The sample was separated into grass (ryegrass plus <10% volunteer grasses), white clover, plantain, weed and dead material. Each fraction was dried in a forced convection oven at 75ºC for at least 48 h and then weighed to calculate the proportions of the five fractions in the pre-grazing pasture mass.

The data were grouped into five seasonal periods within each year, reflecting the typical pasture growth pattern in Manawatu: winter/early spring (June–September), late spring (October–November), early summer (December–January), late summer (February) and autumn (March–May). These groups distinguished the period of peak pasture growth from the typically drier late-summer period. The data were analysed within each season, with treatment as the fixed effect, and across seasons as repeated measures, with treatment, season, year and interactions as fixed effects. Significantly different (P<0.05) means were identified using pairwise comparisons of least squares means with Tukey-Kramer adjustment. All analyses were done using the MIXED procedure in SAS version 9.4.

Results

Pasture growth was not different across all treatments over the 5 years (Figure 2). On average, pasture growth was 63–64 kg DM/ha/day in late spring and early summer compared with (P<0.01) 32 kg DM/ha/day in autumn, and 47–60 kg DM/ha/day in Years 1, 2 and 5 compared with (P<0.01) 40–41 kg DM/ha/day in Years 3 and 4. An interaction between season and year (P<0.01) revealed that growth was higher in late spring and early summer of Year 1 (84–90 kg DM/ha/day) than in any other year.

Pasture composition differed (P<0.01) across treatments and years (Figure 3). On average, plantain increased (P<0.01) from 4% to 38% for Nil to High and decreased (P<0.01) from Year 2 to 5. A treatment × year interaction (P<0.01) showed that plantain content increased for Nil to High in Years 1, 3 and 4, but

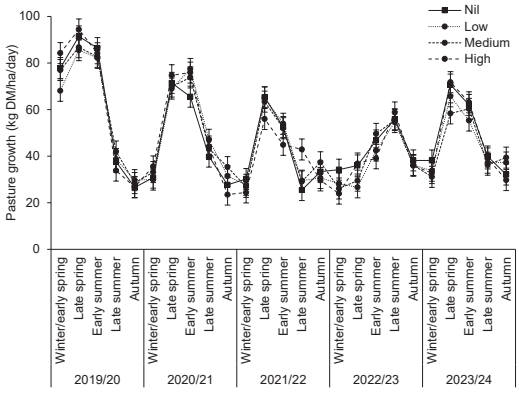


Figure 2 Mean pasture growth rate in each season for the establishing dairy pastures with nil, low, medium and high target plantain contents within each year after the initial sowing in April 2019 at No. 4 Dairy Farm, Massey University. Bars show standard errors of the means.

increased for Nil to Medium, with no further increase for High, in Years 2 and 5. Grass decreased (P<0.01) from 71% to 34% for Nil to High and increased (P<0.01) from Year 2 to 5, with the decrease for Nil to High in Years 1, 3 and 4 compared with (P<0.01) Nil to Medium in Years 2 and 5. White clover increased (P<0.05) from 14–15% for Nil–Medium to 19% for High, and was lower (P<0.01) in Year 1 than 3 and 4. Weeds increased (P<0.05) from 1% to 3% for Nil to High and from 1% to 5% for Years 1 to 5. Dead material decreased (P<0.01) for Nil to Medium and from Year 1 to 3 and 4, but the decrease for Nil to Medium was most obvious (P<0.05) in Years 1 and 2.

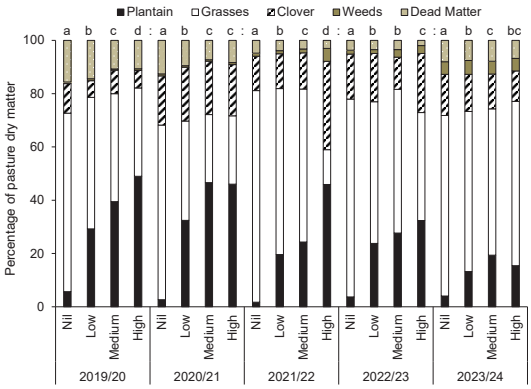


Figure 3 Mean botanical composition, averaged over seasons, for the establishing dairy pastures with nil, low, medium and high target plantain contents for each year after the initial sowing in April 2019 at No. 4 Dairy Farm, Massey University. Within years, mean plantain contents with different letters above the columns are significantly different (P<0.05).

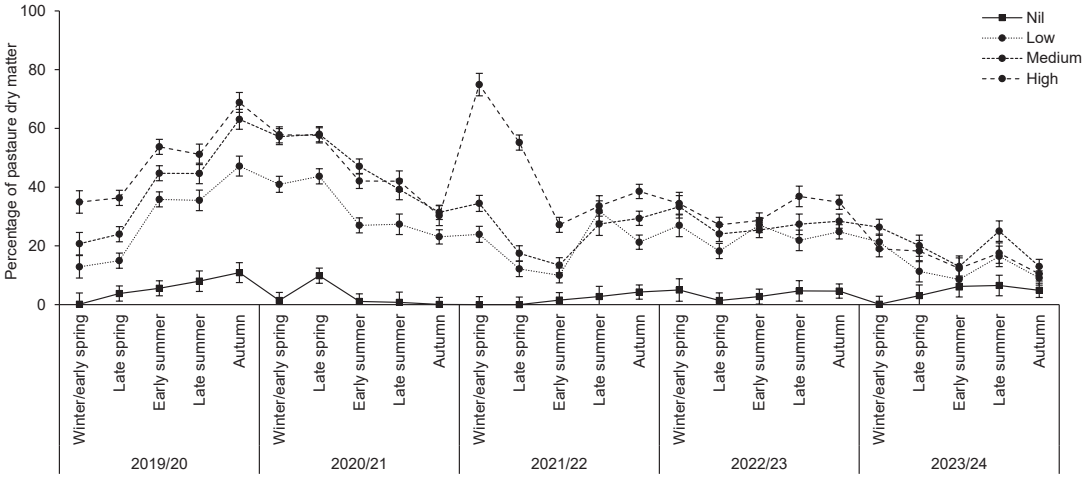


Figure 4 Mean plantain content in each season for the establishing dairy pastures with nil, low, medium and high target plantain contents within each year after the initial sowing in April 2019 at No. 4 Dairy Farm, Massey University. Bars show standard errors of the means.

The pattern of change in plantain content between seasons and years differed ($P<0.01$) across the treatments (Figure 4). Between winter/early spring and autumn in Year 1, plantain content increased from 0% to 10% for Nil (unsown plants) compared with 13% to 47% for Low, 21% to 63% for Medium and 35% to 69% for High. It then decreased back to 0% for Nil, 23% for Low and 30–31% for Medium–High in autumn of Year 2. In winter/early spring of Year 3, plantain content had not changed for Nil–Medium, but it increased to 75% for High, following the grass spray and second re-seeding of this treatment in April 2021. It then increased to 4% for Nil in autumn but decreased to 10–13% for Low–Medium and 27% for High in early summer before increasing to 21% and 29% for Low and Medium and 39% for High in autumn. In Year 4, plantain content was stable across all seasons at 1–5% for Nil, 18–27% for Low, 24–34% for Medium and 27–37% for High. In Year 5, it remained at 0–7% for Nil but decreased to 10–13% for Low–High in autumn.

Discussion

This experiment found that ryegrass-based dairy pastures sown and repeatedly re-seeded with plantain and other high-quality pasture species had similar mean pasture growth rates compared with pastures sown without plantain over 5 years, regardless of the sowing rates of plantain and other species used (Figure 2). This reflects the results of Al-Marashdeh et al. (2021), which showed that pasture production was not different between irrigated perennial ryegrass-white clover dairy pastures with and without plantain. In contrast, other studies have reported greater summer and autumn growth following plantain inclusion in pastures (Moorhead and Piggot 2009; Dodd et al. 2022). The absence of a seasonal production response in the present study may reflect the relatively moist summers and warm winters experienced during the experiment (Figure 1), together with the use of the modern, winter-active plantain cultivar, Agritonic (Dodd et al. 2025).

There was no evidence that the substitution of perennial ryegrass with increased sowing rates of plantain compromised pasture growth (Figure 2). This is in line with previous studies where ryegrass sown at 6 and 18 kg/ha (Lee et al. 2018), and 11 and 34 kg/ha (Culleton et al. 1986), had similar annual yields within 1–2 years after sowing. The suppression of weeds, predominantly *Rumex obtusifolius* L., by the sown species was also highly effective in all treatments over the first 4 years of the current study, including the High Plantain treatment which had the lowest ryegrass sowing rates (Figure 3). This supports the results of Black et al. (2006), which showed weeds were sufficiently suppressed when perennial ryegrass was autumn-sown between 3 and 12 kg/ha with 2 kg white clover/ha. The repeated re-seeding of plantain and other species may have contributed to maintaining low weed contents by increasing the occupation of any gaps in the sward by sown plants and reducing opportunities for weed establishment. This reflects the observed ecological strategy of plantain, which, as a ruderal species, can quickly colonise open or disturbed areas prior to the establishment of competitor species (Pons and van der Toorn 1988; Grime et al. 1989). Weed content increased in Year 5 for all treatments (Figure 3), suggesting that pasture ageing and the gradual decline of the sown species created more opportunities for weed establishment.

The differences in pasture botanical composition in Years 1 and 2 (Figure 3) largely reflected differences in the initial sowing rates of perennial ryegrass, white clover and plantain, and the re-seeding rates and dates of plantain and other species used. The mean plantain content of 49% achieved in the High Plantain pasture in Year 1 was greater than the 33% plantain content in Wilson et al. (2024), where identical sowing rates of plantain and ryegrass were used in a nearby autumn-sown pasture. Additionally, the greater initial peak in plantain content in the Low Plantain pasture, in comparison with local commercial pastures direct drilled with similar rates of plantain in autumn (Dodd et al. 2022), would suggest that the plantain establishment achieved at the current site was highly successful. The plantain content decreased over the course of the current experiment and was replaced by an increasing grass component, and to a lesser extent weeds. This trend was also noted in Wilson et al. (2024). The gradual decline in plantain content reflected the difficulty of maintaining plantain recruitment within an ageing sward, where competition from established grass likely limited plantain persistence, while declining sown species density increased opportunities for weed establishment.

The greatest proportions of plantain were observed in the High Plantain treatment (Figures 3 and 4). Its high plantain contents in the first 2 years were likely due to its higher initial sowing rate and re-seeding rates of plantain and its lower initial sowing rate of ryegrass. This suggests that substituting ryegrass with more plantain in the initial seed mixture could be an important consideration for achieving high initial plantain contents, particularly in autumn sowings, where ryegrass commonly has an advantage over other species (Black et al. 2006). Similarly, in Ireland, researchers found that an increase in plantain sowing rate from 2 to 5 kg/ha together with a reduction in ryegrass sowing rate from 23 to 20 kg/ha in a summer-sown experiment, resulted in an increase in the mean plantain content from 20% to 33% in the pasture over 2 years (McGrane et al. 2025). In the later years of the current experiment, the high plantain contents in the High Plantain treatment were likely caused by the combined effects of high plantain re-seeding rates, low ryegrass re-seeding rates and the application of a grass-selective herbicide before the second re-seeding in autumn of Year 2. Because this re-seeding event was preceded by grass removal, it is not possible to attribute the subsequent increase in plantain content to altered sowing rates alone. Rather, the large increase in plantain content likely resulted from reduced competition for light from the existing grass (Pons and van der Toorn 1988; Bryant et al. 2019), together with the establishment of new plantain seedlings within the pre-existing plantain population. The concurrent increase in white clover content following this re-seeding event also suggests that reducing grass competition promoted the establishment and growth of other less competitive, high-quality species, including white clover (Black et al. 2006).

The reduction in plantain content in Year 2 (Figures 3 and 4) is consistent with other reports showing plantain declines to less than 20% of pasture DM within 2 years after sowing (Dodd et al. 2025). This decline occurred despite autumn re-seeding in Year 1, and similar patterns were observed following the autumn re-seeding events in Years 2 (Low and Medium Plantain only) and 4, suggesting that re-seeded plantain did not contribute immediately to pasture plantain content. Although the pre-existing and newly established plantain populations could not be distinguished, these results indicate that autumn re-seeding alone did not substantially increase plantain abundance in the short term. One potential reason for poor establishment of new plantain could be shading from the existing pasture canopy. While the majority of plantain seeds germinate soon after sowing, regardless of light supply (Pons and van der Toorn 1988; Phillips et al. 2016), plantain seedlings are particularly sensitive to shading (van der Toorn and Pons 1988). At the current site, the dense established ryegrass component, together with the low-angle leaf canopy of existing plantain plants, would have reduced light penetration to emerging seedlings at the base of the pasture canopy (McKenzie et al. 1999; Wilson et al. 2024).

The spring re-seeding event in Year 3 appeared to coincide with a modest increase in plantain content (Figure 4). However, previous work has shown that direct drilling plantain into established grass-based pastures in spring may result in poor establishment because of strong competition from the existing sward (Bryant et al. 2019; Dodd et al. 2022). Consequently, it is unlikely that the observed increase resulted solely from the spring re-seeding. A more plausible explanation is that the relatively dry conditions in Year 3 (Figure 1) reduced ryegrass growth more than plantain growth (Moorhead and Piggot 2009; Dodd et al. 2022), thereby increasing the proportion of plantain in the pasture DM.

Collectively, these results suggest that changes to the sowing rate and timing of re-seeding alone are insufficient to substantially increase plantain content once a competitive ryegrass-based sward is established. Instead, reducing competition from existing grass appears to be the key factor determining successful establishment of re-seeded plantain. Nevertheless, repeated re-seeding of plantain at 3–6 kg/ha was associated with average annual plantain contents above 24% over 4 years. Although the re-seeding did not produce an immediate increase in plantain abundance, it

is possible that some seedlings established and survived through winter and spring (Phillips et al. 2016), contributing little to pasture growth until the following late summer or autumn. If so, annual autumn re-seeding may help to maintain desirable plantain contents over time despite the absence of an immediate response. Although the mechanisms remain uncertain, these results suggest that annual autumn re-seeding may be a practical strategy for maintaining desirable plantain contents in Manawatu dairy pastures. However, the marked decline in plantain content in Year 5, despite re-seeding in the preceding autumn, indicates that re-seeding alone may delay, rather than prevent, long-term declines in plantain content.

Practical implications

The sowing strategies used, which included the substitution of ryegrass with increased sowing rates of plantain, and repeated re-seeding of plantain and other high-quality pasture species over successive years, were successful at increasing the plantain content of Manawatu dairy pastures with no negative impacts on pasture growth and weed suppression.

Specifically, pasture sown with 5 kg ryegrass, 3 kg white clover and 10 kg plantain/ha achieved the most plantain initially, and with repeated re-seeding of plantain and other pasture species, maintained similar pasture growth and weed suppression compared with pastures sown with 20 kg ryegrass and 3 kg white clover/ha and not re-seeded over 5 years. Pastures sown with 10–15 kg ryegrass, 3 kg white clover and 4–7 kg plantain/ha and regularly re-seeded with 3–6 kg plantain/ha, maintained plantain contents greater than 24% of pasture DM over 4 years. However, the marked decline in plantain content in Year 5 suggests that regular re-seeding may delay, rather than prevent, long-term declines in plantain content. The greatest increase in plantain content followed re-seeding after removal of the existing grass with a grass-selective herbicide, highlighting the importance of reducing competition from the resident sward when direct drilling.

Collectively, these results suggest that farmers could consider the substitution of ryegrass with increased sowing rates of plantain, and autumn direct drilling of plantain to improve establishment and help maintain effective plantain populations in dairy pastures. The potential environmental benefits of maintaining plantain should be weighed against the additional costs associated with repeated direct drilling when assessing the suitability of this strategy for individual farm systems.

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