

Plantain (*Plantago lanceolata* L.) content within plantain/perennial ryegrass (*Lolium perenne* L.) pastures may be temporarily reduced by livestock treading damage

Samuel S. WILSON^{1*}, Daniel J. DONAGHY¹, David J. HORNE¹, Soledad NAVARRETE¹, Peter D. KEMP¹

¹Massey University, New Zealand

Massey University School of Agriculture and Environment,
Tennent Drive, Palmerston North 4410, New Zealand.

*Corresponding author: s.s.wilson@massey.ac.nz

Abstract

There is evidence that plantain (*Plantago lanceolata* L.) persistence within perennial ryegrass (*Lolium perenne* L.) dominant dairy pastures is usually poor. One factor potentially limiting plantain content and persistence is treading damage, caused by cows grazing pasture while the soil moisture content is high. The impact of treading damage on plantain regrowth and survival was investigated in two field experiments at Massey University, Palmerston North. In a small-plot study, cow treading damage was simulated on separate plantain and perennial ryegrass pastures using a novel treading device. Subsequently, a larger-scale experiment investigated the impact of treading damage by grazing dairy cows on plantain regrowth and survival within a mixed plantain/perennial ryegrass pasture. Damage by the treading device, in late spring, immediately reduced the growth rate of both plantain and perennial ryegrass pastures by 30%, however neither plantain content nor density were reduced. In experiment 2, treading damage reduced the growth rate of the mixed pasture by 50% in early spring but it recovered during late spring. Plantain content and density were both initially reduced by the treading damage treatment but recovered to pre-treading levels by autumn. These results suggest that treading damage from cows may be an important cause of reduced plantain content in dairy pastures during spring, however there was no evidence that treading damage reduced plantain persistence.

Keywords: Pugging, compaction, persistence, plant survival, treading tolerance.

Introduction

Plantain (*Plantago lanceolata* L.) is becoming an increasingly important component of New Zealand dairy pastures because of its ability to mitigate nitrogen (N) losses. When included in dairy pastures, plantain (PL) can reduce N loading in urine patches (Navarrete et al. 2022) and suppress soil nitrification (Judson et al. 2019), leading to a reduction in N losses from the pastoral system (Nguyen et al. 2022). These attributes,

along with a high nutritive value, have made PL a suitable, low-cost option for reducing N losses from highly productive, perennial ryegrass (*Lolium perenne* L. - PR) based dairy farm systems.

However, there is growing anecdotal and scientific evidence that PL has poor persistence in PR-based pastures (Dodd et al. 2019) under conventional management (Ayala et al. 2011). Data from New Zealand farms suggest that PL contents greater than 30% on a dry matter (DM) basis are only attainable in the first two years following establishment as a mixed PL-grass pasture (Dodd et al. 2019). This poses a problem, as at least 30% PL is required in a cow's diet to enable meaningful reductions in urine N concentration and excretion (Minnée et al. 2020). Competition from pasture and weed species (Stewart 1996; Sanderson et al. 2003), and livestock treading damage and associated soil compaction (Blom 1979) are potential causes of this decline in PL content. Herb species are reportedly particularly sensitive to livestock treading in wet soil (Jones and Haggard 1994), however literature detailing the effects of livestock treading damage on PL-inclusive pastures or PL plants, is limited. Blom (1979) showed that PL shoot and root growth was highly sensitive to treading, which agrees with observations by Chappell et al. (1971), who found denser populations of PL in lightly trampled areas, than in well-worn areas. In contrast, PR is one of the most treading-tolerant pasture species (Edmond 1964), although significant growth reductions are possible following severe treading damage (Nie et al. 2001). Menneer et al. (2005) showed that pasture botanical composition can be altered following treading damage, whereby the content of species with a good tolerance of treading increases, while the content of species sensitive to treading decreases.

Treading damage, also known as pugging, is regarded as inevitable on many New Zealand farms (Drewry et al. 2000), where high stock densities are managed in confined winter and spring rotations. The extent of damage to any given soil during winter and spring is largely governed by the soil moisture content (SMC) during that period (Howes 2019). Livestock treading

damage is inherently random and can result in a large variability of treading pressure, density, and spatial pattern (Di et al. 2001). Therefore, the use of livestock for implementing treading damage is impractical in small-plot or high-precision experiments where consistent treatment replication is required. In these situations, a mechanical device capable of producing repeatable, realistic treading damage is desirable. There have been attempts to mechanically simulate the treading impact of cattle (Scholefield and Hall 1986; Di et al. 2001; Hu et al. 2018), and while these machines were able to deliver treading precisely, they often failed to simulate the lateral soil damage effect of cattle hooves or had poor manoeuvrability. In the current study, we created and assessed the effectiveness of a novel technique for simulating cattle treading damage on pasture.

The current studies aimed to 1. investigate the impact of treading damage on the productivity and PL plant populations of PL dominant vs PR dominant pastures; 2. investigate the impact of treading damage on PL content and persistence within a PL/PR pasture; and 3. consider the effectiveness of a novel treading device for simulating pasture treading damage.

Materials and Methods

Experimental sites and layout

Experiment 1 – Massey No. 4 Dairy Farm, November 2021 to April 2022

This experimental site included two paddocks with different pasture compositions: 1. PL cv. *Agritonic*/ white clover (*Trifolium repens* L.) cv. *Tribute*/ PR cv. *One*⁵⁰; and 2. PR cv. *One*⁵⁰/ white clover cv. *Tribute*. Both pastures were drilled in April 2019 into a Tokomaru silt loam. There was 534 mm of rainfall between November 2021 and April 2022. Daily maximum temperatures ranged between 21°C for November to 25°C in January and daily minimum temperatures ranged between 12°C for November to 13°C for January. Meteorological data was sourced from the NIWA weather station, Palmerston North, approximately 1km from the site.

Experiment 2 – Massey Pasture and Crop Research Unit (PCRU), August 2022 to April 2023

This experimental site was established in autumn 2022. PL cv. *Agritonic* and PR cv. *Maxsyn* were direct drilled at 10 kg and 5 kg per hectare, respectively, on April 8 with the seeding rate designed to achieve an equal proportion (on a DM basis) of PL and PR at the start of the experiment. The soil is a Manawatu silt loam. There was 759 mm of rainfall between August 17, 2022, and April 28, 2023. Daily maximum temperatures ranged between 15°C in August to 24°C in January and daily minimum temperatures ranged between 7°C for August to 15°C for January. Meteorological data was sourced from the NIWA weather station, Palmerston North,

approximately 200m from the site.

Treatments

Experiment 1

The treatments consisted of the PL and PR pastures subjected to three treading damage severities: undamaged (UD), light damage (LD) and heavy damage (HD). Within each pasture type there were 15 plots (three treading treatments, five replicates) of 4 m², laid out in a randomised complete block design. Herbage was cut and removed with a Honda push mower to a height of 5 cm prior to treading and during subsequent harvests, which occurred whenever mean estimated pasture DM across the experiment exceeded 3000 kg DM/ha. The severity of treading damage was governed by the SMC at the time of treading. All plots were watered prior to treading with the intent to reach saturation, which was equivalent to 44% gravimetric water content (GWC), (Howes 2019). The cutting of HD and UD plots and treading of the HD plots was carried out on 1 November. Treading was implemented with a novel device, named the 'puggo-stick'. It consisted of a fence-post laden with 20 kg of cast-iron weights, steel footrests and handles, and cost ~\$150. The base area of the device was 78.5 cm² and with an operator, delivered a pressure on the soil surface of approximately 167 kPa, which is comparable to that of one hoof, exerted by a stationary dairy cow (132.5 kPa) (Scholefield and Hall 1986). Soil resistance to treading was monitored in the following days by measuring the depth of pug marks produced by the puggo-stick in areas adjacent to LD plots. When the mean depth of pug marks was less than half of those produced on 1 November, it was determined that the risk of damage had fallen sufficiently. On 4 November, the LD plots were cut (as previously described), and treading implemented.

Experiment 2

Experiment 2 consisted of two treading treatments, damaged (DD) and undamaged (ND) with four replicates of each treatment, for a total of eight plots, in a randomised complete block design. Each plot was 13 m by 14 m (182 m²). Dairy cows were used to implement treading damage, which was based on a difference in SMC at the time of grazing. Procedures were approved by the Massey University Animal Ethics Committee (AEC 22/34). Based on previous work (Howes 2019), it was decided that grazing at a soil water deficit of 5 - 10 mm, or 37% - 33% soil volumetric water content (VWC), would ensure that ND plots were not damaged by the cows. On August 17, ND plots were grazed. Each plot was grazed with 6 pregnant dairy cows at a density equivalent to 330 cows/ha. In the 48 hours following this initial grazing there was 25 mm of rainfall, which greatly increased soil VWC and so DD plots were grazed (and damaged) on August 19. At each grazing, plots were grazed for

2.5 hours. Subsequent grazings were carried out with lactating dairy cows whenever mean estimated pasture mass across the site reached approximately 2800 kg DM/ha. The target residual was 1500 kg DM/ha and care was taken to avoid further treading damage to the plots by cows.

Measurements

Experiment 1

Soil measurements were taken to assess treading damage severity. Pug mark depth (cm) was determined by averaging the three deepest and three shallowest pug marks in three 0.25m² quadrats per plot with a ruler. Pug mark density (pugs/m²) was determined by counting the number of pug marks within the same quadrat. Soil GWC was measured by collecting four soil cores to 10 cm depth per plot, which were then weighed and oven-dried at 105°C until a constant weight was achieved. Soil GWC data for the UD plots in the PR pasture were missed, so were assumed to be comparable to that of the HD plots in that pasture. Pasture DM yield was measured before each lawnmower cut by hand-clipping three random 0.1m² quadrat cuts per plot to 5 cm height, then drying the herbage at 60°C for 48 hours. Harvests were made on December 1, January 11, February 21, and March 29 (PL only). Herbage accumulation rate was then calculated by dividing DM yield by the number of days in the regrowth period and then fitting those rates to specific months. Botanical composition was visually evaluated in the PL pasture by scoring the proportion of ground cover occupied by PL, PR, white clover, and dock (*Rumex obtusifolius* L.) in each plot prior to each DM harvest (Lynch 1960). At the December harvest, one yield sample per plot was used to measure leaf area index (LAI) using a LI-COR 3100 leaf area meter. Plant density was determined in the PL pasture by counting the number of PL plants within three 0.25m² quadrats per plot.

Experiment 2

Estimations of treading damage severity followed the same method as experiment 1 but included five quadrats per plot. Soil VWC was measured with a time-domain reflectometer in 10 locations per plot. Pasture DM yield pre- and post-grazing was measured by hand-clipping herbage to ground level in three 0.1m² quadrats per plot and drying the herbage at 60°C for 48 hours. Quadrat locations were selected for the purpose of obtaining a representative pasture sample from each plot. Where necessary, soil was removed from samples by washing. Pasture growth rate was calculated by subtracting the current pre-grazing DM from the post-grazing DM of the previous grazing and dividing by the number of days in the regrowth period. Light interception measurements were made using a Spectrosense2+® device 14 days after each grazing event by measuring light intensity above and below the canopy in three fixed

locations in each plot. Herbage was cut from a 10×50 cm strip adjacent to each pre-grazing DM quadrat and separated into PL, PR, annual poa (*Poa annua* L.), dead matter, broadleaf weeds, PL seed head and volunteer white clover. Samples were dried at 60°C for 48 hours to determine pasture botanical composition on a DM basis. The density of PL and PR was measured by counting the number of shoots (PL) or tillers (PR) in four fixed 0.1m² quadrats per plot (tillers were counted in one half of the quadrat, i.e., 0.05 m²).

Statistical analyses

Statistical analyses were conducted using the MIXED procedure in SAS (version 9.4, SAS institute 2018). The least squares means test was used for mean comparison and significance was declared at $P < 0.05$. In experiment 1, botanical composition and PL plant density were analysed at each sampling date with treatment as the fixed effect. All other results from experiment 1 were analysed at each sampling with pasture, treatment, and pasture×treatment as fixed effects. All data were also analysed for repeated measures, with month, pasture×month, treatment×month and pasture×treatment×month as fixed effects. In experiment 2, all results were analysed within each sampling date with treatment as the fixed effect. All data were also analysed for repeated measures, with season and treatment×season as fixed effects.

Results

Experiment 1

Treading damage

Soil GWC, pug depth and pug density were significantly higher in the PL pasture, in comparison with the PR pasture (Table 1). Soil GWC was significantly higher ($P < 0.01$) during the treading of the HD plots, than the LD plots, regardless of pasture type. Pug marks were deeper in HD plots in comparison with LD plots ($P < 0.01$), but LD plots had a significantly higher pug density than HD plots ($P < 0.05$).

Pasture production and leaf area index

The PR pasture had a higher herbage accumulation rate than the PL pasture ($P < 0.01$) throughout the experiment (Table 2). Herbage accumulation rate was significantly lower in HD plots in comparison with LD and UD plots, regardless of pasture type, during November, January, and February ($P < 0.01$). The DM production for PL and PR pastures was 31% and 32% lower respectively in HD plots than in UD plots during November. The PL herbage accumulation rate was highest during December and March and was lowest during January and February ($P < 0.01$), while PR herbage accumulation rate was highest in November and December and decreased over January and February ($P < 0.01$). There were no significant pasture×treatment

Table 1 Mean soil gravimetric water content (%) at the time of treading damage in November 2021, and the mean pug mark density (pugs/m²) and pug depth (mm) resulting from plantain and perennial ryegrass-based pastures that were subjected to light damage (LD) or heavy damage (HD).

Pasture	Treatment	Soil water content ¹ (%)	Pug depth (mm)	Pug density (pugs/m ²)
Plantain	UD	48	-	-
	LD	42	13	95
	HD	51	35	92
Perennial ryegrass	UD	-	-	-
	LD	36	11	91
	HD	45	18	78
SEM		2.62	1.67	2.83
ANOVA p-values				
Pasture		<0.01	<0.01	<0.01
Treatment		<0.01	<0.01	0.010
Pasture*Treatment		0.899	<0.01	0.127

Table 2 Herbage accumulation rate (kg DM/ha/day) and leaf area index (LAI; cm² leaf/ cm² ground) of three-year-old plantain and perennial ryegrass-based pastures following no treading damage (UD), light treading damage (LD) or heavy treading damage (HD) in November 2021. Sown April 2019.

Pasture	Treatment	Herbage accumulation rate (kg DM/ha/day)					Mean	LAI (cm ² leaf/ cm ² ground)
		2021		2022				
		Nov	Dec	Jan	Feb	Mar		
Plantain	UD	96	110	77	69	103	91	3.73
	LD	85	114	85	77	104	93	3.05
	HD	67	107	75	69	111	86	2.12
Perennial ryegrass	UD	143	138	109	94	*	121	-
	LD	147	128	116	110	-	125	-
	HD	100	124	100	86	-	103	-
SEM		8.82	7.31	4.12	3.62	3.28	4.39	0.39
ANOVA p-values								
Pasture		<0.01	<0.01	<0.01	<0.01	-	<0.01	
Treatment		<0.01	0.549	0.017	<0.01	0.220	<0.01	0.052
Month							<0.01	
Pasture*Month							<0.01	
Treatment*Month							<0.01	

* Perennial ryegrass treatment ended before the final harvest.

Table 3 Botanical composition (% ground cover) of a three-year-old plantain pasture following no treading (UD), light treading damage (LD) and heavy treading damage (HD) over the summer of 2021-2022. Sown April 2019.

Date	Species	Treatment			SEM
		UD	LD	HD	
1 Dec 2021	Plantain	17.6	21.0	16.6	2.99
	White clover	51.8 ^{ab}	50.2 ^b	69.8 ^a	5.16
	Perennial ryegrass	2.6	3.8	1.2	1.74
	Dock	28.0	25.0	12.4	5.80
22 Mar 2022	Plantain	8.0	8.8	9.8	1.80
2022	White clover	67.0	61.2	67.0	3.99
	Perennial ryegrass	15.4	20.4	19.0	4.96
	Dock	9.6	9.6	4.2	2.39

Letters indicate means within rows that are significantly different (P<0.05).

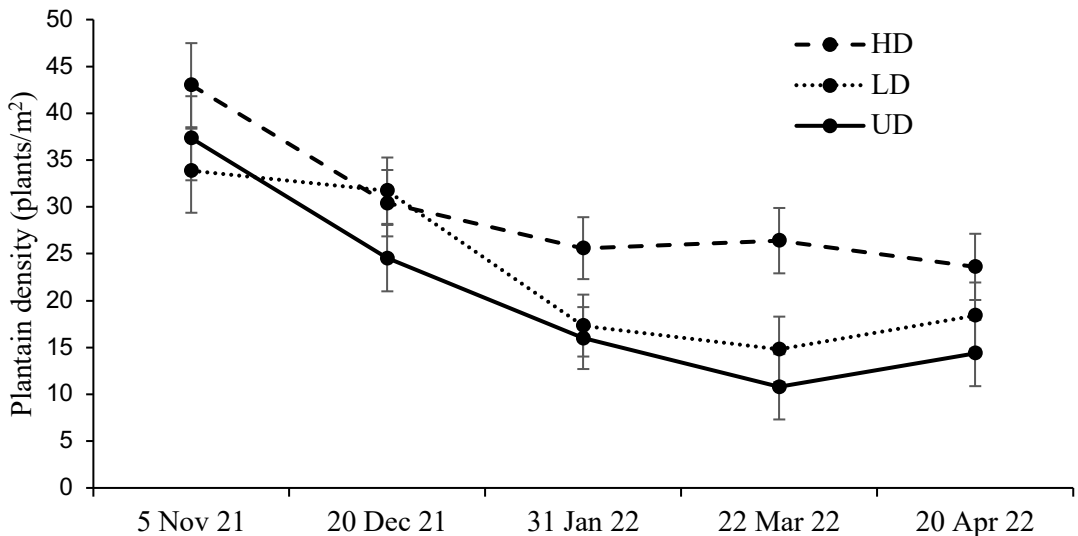


Figure 1 Density of plantain plants (plants/m²) in a three-year-old plantain-dominant pasture following no treading (UD – solid line), light damage (LD – dotted line) and heavy damage (HD – dashed line). Bars show standard error of the mean. Sown April 2019.

or pasture×treatment×month interactions. In the PL pasture the LAI of HD plots was 43% lower than that of UD plots at the end of the first regrowth following the treading damage, although the treatment effect was non-significant.

Botanical composition

The mean PL content decreased from 18% at harvest 1 (H1), to 9% at the end of the experiment ($P<0.01$) (Table 3). The mean white clover content was constant over the experiment, while the PR content increased. There was more white clover in HD plots than UD plots at H1 ($P<0.05$). The mean dock content of plots declined from 22% at H1 to 8% at the end of the experiment ($P<0.01$). Treading treatment appeared to have had little effect on the botanical composition of this pasture.

Plantain plant density

The mean PL plant density across the experiment was 38 plants/m² and 29 plants/m² in November and December respectively, but there was no difference between treatments (Figure 1). In January, HD plots had a PL density that was 60% and 48% higher than UD and LD plots, respectively ($P<0.05$). In March, the PL plant density in HD plots was 144% and 78% greater than that of UD and LD plots, respectively ($P<0.01$). In April, PL density was not significantly different between treatments. The mean PL density decreased significantly between November and January but was constant between January and April ($P<0.01$). During the experiment, PL density decreased by 51%

on average across the site ($P<0.01$). There was no effect of a treatment×month interaction on PL plant density.

Experiment 2

Treading damage

Soil volumetric water content was significantly higher ($P>0.01$) on the day that DD plots were tressed than when the ND plots were tressed, two days earlier (Table 4). The mean pug depth ($P<0.01$) and pug density ($P<0.01$) were significantly greater in DD plots than ND plots following the treading treatment.

Pasture production

During early spring, pasture growth was 50% lower in DD plots than in ND plots ($P<0.05$) but was not statistically significantly different between treading treatments from late spring onwards (Table 5). Average pasture growth rate increased from 36 kg DM/ha/day in early spring to 82 kg DM/ha/day during late spring, but then decreased to 46 kg DM/ha/day during early summer ($P<0.01$). Mean pasture growth was similar between early and late summer, but then decreased during autumn, to 31 kg DM/ha/day. The total mean pasture growth rate was not significantly different between treading treatments and there was no treatment×season interaction. The mean canopy light interception of DD plots was significantly lower than that of ND plots 14 days after the treading damage in early spring ($P<0.01$) but was not significantly affected by treading treatment in any other season. The mean light interception at 14 days after grazing, across the experiment, was greater from early summer to autumn than in early or late spring ($P<0.01$).

Table 4 Mean soil volumetric water content (%) during treading by dairy cows in August 2022, and resulting mean pug mark density (pugs/m²) and depth (mm).

Treatment	Soil volumetric water content (%)	Pug depth (mm)	Pug density (pugs/m ²)
Damaged	43.0	34.3	45.3
Undamaged	35.2	13.8	37.3
SEM	0.8	1.7	2.2
ANOVA p-values	<0.01	<0.01	<0.01

Table 5 Pasture growth rate (kg DM/ha/day) and light interception (%) of a plantain-perennial ryegrass pasture sown in April 2022, following treading damage (DD) or no treading damage (ND) from dairy cows during August 2022.

Season	Pasture growth rate (kg DM/ha/day)			Light interception ¹ (%)		
	DD	ND	SEM	DD	ND	SEM
Early spring (17/08-13/09)	24 ^b	48 ^a	8.85	84 ^b	95 ^a	1.22
Late spring (14/09-24/11)	82	83	12.57	88	90	1.02
Early summer (25/11-12/01)	52	41	6.02	91	93	1.14
Late summer (13/01-03/03)	38	47	5.49	93	94	0.95
Autumn (04/03-28/04)	26	36	3.95	93	92	0.90
Mean	44	51	3.92	90	93	0.79
ANOVA p-values						
Treatment	0.307			0.069		
Season	<0.01			<0.01		
Treatment×Season	0.252			<0.01		

¹ Mean canopy light interception measured 14 days after each grazing event. Letters indicate means within rows that are significantly different (P<0.05).

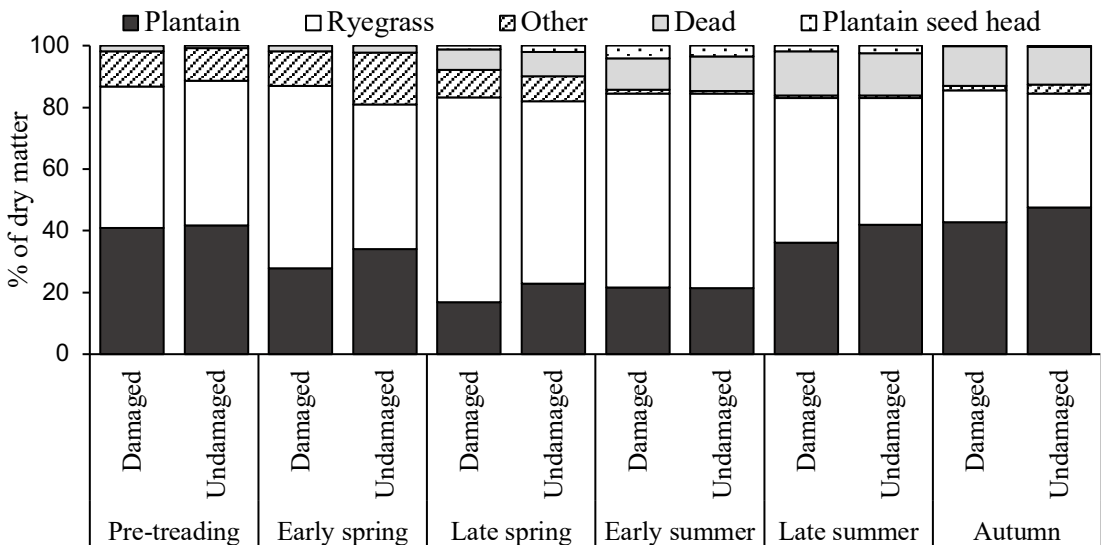


Figure 2 Botanical composition (% of dry matter) of a plantain-perennial ryegrass pasture sown in April 2022, following treading damage by dairy cows in August 2022. 'Other' comprised of annual poa, weeds and white clover.

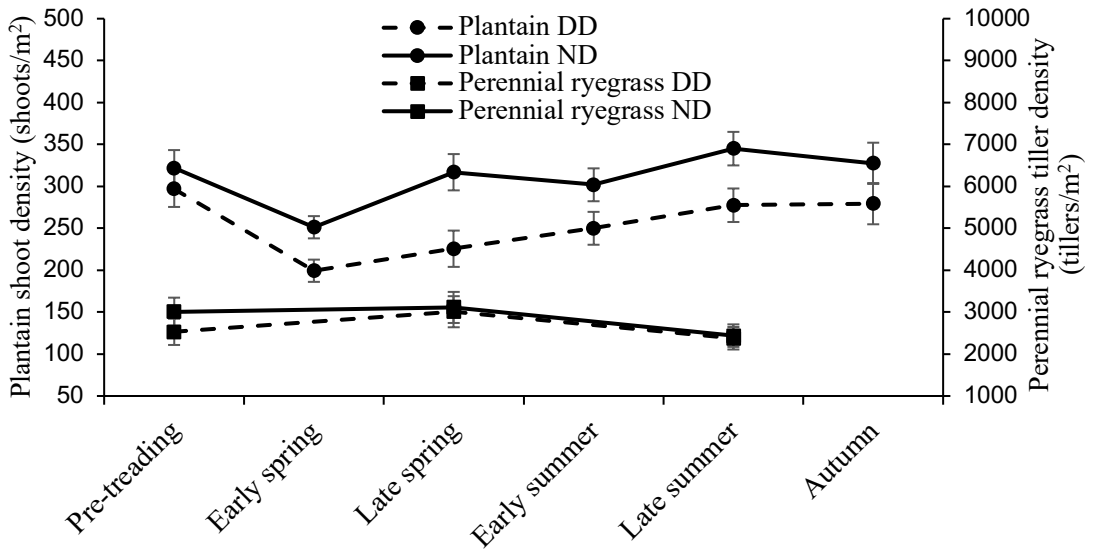


Figure 3 Density (number/m²) of plantain shoots (circles) and perennial ryegrass tillers (squares) in a first-year plantain/perennial ryegrass pasture sown in autumn, following treading by dairy cows in early spring. Damaged by treading (DD – dashed lines), not damaged by treading (ND – solid lines). Bars show standard error of the mean.

Botanical composition

Prior to the experiment, PL content was on average 41% across the site, while PR (46%) made up much of the remaining DM (Figure 2). During early spring, PL content was 19% lower in DD plots than in ND plots, though this difference was not significant. In contrast, the mean PR content was 28% higher in DD plots than in ND plots over the same period ($P < 0.05$). The effect of treading damage was evident in DD plots during late spring, where PL content was 26% lower than in ND plots ($P < 0.05$). The content of PR was significantly higher in DD plots than ND plots during late spring ($P < 0.05$). The effects of treading damage treatment on PL and PR content diminished after late spring. The PL content varied in both treatments between the seasons and after declining to 20% on average during late spring recovered throughout summer to reach 44% on average across the site in autumn ($P < 0.05$). In contrast, the PR content increased in both treatments during spring and then decreased over summer to 40% on average across the site in autumn. When averaged over the whole experimental period, PL content tended to be higher in ND plots (35%) than in DD plots (31%) although this effect was not significant. Other notable changes to pasture composition, were the reduction in annual poa content between spring and summer ($P < 0.01$), and the increase in dead material from spring to summer ($P < 0.01$).

Plantain shoot density and perennial ryegrass tiller density

Prior to the implementation of the treading treatments, PL shoot density was 309 shoots/m² on average (Figure 3). The PL shoot density was 21% and 29% lower in DD plots than in ND plots during early and late spring respectively ($P < 0.05$). In late summer PL shoot density was 20% lower in DD plots than in ND plots ($P < 0.05$), but there was no difference between treatments during autumn. When averaged over the whole season, DD plots (255 shoots/m²) appeared to have a lower PL shoot density than ND plots (311 shoots/m²) although this effect was not significant. Following the first grazing (and treading) in August, mean PL shoot density across the site decreased ($P < 0.01$) to 225 shoots/m². During late spring, this increased to 271 shoots/m² ($P < 0.01$) and then remained steady into early summer. Mean PL shoot density increased further during late summer to 311 shoots/m² ($P < 0.01$) but there was no further change from late summer to autumn. There was no effect of a treatment \times season interaction. The mean PR tiller density across the site was 2755 tillers/m² prior to the treading damage from cows. Treading treatment had no significant effect on PR tiller density during the experiment. The mean PR tiller density didn't differ significantly between seasons and there was no effect of a treatment \times season interaction.

Discussion

Treading damage

In both experiments, pug depth and thus treading damage severity, increased with an increase in SMC at the time of grazing, which agrees with previous studies (Climo and Richardson 1984), and confirms that the treading treatments were implemented as planned. In experiment 1, the greater treading damage severity observed in the PL pasture appeared to be a consequence of the higher SMC in those plots during treading, in comparison with the PR pasture with the difference most likely due to site differences. However, it is difficult to rule out any effect that different species, composition, and plant density might have had on the resistance of soil to treading. The treading damage caused by the puggo-stick is comparable to damage caused by cattle in other studies. For example, Betteridge et al. (2003) reported pug depths greater than 30mm in a saturated silt loam, Nie et al. (2001) reported larger pug depths of 43mm in a wet clay loam and in the current work a mean pug depth of 34mm was recorded in a wet silt loam in experiment 2. The lateral soil damage effects of the puggo-stick were not evaluated.

Plantain/ perennial ryegrass pasture DM production following treading damage

The effects of treading damage on herbage production in the current experiments agree with previously established reductions of between 30-50% (Pande et al. 2000; Nie et al. 2001) which provides further confirmation that the treading treatments were implemented appropriately by the puggo-stick and cows. One important finding was that the loss of pasture production caused by the puggo-stick damage was similar for both the PL and PR pasture types. This potentially contradicts earlier statements (Stewart 1996) that PL is more sensitive to treading damage than PR. However, since the PL content in the PL pasture was low, it is not possible to claim that PL was as tolerant of treading damage as PR. In experiment 2 the pasture growth rate of DD plots appeared to recover as soon as the second regrowth period after treading, suggesting that any negative impacts of the damage had subsided. However, in experiment 1, HD plots still had a reduced herbage accumulation rate in January and February, suggesting that the damage may have caused a longer-term impact such as a deterioration of soil physical quality (Hu et al. 2018). The influence of temperature on pasture growth could explain why pasture growth appeared to be limited less by damage in experiment 1 than in experiment 2 i.e., November vs August pugging events. Temperature is a major driver of pasture growth rate (Baars and Waller 1979). Daily temperatures were closer to optimal for temperate species (20-25°C) following treading in experiment 1, than in experiment 2, likely enabling a faster pasture regrowth in the former, regardless of pasture type or treading treatment.

If an interaction between temperature and treading damage exists, it might be expected that the impact of treading damage on pasture regrowth would be more severe in cooler seasons, therefore future studies might consider implementing treading in autumn or winter. It was noted that herbage accumulation rates during experiment 1 were very large and care should be taken when comparing these with other studies. The high growth rates were potentially due to the nature of the experiment site including the optimal soil moisture and nutrient inputs, and the absence of typical grazing detriments including further treading damage and over-grazing.

The immediate effect of the damage on pasture growth appears to have been driven by a reduction in the light intercepting capacity of the pasture canopy, potentially caused by the burial of plants and a reduction in leaf extension on injured shoots. This agrees with work by Pande et al. (2000), who found that the LAI of a PR pasture was reduced by cattle treading damage, which was strongly correlated with reduced pasture growth. In the current study, an apparent reduction in LAI and reduced pasture growth were observed in HD plots in experiment 1. Although canopy light interception, and subsequently pasture growth, were initially reduced in the DD pasture in experiment 2, these recovered quickly, probably due to the increased growth of PR in those plots during spring.

Plantain content and plantain persistence following treading damage

The effects of the simulated treading damage on PL content in experiment 1 were not obvious, probably having been confounded by the low PL content and PL density in the sward prior to the experiment, which are common features of a three-year-old sward (Dodd et al. 2019). An interesting finding was the apparent enhancement of PL plant density by the HD treatment and consequent diversion from a decline during summer, which is typical of older PL swards (Ayala et al. 2011). It is plausible that new PL plants emerged in HD plots, in areas of bare soil which commonly occur following treading damage (Elliott et al. 2002) and which provide an environment ideal for seedling establishment (Bakker 1985). Alternatively, cattle treading has been shown to speed up clonal fragmentation of prostrate-growing pasture plants (Edmond 1964; Menneer et al. 2005), which could also be responsible for increased PL plant density under heavy treading. Lastly, it is possible that improved light availability in HD plots, due to the low dock content following treading, enhanced the survival of existing PL plants. In contrast, the high dock content of UD plots may have shaded PL plants and contributed to PL density decline. Weed invasions were shown to coincide with PL density decline by Sanderson et al. (2003).

In experiment 2, treading damage reduced PL

content during early and late spring, likely due in part to the reduction in PL shoot density in DD plots during that time. In contrast, PR tiller density appeared to be largely unaffected by the treading damage, probably allowing for a quicker recovery of leaf production and growth following the damage, confirming previous findings that PR is one of the most treading-tolerant pasture species (Edmond 1964). Menneer et al. (2005) previously showed that following treading damage, white clover, a prostrate and treading-sensitive species, also had a significantly lower content in a PR pasture. The reduction in PL content in DD plots in experiment 2 also likely enhanced the increase in PR growth in the sward from early spring to early summer, which is its major growing season (Kemp et al. 1999). Additionally, low temperatures following treading damage could have further limited PL regrowth (Teramura et al. 1981) and encouraged the shift in pasture composition from PL to PR in all plots during spring. The PL and PR content in the pasture appeared to be negatively correlated, which was particularly evident when comparing pasture composition for late spring and late summer. More work is required to gain a full understanding of what factors drove the shift from PR dominance in spring to PL dominance in late summer.

It is difficult to determine from experiment 2, whether the treading damage had any permanent effect on PL persistence. The reduction in PL shoot density in both treatments following the first grazing event, suggests that the PL population was sensitive to the early-spring grazing, regardless of grazing management. Although the PL shoot density of DD plots was lower than ND plots during spring, it recovered to within a similar range of ND plots by autumn. It is plausible that the PL shoot density recovered in DD plots because of new shoot production from individual plants, which could compensate for a loss of plants in the short-term, such as has been observed in chicory (Li et al. 1997). However, it is unknown how these new shoots would respond to repeat treading damage during subsequent years. Since the PL shoot density in DD plots eventually recovered to near pre-experiment levels, it would be theoretically capable of sustaining the pasture PL content achieved during this experiment, into the future. Therefore, there is no evidence that treading damage had any negative effect on PL persistence.

The general trend for the recovery of PL shoot density over the course of the year in experiment 2 was in stark contrast with the continual decrease in the PL density of the 3-year-old PL sward over summer in experiment 1. The difference between these trends suggests that PL population age may have important implications for the recovery of PL density following damaging events and might suggest that PL populations are more tolerant of density loss within the first year following sowing due to their improved capacity for recovery.

The current study highlighted the necessity for

continued research on other factors affecting PL content and persistence, including the long-term effects of treading damage, the effect of repeat treading damage, the interaction of PL age with treading damage, suitable companion species, and the interaction of treading damage with other abiotic stresses such as low temperature.

Conclusions

The reductions in the DM production of the PL pasture following simulated treading damage and the PL/PR pasture following cattle treading damage were comparable to reductions previously observed for PR-dominant pastures. The results indicate that treading damage may be an important cause of reduced PL content in PR-based dairy pastures during spring and highlight the need for careful management of pastures that are prone to treading damage, to ensure sufficient PL content. It was not clear from the current experiments that treading damage reduced the ability of PL to persist. On first assessment, the puggo-stick appeared to be an effective method for simulating cattle treading damage, although further work is required to fully validate the method.

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