The effect of defoliation frequency and height on plantain and chicory-based swards

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Abstract

Herb and clover mixes; containing chicory (*Cichorium intybus*), plantain (*Plantago lanceolata*), red clover (*Trifolium pratense*) and white clover (*T. repens*) are widely used in New Zealand. The objective of this study was to examine the effect of defoliation strategies on the herbage accumulation, botanical composition, and taproot diameter of three sward types: i) Chicory Sward, ii) Plantain Sward, iii) Herb and Clover Mix. A combination of four defoliation frequencies (every week, two-weeks, three-weeks and six-weeks), and three stubble heights (25 mm, 50 mm, 75 mm) were compared over 24 weeks from September to March. In the chicory sward, defoliation every six-weeks is advisable for producing a chicory dominant sward as well as plants with larger taproot diameters. In the plantain sward, defoliation every three to six-weeks to a short stubble height (25-50 mm) is advisable for maximising yield, producing a plantain dominant sward and supporting larger taproot diameters. In the herb and clover mix, defoliation every three to six-weeks is suggested to maximise yield, with six-weekly defoliation being most favourable for supporting a higher proportion of red clover in the sward as well as chicory plants with larger taproot diameters. Overall, this study highlights some valuable grazing management strategies for farmers to enable them to get the most out of their herb swards.

Additional keywords: frequency, stubble height, *Plantago lanceolata*, *Cichorium intybus*

Introduction

Chicory (*Cichorium intybus* L.) and narrow leaf plantain (*Plantago lanceolata* L.) are summer active, perennial herbs which can produce a large amount of high-quality herbage during spring, summer and autumn (Lee *et al.*, 2015a). Many New Zealand farmers utilise chicory and plantain in diverse grass dominant mixes (Nobilly *et al.*, 2013) and as supplementary forage crops. These forage crops can be monocultures (Lee *et al.*, 2015a) or herb and clover mixes containing combinations of chicory, plantain, red clover (*Trifolium pratense* L.) and white clover (*T. repens* L.) (Cranston *et al.*, 2015a). Herb and clover mixes have a greater herbage yield, longer growing season and greater persistence compared to chicory monocultures, and a greater nutritive value compared to plantain monocultures (Navarrete, 2015). While there is reasonable knowledge on the effect of defoliation on monocultures of chicory and plantain (Lee *et al.*, 2015a), there is limited information available on the optimal defoliation management of herb and clover mixes to maximise their yield and persistence while maintaining a mixed botanical composition.

Chicory and plantain are both taprooted plants, with chicory having a wider and deeper taproot than the truncated taproot of plantain (Lee *et al.*, 2015b). They store non-structural carbohydrates in the taproot and use this carbohydrate for the initiation of leaf growth following defoliation (Li *et al.*, 1997a). These carbohydrate reserves are associated with persistence, and taproot diameter can be used as an indicator of these reserves (Li *et al.*, 1997a). There is limited knowledge on the effect of defoliation management on taproot carbohydrate reserves, particularly in plantain monocultures and herb and clover mixes. Cranston *et al.* (2015b) found that a lower stubble height (40 vs 80 mm) had a positive effect on the herbage yield of a herb and clover mix over a two year period, but had a negative effect on the taproot diameter of chicory and reduced the percentage of chicory in the sward. A comprehensive understanding of the effect of a wide range of defoliation frequencies and stubble heights would be invaluable for farmers using herb and clover mixes. The objective of this experiment was to examine the effects of different combinations of defoliation frequencies and stubble heights on the herbage accumulation, botanical composition and taproot diameter of a herb and clover mix compared to monocultures of chicory and plantain.

Materials and Methods

Site preparation and description

The experiment was carried out between March 2012 and March 2013 at the Massey University Pasture and Crop Research Unit, Palmerston North, New Zealand (40°S, 175°E). The soil was a Manawatu fine sandy loam (Dystric Fluventric Eutrochrept) (Hewitt, 1988). The area had previously been in perennial ryegrass and white clover sward prior to mouldboard ploughing and secondary cultivation followed by sowing via roller drill on 26 March 2012. Soil test results prior to sowing were: P, 36 mg/kg, S, 28 mg/kg, K, 86 mg/kg, Ca, 1380 mg/kg, Mg, 146 mg/kg and a pH of 5.7. Nitrogen fertiliser was applied to the experimental area to support plant growth (50 kg N/ha on 18 August 2012, 35 kg N/ha on 20 November 2012, 35 kg N/ha on 31 January 2013) and all herbage was removed at each defoliation event. The site has a warm-temperate environment (Table 1) with a mean annual rainfall of 1013 mm. Irrigation was utilised between November and February when monthly rainfall fell below the long-term average or when herbage growth was visually limited due to lower-than-average soil moisture conditions. All plots were defoliated on 23 August 2012 to 62.5 mm to prevent shading and remove herbage growth. Weeds were controlled by applying herbicides on 19 July 2012. Grass weeds were controlled with Haloxyfop at a rate of 0.5 L/ha with 1.0 L/ha Uptake (a.i 582 g/l paraffinic oil and 240 g/l alkoxylated alcohol non-ionic surfactants). Broadleaf weeds were controlled with Flumetsulum at a rate of 52 g/ha with 1.0 L/ha Uptake (Chicory plots and the Herb and clover mix plots) or with 500 g/L 3,6-dichloro-2-methoxybenzoic acid at a rate of 1.0 L/ha (Plantain plots).

Experimental design

The experimental design was a 3 × 4 × 3 factorial arranged in a randomised complete block with three replicates. Each replicate (plot) was 1m wide by 6m long. Three sward treatments were sown and then defoliated at four defoliation frequencies and three stubble heights as follows:

a) Sward treatments: Chicory sward (cv. Puna II, 6 kg/ha), Plantain sward (cv. Tonic, 6 kg/ha), Herb and clover mix (cv. Puna II, 6 kg/ha; cv. Tonic, 6 kg/ha; Red clover cv. Sensation, 6 kg/ha; White clover cv. Tribute, 4 kg/ha).
b) Defoliation frequencies (DF): Weekly (F1), Two-weekly (F2), Three-weekly (F3), Six-weekly (F6).
c) Stubble heights (SH): 25 mm (H25), 50 mm (H50), 75 mm (H75).

A number of the chicory plots had very poor establishment, so the weekly chicory defoliation treatment combinations (F1-H25, F1-H50, F1-H75) were removed from the experiment, as previous research has shown chicory does not respond well under very frequent defoliation (Li *et al.* 1997a). All plots were defoliated to their respective treatment SH on 19 September 2012 (start of study). Following this each plot was defoliated according to their DF and SH treatment for a period of 24 weeks (March; end of study).

Table 1: Mean monthly soil temperature, maximum and minimum air temperatures (°C), total monthly rainfall and irrigation water applied (mm) between September 2012 and March 2013 compared with the long-term mean (10 year). Measurements were collected from a weather station located approximately 500 m from the experimental site (40°S, 175°E).

	Sept	Oct	Nov	Dec	Jan	Feb	Mar
Experimental period (September 2012 to March 2013)							
100 mm soil temperature (°C)	9.9	12.0	14.5	18.4	18.3	19.3	17.7
Max. daily air temperature (°C)	15.2	16.1	17.6	22.3	23.3	24.1	23.6
Min. daily air temperature (°C)	5.7	7.1	7.8	12.5	11.7	12.2	11.1
Rainfall (mm)	59	64	20 (50)[1]	100 (62)[1]	29 (50)[1]	34 (63)[1]	37
Long-term mean (10 year)							
100 mm soil temperature (°C)	10.0	12.5	14.7	17.1	18.6	18.6	16.6
Max. daily air temperature (°C)	15.4	16.9	17.9	20.8	22.5	23.3	21.7
Min. daily air temperature (°C)	7.0	8.5	9.5	12.1	12.7	13.3	11.9
Rainfall (mm)	87	108	100	90	52	55	60

[1]Irrigation applied (mm). Application dates and rates were 22 November 2012 (50 mm), 11 December 2012 (25 mm), 21 December 2012 (37 mm), 30 January 2013 (50 mm) and 25 February 2013 (63 mm).

Measurements

Herbage mass was measured pre-defoliation at all harvest dates and post-defoliation at Week 6, Week 12, Week 18 and Week 24 by taking one 0.4 × 0.25 m quadrat cut (0.1 m^2) taken along the drill rows per plot (Frame, 1993). These samples were cut at ground level with an electric shearing hand-piece and then washed before oven drying for at least 24 hours at 70 °C, to a constant weight. Apparent herbage yield for each plot was calculated as the pre-defoliation mass minus the average of the post-defoliation herbage mass from the closest relative harvest dates (Week 6, 12, 18 or 24). The total accumulated herbage yield for each plot was calculated as the sum of the apparent herbage yields from all harvest dates. One herbage sample (~100g wet weight) per plot was collected for botanical composition analysis at the start and end of the study (September and March) by taking a 0.1 m^2 quadrat cut at ground level. These samples were sorted into individual sown species, weeds and dead material and the botanical composition was calculated on a dry weight basis following oven drying. Taproot diameters were assessed at the start and end of the study by harvesting a 0.18 × 0.18 m area per plot and measuring the widest part of the root using callipers of all plants within that area. The number of plants within each harvest area ranged between 5-25 plants, with a median of approximately 12 plants per harvest area.

Statistical analysis

All statistical analyses were performed using SAS (Statistical Analysis System, version 9.2; SAS Institute Inc., Cary, NC, US). Each sward treatment was analysed separately in order to detect differences between defoliation treatments within each sward treatment more accurately. Total herbage accumulation was analysed using a MIXED model which included the fixed effects of DF, SH and the interaction between DF and SH and the random effect of replicate. The botanical composition data were arcsine square root transformed to homogenise variance prior to analysing as percentages using the MIXED procedure. The model included the fixed effects of DF, SH, week, components of the sward and all interactions between DF, SH, week and components of the sward and the random effect of replicate. Taproot diameters were analysed using a MIXED model which included the fixed effects of DF, SH and week and all interactions between DF, SH, week and the random effect of replicate.

Results

Total accumulated herbage yield

The combined effect of DF and SH on the total accumulated herbage yield of the three sward treatments is displayed in Figure 1 and mean significant effects are described below. Within the chicory sward, there was no main effect of DF or SH or interaction between DF and SH or on total accumulated herbage yield (mean of 9400 ± 815 kg DM/ha; $P>0.05$).

Within the plantain sward, there was an interaction between DF and SH on total accumulated herbage yield ($P<0.05$; Figure 1). Plantain plots defoliated weekly to 75 mm had a greater total accumulated herbage yield than plots defoliated weekly to a lower stubble height ($P<0.05$). Further, when plantain plots were defoliated to a 25 mm SH, the total accumulated herbage yield was greater in plots defoliated every three-weeks or six-weeks than plots defoliated more frequently ($P<0.05$).

Within the herb and clover mix, total accumulated herbage yield was affected by DF ($P<0.05$), however, there was no effect of SH (data not shown) or interaction between DF and SH or effect ($P>0.05$). Plots defoliated every three-weeks or six-weeks had a greater total accumulated herbage yield compared to plots defoliated weekly or every two-weeks (F1, 8151 ± 954; F2, 9261 ± 884; F3, 13180 ± 884; F6, 12878 ± 884 kg DM/ha).

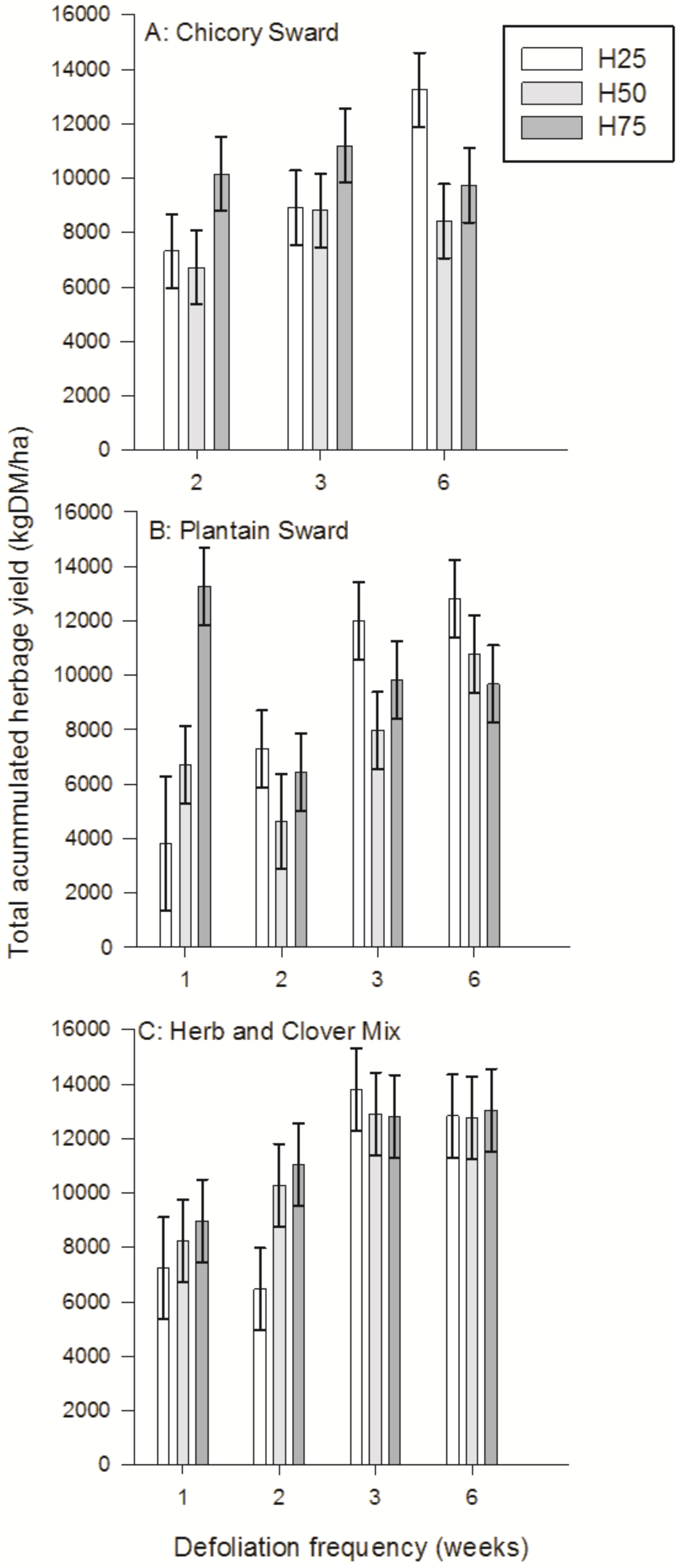

Figure 1: Effect of defoliation frequency (1, 2, 3, 6 weekly) and stubble height (25 mm; H25: white bars, 50 mm; H50; light grey bars, 75 mm; H75; dark grey bars) on the total accumulated herbage yield of the Chicory Sward (A), Plantain Sward (B) and Herb and Clover Mix (C). Vertical bars represent standard error of the mean.

Botanical composition

Within the chicory sward, there was an interaction between DF and season and between SH and season for the botanical composition (P<0.05, Figure 2). Between September and March, the percentage of chicory did not differ in plots defoliated every six-weeks (P>0.05), however, plots defoliated every two-weeks had 32% points less chicory in March than September (P<0.05). Further, in March, plots defoliated every six-weeks had 25% points more chicory and 32% points less weeds than defoliated every two-weeks (P<0.05).

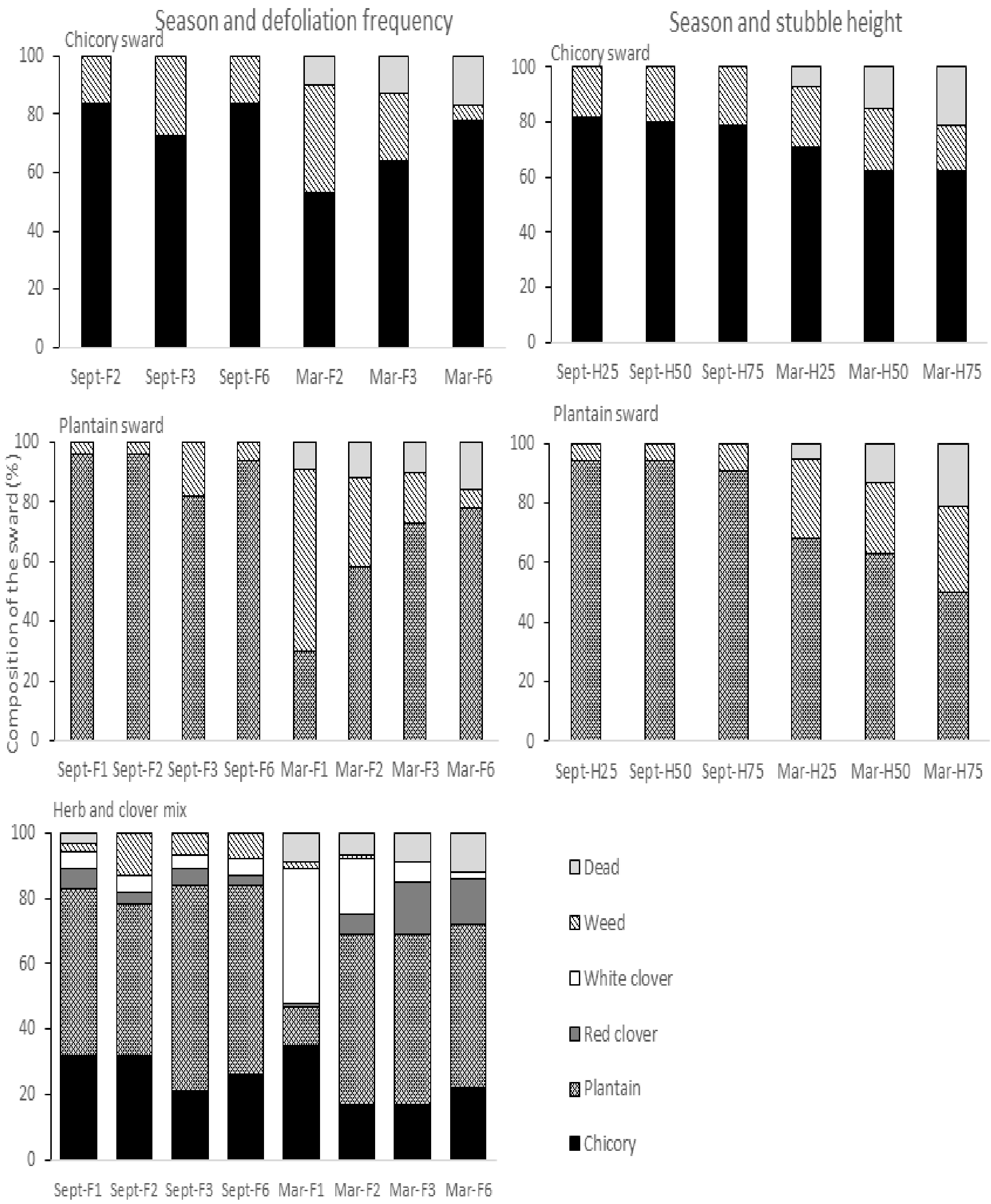

Figure 2: Effect of defoliation frequency (Weekly, F1; Two-Weekly, F2; Three-Weekly, F3; Six-Weekly, F6) and stubble height (25mm, H25; 50mm, H50; 75mm, H75) on the botanical composition (% back-transformed) of the chicory sward, plantain sward and the herb and clover mix in September and March.

Within the plantain sward, there was an interaction between DF and week and between SH and week on the botanical composition ($P<0.05$; Figure 2). Between September and March, the percentage of plantain decreased in all defoliation frequency treatments ($P<0.05$). In March, plots defoliated every week had 24% points less plantain than plots defoliated every two-weeks ($P<0.05$), which in turn, had 15-19% less plantain than plots defoliated every three-weeks or six-weeks ($P<0.05$), which had a similar amount of plantain ($P>0.05$). In addition, in March, the weed content was greater with each decreasing defoliation frequency treatment ($P<0.05$). Further, in March, plots defoliated to 75 mm had 14-19% points less plantain and greater dead material than plots defoliated to lower stubble heights ($P<0.05$).

Within the herb and clover mix, there was no effect of SH on the botanical composition (data not shown; $P>0.05$), however, there was an interaction between DF and season ($P<0.05$; Figure 2). In March, the white clover content was greater with each decreasing defoliation frequency treatment ($P<0.05$). Conversely, the opposite trend was observed in red clover. Whereby, in March, plots defoliated every week had 5% points less red clover than plots defoliated every two-weeks ($P<0.05$), which in turn had 7-8% points less red clover than plots defoliated every three-weeks, or six-weeks ($P<0.05$), which were similar to one another ($P>0.05$).

Taproot diameter

Stubble height had no effect on the mean taproot diameter in any of the sward treatments (data not shown; $P>0.05$). Conversely, DF had an effect on the taproot diameter of all the sward treatments ($P<0.05$; Table 2). Within the Chicory Sward, chicory plants in all of the DF treatments had a similar taproot diameter in September ($P>0.05$) and their taproot diameter increased between September and March ($P<0.05$). In March, the taproot diameter of chicory plants was greater in plots defoliated every six-weeks than plots defoliated more frequently ($P<0.05$).

Within the plantain sward, season and DF both had an effect on the mean taproot diameter ($P<0.05$; Table 2) but there was no interaction between season and DF ($P>0.05$). The taproot diameter of plantain plants increased between September and March (3.6 ± 0.19, 4.6 ± 0.19 mm, respectively; $P<0.05$). The effect of DF on the taproot diameter of plantain plants, was such that defoliation every six-weeks resulted in plants with greater taproot diameters (4.7 ± 0.24 mm) than those defoliated every week, two-weeks or three-weeks (3.8 ± 0.24, 3.8 ± 0.24, 4.0 ± 0.24 mm, respectively; $P<0.05$).

Within the herb and clover mix, in September, the mean taproot diameter of chicory plants was similar between the DF treatments ($P>0.05$; Table 2). However, by March, the taproot diameter of chicory plants was greater in plots defoliated every six-weeks than plots defoliated more frequently ($P<0.05$). Taproot diameter of plantain plants within the herb and clover mix was similar between the DF treatments in September ($P>0.05$), however by March, the taproot diameter was smaller in plots defoliated every week compared to plots defoliated less frequently ($P<0.05$).

Table 2: Effect of defoliation frequency (Weekly; F1, Two-Weekly; F2, Three-Weekly; F3, Six-Weekly; F6) and season (September and March) on the taproot diameter (mean ± SEM; mm) of chicory and plantain within the Chicory Sward, Plantain Sward and the Herb and Clover Mix.

Sward treatment	Taproot diameter (mm)		*P* value	
	September	March	Season	Season x Defoliation frequency
Chicory Sward			<0.001	<0.05
F2	5.1 ± 0.62	7.4 ± 0.66		
F3	4.7 ± 0.62	8.5 ± 0.62		
F6	5.2 ± 0.62	11.0 ± 0.62		
Plantain Sward			<0.001	NS
F1	3.5 ± 0.33	4.2 ± 0.33		
F2	3.5 ± 0.33	4.1 ± 0.33		
F3	3.4 ± 0.33	4.6 ± 0.33		
F6	4.0 ± 0.33	5.4 ± 0.33		
Herb and clover mix				
Chicory			<0.001	<0.05
F1	3.8 ± 0.45	4.8 ± 0.42		
F2	4.0 ± 0.40	5.2 ± 0.40		
F3	3.6 ± 0.42	4.9 ± 0.40		
F6	4.1 ± 0.40	7.4 ± 0.40		
Plantain			<0.001	<0.01
F1	3.3 ± 0.26	3.1 ± 0.24		
F2	2.8 ± 0.23	4.0 ± 0.23		
F3	2.8 ± 0.24	4.4 ± 0.23		
F6	3.1 ± 0.22	4.6 ± 0.23		

Discussion

Chicory sward

The present study suggests that chicory monocultures respond most favourably to defoliation every six-weeks as opposed to more frequently, with swards maintaining a greater proportion of chicory and fewer weeds and with chicory plants having larger taproot diameters. Taproot diameter provides a measure of the amount of carbohydrate reserves stored in the taproot (Li et al., 1997a). Following defoliation, chicory plants mobilise taproot carbohydrate reserves in order to support new leaf growth, and once sufficient above ground herbage is present, the plants slowly restore the root carbohydrate reserves via photosynthesis (Lee et al., 2015b). However, if chicory plants are not provided sufficient time to recover from a defoliation event, then their carbohydrate reserves will continue to diminish which can lead to reduced herbage production and ultimately a lower plant density (Li et al., 1997b; Lee et al., 2015b). Under glasshouse conditions, Cranston et al.

(2016) also found chicory taproot diameter was reduced under frequent defoliation compared to less frequent defoliation (every week versus three-weeks). More recently, Mangwe et al. (2020), found chicory defoliated using a shorter grazing rotation (every 300 vs 600 growing degree days) had narrower roots with lower concentrations of sugars and suggested that this was likely to compromise these plants longevity.

Grazing studies over several years suggest more frequent defoliation of chicory results in a greater decline in plant density from year two onwards (Alemseged et al., 2003; Navarrete, 2015). Although there was no herbage yield benefit associated with less frequent defoliation in the present study, other long-term studies have consistently shown that chicory produces greater herbage yields when defoliated every five to six weeks rather than more frequently (Belesky et al., 1999; Labreveux et al., 2004). In the present study, defoliation height had no effect on herbage production or taproot diameter. Other studies have also observed that defoliation interval has a stronger influence on chicory herbage production and other functional traits compared to stubble height (Mangwe et al., 2020; Lee et al., 2015b). Overall, the results of this study, combined with previous studies, indicates that defoliating every six-weeks is advisable to maintain taproot diameter, which is a proxy for persistency. Conversely, when chicory is utilised as a short-term summer crop, appropriate grazing management appears to be less important.

Plantain sward

The present study suggests that the combination of both defoliation frequency and stubble height are important criteria for successfully managing plantain monocultures. When plantain was defoliated to a short stubble height (25 mm), herbage accumulation increased when the sward was given longer to recover (defoliated every three to six weeks). Furthermore, defoliation to 25 or 50 mm maintained a greater percentage of plantain in the sward and less dead material compared to defoliating to the higher stubble height (75 mm). Similarly, other studies have found plantain produces a greater herbage yield when defoliated to 30-50 mm rather than a higher stubble height (80-100 mm), provided it has a minimum defoliation frequency of two weeks (Ayala et al., 2011; Lee et al., 2015a). In the present study, less frequent defoliation resulted in swards with greater proportions of plantain and fewer weeds as well as plantain plants with larger taproot diameters. These combined results suggest that grazing plantain hard to a 25-50 mm stubble height every three to six weeks is advisable for maximising yield, producing a plantain dominant sward and supporting taproot reserves, thereby promoting persistence. Alternatively, if plantain is to be used in a continuous stocking system, the choice of stocking rate to maintain a relatively high residual (75 mm) is very important to maximise herbage accumulation.

Herb and clover mix

The present study suggests that defoliation frequency is an important criterion for managing herb and clover mixes to achieve optimal herbage yields, composition and persistence, while stubble height doesn’t appear to be important. Herbage accumulation was greatest when the herb and clover mix was defoliated every three to six weeks, rather than more frequently. Similarly, previous studies with chicory and plantain monocultures have also shown that longer rotation intervals lead to greater herbage accumulation (Belesky *et al.*, 1999;

Labreveux *et al.*, 2004; Lee *et al.*, 2015a). However, Navarrete (2015) found no difference in the herbage yield of a herb and clover mix grazed either every two weeks or every four weeks over two years.

The botanical composition of the sward was also affected by the defoliation frequency, whereby less frequent defoliation resulted in swards with a higher proportion of red clover. This effect has been consistently observed in monocultures of red clover, whereby herbage accumulation markedly increases with less frequent defoliation (Hay and Ryan, 1989). In addition, swards defoliated every six weeks had chicory plants with larger taproot diameters relative to the more frequent defoliation treatments and weekly defoliation resulted in plantain plants with smaller taproot diameters compared to less frequent defoliation treatments. In a grazing study, Cranston *et al.* (2015b) found lax grazing (stubble height of 8 cm) also favoured the proportion of red clover and larger taproot diameters of chicory plants in a herb and clover mix compared to hard grazing (stubble height of 4 cm). Given that chicory and red clover have a higher crude protein content, organic matter digestibility and a lower fibre content than plantain (Brown *et al.*, 2005; Ekanayake *et al*., 2019; Lee *et al.*, 2015a), it is important that the defoliation management applied to herb and clover mixes favours red clover and chicory to enable the overall herbage quality to be maximised.

While infrequent defoliation favoured the proportion of red clover in the mixed sward, more frequent defoliation favoured the proportion of white clover. However, it is acknowledged that frequent defoliation via mowing can over-express the percentage of white clover in the sward compared to what would be found under grazing (Swift *et al.*, 1992). In addition, white clover is lower in the sward structure compared to the more upright species of chicory, plantain and red clover and consequently is not preferentially grazed in herb and clover mixes (Cave *et al.*, 2015). This suggests that there may therefore be little benefit in including white clover in a herb and red clover sward mix, other than for the purpose of fixing nitrogen and filling gaps in the sward thereby potentially reducing weed invasion, or by minimising the risk of variable defoliation management, which may occur under practical farming conditions, negatively impacting red clover. Instead, a focus on utilising longer defoliation frequencies to enhance the overall herbage accumulation and amount of red clover and chicory in the sward is advisable when utilising herb and clover mixes as supplementary forage crops.

Conclusion

This study indicates that appropriate defoliation frequency is important when managing both chicory swards and herb and clover mixes. While for plantain swards, both defoliation frequency and stubble height are important when trying to optimise the performance of the sward. In the chicory sward, defoliation every six-weeks supported a sward with a greater proportion of chicory as well as plants with larger taproot diameters. In the plantain sward, under a rotational grazing system, defoliation every three to six-weeks to a short stubble height (25-50 mm) is advisable for maximising yield, producing a plantain dominant sward and supporting larger taproot diameters. In the herb and clover mix, defoliation every three to six-weeks maximises yield, with six-weekly defoliation being most favourable for supporting a higher proportion of red clover in the sward as well as chicory plants with larger taproot diameters. Overall, this study highlights some valuable grazing management strategies for farmers to enable them to get the most out of their herb swards.

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