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An examination of the effect of autumn closing date on over-winter herbage production and spring yield

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Abstract

Altering autumn management affects the herbage mass available in spring. An experiment was established to determine the effect of five autumn closing dates (CDs) on herbage production, herbage quality, leaf, stem and dead proportions and tiller density over winter. In the study 50% of the herbage available in spring was accounted for by autumn CD. Each 1 d extra a sward was closed from 25 September to 9 December increased herbage mass by 16 kg DM/ha in spring. Swards closed earlier (25 September–26 October) had consistently higher herbage masses in spring (1,301 kg DM/ha) compared to swards closed later (11 November–9 December; 703 kg DM/ha). Later closed swards had greater herbage quality compared to earlier closed swards (organic matter digestibility = 852 and 825 g/kg DM, respectively) due to increased stem and dead material in the grazing horizon of earlier closed swards. There was no effect of autumn CD on sward quality in the subsequent defoliation in spring. However, following the initial spring grazing there was an effect of autumn CD on subsequent grass growth rates; swards closed in October had a lower growth rate (33 kg DM/ha per day) compared to swards closed in November and early December (49 kg DM/ha per day). Results indicate that earlier autumn closing is beneficial to meet high-feed demand in spring but can affect sward quality and growth rates in spring.

Keywords

Autumn grazing date • herbage mass • spring grass • sward quality

Introduction

In temperate regions of the world grass-based dairy production systems offer a competitive and sustainable alternative to intensive, high-output systems (Dillon *et al.*, 2008; Peyraud *et al.*, 2010; Ramsbottom *et al.*, 2015). Grazed grass is the cheapest feed source available for ruminant production systems (Finneran *et al.*, 2010), and increasing the production and utilisation of grazed grass is of the utmost importance in improving environmental (Donnellan *et al.*, 2018) and economic (MacDonald *et al.*, 2010; Hanrahan *et al.*, 2018) sustainability. In spring calving systems, which are dominant in Ireland (Dillon *et al.*, 1995; O'Donovan *et al.*, 2011), there are high-feed requirements to meet animal demands in spring. In temperate climatic zones, such as Ireland and New Zealand, there is a high dependence on environmental conditions such as temperature for perennial ryegrass (*Lolium perenne* L.; PRG) growth. As a result there is little grass growth during late autumn, winter and early spring (Dillon *et al.*, 1995; Parsons & Chapman, 2000; Hennessy *et al.*, 2008), which can lead to inadequate quantities of grazed herbage available on farm in spring (Ryan *et al.*, 2010; Lawrence *et al.*, 2017). Autumn closing date (CD) is one of the main factors contributing to the accumulation of herbage over the winter months (Roche *et al.*, 1996; Hennessy *et al.*, 2006). The date on which a sward is grazed in the previous autumn has a direct impact on the amount of grass available in the following spring (Davies & Simons, 1979; O'Donovan *et al.*, 2002; Lawrence *et al.*, 2017). It has previously been reported that every 1-d delay in closing from 1 October results in a reduction in spring herbage accumulation of between 10 and 15 kg DM/ha per day in pre-grazing herbage mass (O'Donovan *et al.*, 2002; Lawrence *et al.*, 2017). Closing swards earlier in autumn (early October) can lead to an increase in herbage available

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in spring, which can allow for an earlier turnout of animals (Roche *et al.*, 1996; Hennessy *et al.*, 2006).

Despite low over-winter growth rates on farms in Ireland (3 to 8 kg DM/ha per day; December–January; PastureBase Ireland Data, M. O'Leary, Teagasc, Personal Communication), herbage is continuously accumulating throughout the winter (Brereton *et al.*, 1985) albeit at a slower rate compared to in spring, summer and autumn. When a high herbage mass (>2,000 kg DM/ha; approximately) is carried over winter, it can result in a reduction in sward quality, as the amount of green leaf material in the sward declines and the level of senescent material increases (Hennessy *et al.*, 2008). Additionally, a high herbage mass results in shading which can reduce tiller production and hinder tiller establishment and survival (Laidlaw & Mayne, 2000).

To meet the target of matching animal feed requirements with available herbage in spring, autumn grazing management has been identified as the key controllable management practice on farm (Claffey *et al.*, 2019). Over the last 10 yr (2008–2017), the 6-wk calving rate on Irish dairy farms has increased from 61% to 72%, while the mean calving date has reduced by 8 d (Dillon *et al.*, 2018). The proportion of cows calving between January and April has increased from 74% in 2008 to 84% in 2018 (ICBF, 2018). This coupled with an increase in average herd size from 48 cows in 2005 to 76 cows in 2016 (Kelly *et al.*, 2020), and an increase in the whole farm stocking rate from 1.7 to 1.9 LU/ha (Hanrahan *et al.*, 2018) has resulted in an increase in dairy cow feed demand on Irish farms in spring. This increased demand must be met through increased grass growth and utilisation if farms are to remain economically sustainable (Dillon *et al.*, 2005). Current autumn grazing recommendations in Ireland are that the farm begins closing in early October; 60% of the farm is closed from grazing by 1 November, with a closing average farm cover (AFC; amount of grass available on farm) of between 650 and 750 kg DM/ha (3.5 cm above ground level) on 1 December and an opening average farm cover in spring of approximately 1,000 kg DM/ha (Teagasc, 2019; Claffey *et al.*, 2020). One option to increase spring grass availability is to close swards early in autumn and thereby carry a greater quantity of grass over winter into spring (Hennessy *et al.*, 2006).

Previous research in the area of autumn CD has been carried out in plot studies (Carton *et al.*, 1988; Hennessy *et al.*, 2006; Lawrence *et al.*, 2017), within grazing studies (Roche *et al.*, 1996; Ryan *et al.*, 2010) or on commercial farms (O'Donovan *et al.*, 2002). However, much of this work was prior to the rapid expansion within the Irish dairy industry (Kelly *et al.*, 2020). Grazing management practices have not evolved to meet increased herd demand in spring in line with increased stocking densities and earlier and more compact calving. Earlier autumn closing has been recommended as a strategy to help meet the herbage demand in spring (Claffey *et al.*, 2019). Some of the previous studies that investigated autumn CDs over multiple years (Hennessy *et al.*, 2006; Lawrence *et al.*, 2017) had very early autumn closing (10 August–10 October), and the grazing dates did not represent that of a dairy farm in spring (20 November–20 February; Hennessy *et al.*, 2006). Closing swards over a period in autumn followed by spring defoliation is more representative of grazing management practices on farm. Additionally, little research has taken place on the impact of autumn CD on the regrowth of swards in spring following initial defoliation. There is still potential to improve both autumn and spring grazing management recommendations through a multiple-year study that is representative of on-farm autumn CDs and spring grazing requirements.

The objective of this experiment was to investigate the effect of closing paddocks between late September and early December on over-winter herbage production, herbage quality, leaf, stem and dead proportions, tiller density in spring and the subsequent effects on herbage production.

Materials and methods

The experiment was conducted at the Teagasc, Animal and Grassland Research and Innovation Centre, Moorepark, Fermoy, Co. Cork, Ireland (Latitude 50°07′N, Longitude 08°16′W) from August 2016 to April 2019. The paddocks were approximately 40 m above sea level with a south-facing aspect. The soil type was a free-draining acid brown earth of sandy to loam texture (Teagasc, 2017). Swards were predominantly PRG (>85%) plus <15% broadleaf plants and weed grass including, white clover (*Trifolium repens* L.) and annual meadow grass (*Poa annua* L.). Soils had a pH of 6.8 (±0.2), phosphorus (P) index of 3.8 (±0.4) and potassium (K) index of 3.3 (±0.8; scale 1 to 4; 1 = deficient, 4 = no response to application of nutrient; Alexander *et al.*, 2008). This study was undertaken within a larger grazing experiment (Claffey *et al.*, 2019, 2020), where the rotation length of the grazing treatments dictated the CDs and initial spring grazing date. Briefly, the larger farm systems study had three autumn closing management treatments: Early (25 September–9 November), Normal (10 October–24 November) and Late (25 October–9 December). A total of 30.6 ha were randomised into three farmlets, with each farmlet split into paddocks and grazed by equal groups of 30 lactating dairy cows, and based on autumn closing treatment. The target post-grazing sward height in autumn and spring were 3.5 cm. The actual post-grazing sward height achieved was 4 ± 0.05 cm in autumn and 3.6 ± 0.06 cm in spring. All animals were turned out in spring on 5 February (± 2 d) regardless of autumn closing treatment. Across all farmlets in spring the daily area allocated to the each grazing group was similar across the first rotation, concentrate supplementation in spring was similar for each grazing group

(3 kg DM/cow per d) and silage was only supplemented to individual groups if the post-grazing sward height went below 3.5 cm (Claffey *et al.*, 2019). For the remainder of the year (second rotation to July, rotation length was gradually extended in late July to allow autumn closing managements to be implemented) all swards were grazed in a 21-d rotational grazing system to a target post-grazing sward height of 4 cm in line with Teagasc recommendations (Teagasc, 2011).

From the farmlet study, 36 paddocks were chosen in year 1 (2016–2017), 48 in year 2 (2017–2018) and 48 in year 3 (2018–2019). The last defoliation of paddocks (swards hereafter) for the season was between 25 September and 9 December. Swards were assigned to each of the five CD treatments; the number of swards assigned to each treatment is shown in Table 1. Sward numbers differed for each CD in each year as the overall farm systems experiment dictated grazing dates; the grazing dates of the individual paddocks then fell independently into the allocated CD treatments (Table 1). The mean CD of each of the treatments was 4 October (CD1), 19 October (CD2), 3 November (CD3), 18 November (CD4) and 3 December (CD5). Following the final grazing, swards remained un-defoliated until the following spring. Herbage mass >3.5 cm was measured on three measurement dates (MD) over winter (Table 1) – MD1 (12 December; average), MD2 (9 January) and MD3 (2 February). Initial spring grazing took place independently of CD over an 8-wk period from 11 February to 8 April. Spring grazing (MD4) followed the current Teagasc recommendations (Teagasc, 2020) to reflect what happens on farm. Grazing in MD5 followed sequentially from grazing in MD4. Immediately prior to the first grazing in spring herbage mass was measured (MD4) on each individual sward. Final herbage measurement on each sward was taken immediately prior to second defoliation in spring (second rotation; MD5). Nitrogen fertiliser was applied in the form of urea at a rate of 53.6 kg N/ha between January and mid-March and at a rate of 26.4 kg N/ha in mid-April. In mid-April, phosphorus (9.6 kg P/ha) and potassium (19.2 kg K/ha) were applied.

Table 1: Closing date treatments (CD; CD1 [27 Sept–11 Oct], CD2 [12 Oct–26 Oct], CD3 [27 Oct–10 Nov], CD4 [11 Nov–25 Nov] and CD5 [26 Nov–9 Dec]) applied in autumn, the number of paddocks allocated per treatment, and measurement dates (MD; MD1 [12 Dec], MD2 [9 Jan], MD3 [2 Feb], MD4 [first defoliation] and MD5 [second defoliation]) over the experimental period

Treatment[1]	Mean CD[2]	2-wk interval	No. of days closed[3]
CD1	4 Oct	25 Sept–11 Oct	121
CD2	19 Oct	12 Oct–26 Oct	106
CD3	3 Nov	27 Oct–10 Nov	91
CD4	18 Nov	11 Nov–25 Nov	76
CD5	3 Dec	26 Nov–9 Dec	61
	No. of paddocks per CD		
	Year 1	**Year 2**	**Year 3**
CD1	8	9	10
CD2	5	13	12
CD3	16	15	12
CD4	7	5	12
CD5	0	6	2
	Measurement date		
MD1[4]	12 Dec		
MD2	9 Jan		
MD3	2 Feb		
MD4	First defoliation (6 Feb–5 April)		
MD5	Second defoliation (6–30 April)		
	Measurement period		
MP1	Paddock closing–12 Dec		
MP2	13 Dec–9 Jan		
MP3	10 Jan–2 Feb		
MP4	3 Feb–first defoliation		
MP5	First defoliation–second defoliation		

[1]Treatment is the autumn closing date applied to swards: CD1 = closing date 1, CD2 = closing date 2, CD3 = closing date 3, CD4 = closing date 4 and CD5 = closing date 5.
[2]Mean date for each 2-wk interval per treatment.
[3]Number of days closed for each closing date between the mean CD and measurement date 3 (2 February).
[4]Measurement dates on swards: MD1 = measurement date 1 = 12 Dec, MD2= measurement date 2 = 9 Jan, MD3 = measurement date 3 = 2 Feb, MD4 = measurement date 4 = first defoliation in spring, MD5 = measurement date 5 = second defoliation in spring.

Measurements

Meteorological data

Meteorological data were recorded at the experimental site for the duration of the experiment. Average daily air temperature (°C), soil temperature to a depth of 100 mm (°C), total daily rainfall (mm) and average solar radiation are shown for the measurement periods in each experimental year (Table 2).

Herbage mass

Herbage mass (>3.5 cm; targeted residual) was determined by cutting two strips 1.2 m wide by a known length (approximately 10 m) in the swards using an Etesia mower (Etesia UK Ltd., Warwick, UK). The mown herbage from each strip was collected and weighed. A sample of approximately 300 g was collected from each cut strip. A sub-sample of 100 g was weighed and dried for 16 h at 90°C to determine dry matter (DM) content. Compressed sward height was recorded pre- and post-cutting on each cut strip by taking

Table 2: Average daily air temperature, mean soil temperature, total rainfall and average solar radiation between September and April for year 1 (2016/2017), year 2 (2017/2018) and year 3 (2018/2019) and the 10-yr average (2006–2016) at the experimental site

	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	Mean
Average daily air temp (°C)									
Year 1 – 2016/2017	13.9	10.6	5.2	6.7	6.3	6.6	8.3	8.7	8.3
Year 2 – 2017/2018	12.9	11.5	7.2	6.3	6.3	4.0	4.7	9.0	7.7
Year 3 – 2018/2019	12.4	9.9	8.1	8.5	6.5	7.7	7.5	9.1	8.7
10-yr average	13.3	10.9	7.6	5.7	5.4	5.5	6.4	8.7	7.9
Mean soil temp to a depth of 100 mm (°C)									
Year 1 – 2016/2017	15.0	11.0	5.7	6.2	5.8	6.6	8.4	10.9	8.7
Year 2 – 2017/2018	14.7	12.3	8.1	5.6	5.5	4.0	5.4	10.0	8.2
Year 3 – 2018/2019	14.6	10.8	7.8	8.0	6.8	7.3	8.3	10.6	9.3
10-yr average	15.0	11.9	7.9	5.4	5.0	5.4	6.9	10.2	8.5
Total rainfall (mm)									
Year 1 – 2016/2017	98.6	27.9	44.5	84.7	85.3	108.4	115.8	35.6	75.1
Year 2 – 2017/2018	115.7	102.2	65.5	110.4	138.4	40.4	88.5	174.8	104.5
Year 3 – 2018/2019	60.0	72.4	167.1	168.2	65.9	56.7	117.9	108.9	102.1
10-yr average	67.5	105.5	116.8	113.2	122.5	82.6	68.7	58.8	92.0
Average solar radiation (MJ/m^2)									
Year 1 – 2016/2017	895	623	375	169	262	445	821	1,108	587
Year 2 – 2017/2018	1,026	477	335	189	264	552	770	1,080	587
Year 3 – 2018/2019	1,074	691	267	176	247	484	937	1,316	649
8-yr average[1]	964	560	320	192	249	408	825	1,314	604

[1]Data presented from 2008 to 2016.

10 measurements per strip using a rising plate meter (Jenquip Rising Plate Pasture Meter, Feilding, New Zealand). This was used to calculate the sward density (cut herbage mass [kg DM/ha]/[pre-cutting height – post-cutting height]). Herbage mass was then corrected for post-grazing sward height using the following equation (Delaby *et al.*, 1998):

$$\text{Corrected Herbage mass } (>3.5 \text{ cm}) = (\text{pre cutting compressed sward height} - \text{targeted residual } (3.5 \text{ cm})) \times \text{sward density}$$

Grass growth rate was calculated by dividing the corrected herbage mass by the number of days closed.

Herbage quality analysis

Selected herbage samples were taken at random from each sward, prior to spring grazing and in the second rotation. The method used was designed to select herbage representative of what cows would consume from the sward based on observation of the previous days grazing. The method used was that described by Ganche *et al.* (2013); samples were taken using handheld Gardena shears (Accu 90, Gardena International GmbH, Ulm, Germany) cut to grazing height and stored at −18°C. The frozen herbage was bowl-chopped (Muller, Type MKT 204 Special, Saabrücken, Germany), freeze-dried at −50°C for 120 h and milled through a 1-mm screen using a Cyclotech 1093 Sample Mill (Foss, DK-3400 Hillerød, Denmark). The chemical composition was analysed by wet chemistry for organic matter digestibility (OMD; g/kg), crude protein (CP; g/kg DM), neutral detergent fibre (NDF), acid detergent fibre (ADF) and ash (AOAC, 1995; method 942.05) concentrations. The OMD was estimated using the *in vitro* neutral detergent cellulase method as described by Morgan *et al.* (1989) (FibertecTM Systems; Foss, Ballymount, Dublin). Crude protein concentration was determined using an N analyser (Leco FP-428; Leco Australia Pty Ltd, Baulkham Hills B.C. NSW, Australia) based on the AOAC method 990-03 (AOAC, 1990). The NDF and ADF concentrations were determined using a fibre analyser (AOAC, 1995, method 973.18; Ankom Technology, Macedon, NY, USA) based on the method described by Van Soest *et al.* (1991). Amylase and a sodium sulphate solution were used in the NDF concentration determination process. Ash concentration was estimated by burning a sub-sample in a muffle furnace at 500°C for 12 h.

Tiller density

Five turves (0.1 m × 0.1 m) were cut to a depth of 0.05 m and removed from each sward twice during per year (December and February). Turves were removed along a "W" shape across the paddock at approximately 25 m intervals to take into account the heterogeneity of the swards (Jewiss, 1993). The grass tillers in each turve were separated into PRG and other grass species (mainly meadow grass, *P. annua* L.) and counted. From these turves, an overall average tiller density per m^2 was calculated.

Perennial ryegrass leaf, stem and dead proportion

Perennial ryegrass leaf, stem and dead proportions >3.5 cm were measured in each sward prior to grazing in spring (MD4) as described by McCarthy *et al.* (2013). Briefly, at eight randomly chosen locations within each sward, PRG tillers were cut to ground level and the vertical structure was maintained, a sub-sample of 40 g was selected and the lower horizon (<3.5 cm) was then removed. The remaining herbage (>3.5 cm) was divided into leaf, stem and dead components. The fresh weight of each component was recorded before drying at 90°C for 16 h to determine the DM proportions (>3.5 cm) of the leaf, stem and dead material. From the DM proportions the masses of green leaf, stem and dead in the overall herbage mass harvested were calculated.

Statistical analysis

Statistical analysis was carried out using SAS 9.4 (SAS Institute Inc., Cary, NC, USA). The effect of CD on herbage mass, growth rate, tiller density, green leaf mass, stem mass, dead leaf mass, OMD, CP, NDF, ADF and ash were determined using the PROC MIXED procedure with CD, MD and year included in the model. Measurement date was the repeated measure and sward was the experimental unit. Data are presented as least square means ± standard error. Variables were analysed using the following model:

$$\begin{aligned} Y_{jkl} = \mu &+ \text{closing date}_j + \text{measurement date}_k \\ &+ \text{year}_l\ (\text{closing date}_j \times \text{measurement date}_k \\ &\times \text{year}_l) + (\text{closing date}_j \times \text{measurement date}_k) \\ &+ (\text{year}_l \times \text{closing date}_j) + (\text{closing date}_j \\ &\times \text{measurement date}_k) \times e_{jkl} \end{aligned}$$

where:

μ = mean value for the variable

e_{jkl} = residual error term

Y_{jkl} = herbage mass (kg DM/ha), growth rate (kg DM/ha per day), tiller density (m^2), green leaf mass (kg DM/ha), stem leaf mass (kg DM/ha), dead leaf mass (kg DM/ha), OMD (g/kg DM), CP (g/kg DM), NDF (g/kg DM), ADF (g/kg DM) and ash (g/kg DM) with sward as the experimental unit.

Results

Weather data collected during the experimental period (September to April) are summarised in Table 2. In year 3 the daily air and soil temperature at 100 mm were greatest (8.7 and 9.3°C, respectively) compared to year 1 (8.3 and 8.7°C, respectively) and year 2 (7.7 and 8.2°C, respectively). Monthly rainfall was similar in years 2 and 3 (104.5 and 102.1 mm, respectively) and was lower in year 1 (75.1 mm). Monthly solar radiation was the same in years 1 and 2 (587 MJ m^2) and was greater in year 3 (649 MJ m^2).

Grass growth rate

Growth rates over winter were significantly ($P < 0.001$) affected by the interaction between CD and MD (Table 3). On MD2, CD3 and CD4 had a lower growth rate than CD5 and CD1, with CD2 intermediate (Table 3). On MD5, CD5 had a greater growth rate compared to CD2 with CD1, and CD3 and CD4 were intermediate to both (Table 3). Growth rates were significantly ($P < 0.001$) affected by the interaction between MD and year (Table 4). In year 3, MD2 (9.6 ± 0.56 kg DM/ha per day) had a greater growth rate than in year 1 and year 2 (5.6 ± 0.64 kg DM/ha per day, average). In year 3, MD4 (4.4 ± 1.11 kg DM/ha per day) had a lower growth rate than in year 1 and year 2 (12.2 ± 1.35 kg DM/ha per day). Closing date and MD significantly ($P < 0.001$) affected the average growth rate (Table 3). Average growth rate varied significantly ($P < 0.001$) by year, with the greatest growth rate in year 1 (28.0 ± 1.65 kg DM/ha per day), the lowest in year 2 (24.9 ± 1.49 kg DM/ha per day) and year 3 (26.9 ± 1.89 kg DM/ha per day) was intermediate.

Herbage mass

There was a significant effect ($P < 0.001$) of the MD × year interaction on herbage mass (Table 4). Herbage mass on MD2 was lower in year 2 (432 ± 55.8 kg DM/ha) compared to year 3 (710 ± 56.2 kg DM/ha). In year 2 MD3 had a lower herbage mass (611 ± 59.8 kg DM/ha) compared to year 3 (836 ± 58.6 kg DM/ha). There was a significant effect ($P < 0.001$) of CD on spring grass availability; each 1-d delay in closing from 25 September resulted in a reduction of 16 kg DM/ha in herbage mass (Figure 1) on 6 February. Measurement date had a significant effect ($P < 0.001$) on herbage mass. Average herbage mass across all treatments was the greatest on MD5 (1,652 ± 77.5 kg DM/ha), followed by MD4 (981 ± 45.9 kg DM/ha) and MD3 (713 ± 37.1 kg DM/ha) with

Table 3: The effect of five autumn closing dates (CD), CD1 (27 Sept–11 Oct), CD2 (12 Oct–26 Oct), CD3 (27 Oct–10 Nov), CD4 (11 Nov–25 Nov) and CD5 (26 Nov–9 Dec), on the over winter growth rate (kg DM/d) and herbage mass (kg DM/ha) in winter over five consecutive measurement dates, MD1 (12 Dec), MD2 (9 Jan), MD3 (2 Feb), MD4 (first defoliation in spring) and MD5 (second defoliation in spring) over 3 yr (year 1 [2016/2017], year 2 [2017/2018] and year 3 [2018/2019])

	CD1[1]	CD2	CD3	CD4	CD5	S.E.	*P*-value		
							CD	MD	CD × MD
Growth rate (kg DM/ha per day)									
MD1[2]	14.9	12.0	10.2	13.9	–[3]	2.38	***	***	***
MD2	10.5	8.0	5.5	6.2	12.3				
MD3	12.3	9.4	9.7	8.6	8.5				
MD4	12.8	12.9	12.2	8.3	9.3				
MD5	39.9	32.6	38.8	35.8	49.4				
Herbage mass (kg DM/ha)									
MD1	1,056	604	372	292	262	93.1	***	***	
MD2	1,003	646	368	321	433				
MD3	1,210	794	504	468	413				
MD4	1,544	1,058	809	626	779				
MD5	1,823	1,545	1,693	1,429	1,501				

[1]Autumn closing date applied to swards: CD1 = 27 Sept–11 Oct, CD2 = 12 Oct–26 Oct, CD3 = 27 Oct–10 Nov, CD4 = 11 Nov–25 Nov and CD5 = 26 Nov–9 Dec.
[2]Measurement dates on swards: MD1 = measurement date 1 = 12 Dec, MD2= measurement date 2 = 9 Jan, MD3 = measurement date 3 = 2 Feb, MD4 = measurement date 4 = first defoliation in spring, MD5 = measurement date 5 = second defoliation in spring.
[3]CD5 on MD1 is excluded due to a short closed period (9 d).

Table 4: The effect of the interaction of year (year 1 [2016/2017], year 2 [2017/2018] and year 3 [2018/2019]) and measurement date (MD1 [12 Dec], MD2 [9 Jan], MD3 [2 Feb], MD4 [first defoliation in spring] and MD5 [second defoliation in spring]) on growth rate (kg DM/ha per day) and herbage mass (kg DM/ha)

	Year 1	Year 2	Year 3		*P*-value		
Growth rate (kg DM/ha per day)				S.E.	MD	Year	MD × yr
MD1[1]	–[2]	14.3	15.4	3.40	**	**	***
MD2	5.6	6.4	9.6				
MD3	16.2	8.2	7.2				
MD4	13.4	13.1	7.4				
MD5	46.5	37.9	31				
Herbage mass (kg DM/ha)							
MD1	–	485	572	123.0	**	**	***
MD2	426	480	710				
MD3	716	574	836				
MD4	1,329	864	836				
MD5	1,412	1,729	1,768				

[1]Measurement dates on swards: MD1 = measurement date 1 = 12 Dec, MD2= measurement date 2 = 9 Jan, MD3 = measurement date 3 = 2 Feb, MD4 = measurement date 4 = first defoliation in spring, MD5 = measurement date 5 = second defoliation in spring.
[2]In year 1, MD1 excluded due to a low number of recordings.

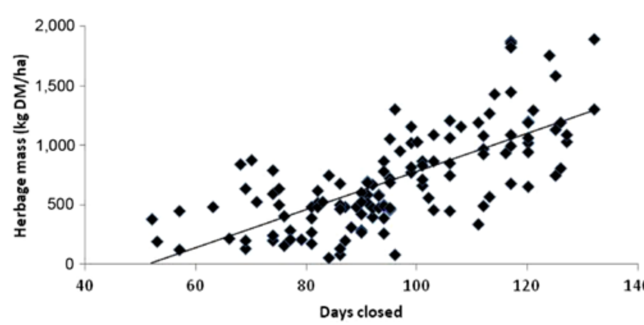

Figure 1. The relationship between the number of days a paddock was un-defoliated over winter, averaged over 3 yr (2016–2019) and the herbage available in MD3 (2 February). The relationship is described by the equation y = 16.11 × –826.33. R2 = 0.50.

the lowest herbage mass on MD1 and MD2 (average 547 ± 36.8 kg DM/ha). Herbage mass was significantly ($P < 0.001$) affected by year being lower in year 2 (837 ± 51.0 kg DM/ha) than years 1 and 3 (average, 956 ± 46.6 kg DM/ha).

Herbage quality

The effect of CD, year and the CD × year interaction on the OMD, CP, Ash, ADF and NDF on MD4 and MD5 are reported in Table 5.

Table 5: The effect of five autumn closing dates (CD; CD1 [27 Sept–11 Oct], CD2 [12 Oct–26 Oct], CD3 [27 Oct–10 Nov], CD4 [11 Nov–25 Nov] and CD5 [26 Nov–9 Dec]) on sward quality including organic matter digestibility (OMD g/kg DM), crude protein (CP g/kg DM), ash, acid detergent fibre (ADF g/kg DM) and neutral detergent fibre (NDF; g/kg DM) on measurement date (MD) 4 (first defoliation in spring) and MD5 (second defoliation in spring) over 3 yr (year 1 [2016/2017], year 2 [2017/2018] and year 3 [2018/2019])

		Closing date						*P*-value		
MD[1]	**Var**[2]	**CD1**[3]	**CD2**	**CD3**	**CD4**	**CD5**	**S.E.**	**CD**	**Year**	**CD × yr**
4	OMD[4]	825	826	844	843	852	6.3	***		*
	CP[5]	244	222	250	277	253	1.6	***	*	***
	Ash[6]	86	83	84	84	83	4.2		***	
	ADF[7]	277	211	217	219	245	6.1	*	***	
	NDF[8]	398	398	375	381	399	6.1	*	**	
5	OMD	856	860	858	860	864	3.9			
	CP	245	231	242	230	250	6.7			
	Ash	89	87	87	86	90	2. 1		***	
	ADF	228	226	229	218	255	6.6		***	
	NDF	407	404	397	398	412	9.6		***	

[1]Measurement dates on swards: MD1 = measurement date 1 = 12 Dec, MD2= measurement date 2 = 9 Jan, MD3 = measurement date 3 = 2 Feb, MD4 = measurement date 4 = first defoliation in spring, MD5 = measurement date 5 = second defoliation in spring.
[2]Variables measured for quality analysis.
[3]Autumn closing date applied to swards: CD1 = 27 Sept–11 Oct, CD2 = 12 Oct–26 Oct, CD3 = 27 Oct–10 Nov, CD4 = 11 Nov–25 Nov and CD5 = 26 Nov–9 Dec.
[4]OMD = organic matter digestibility (g/kg DM).
[5]CP = crude protein (g/kg DM).
[6]Ash (g/kg DM).
[7]ADF = acid detergent fibre (g/kg DM).
[8]NDF = neutral detergent fibre (g/kg DM).

Measurement Period 4

Organic matter digestibility was significantly ($P < 0.001$) affected by CD; CD1 and CD2 had a lower OMD than CD5. The CD × year interaction significantly affected ($P < 0.05$) OMD; in year 2 CD1 and CD2 (average, 821 ± 7.5 g/kg DM) were lower compared to CD5 (874 ± 13.1 g/kg DM), and all other CDs were intermediate (840 ± 8.1 g/kg DM). Organic matter digestibility was significantly ($P < 0.05$) affected by CD and was lower on CD2 compared to CD5 (Table 5). Year had no effect on OMD.

There was a significant effect ($P < 0.001$) of CD × year on CP concentration; in year 3 CD3 (188 ± 9.3 g/kg DM) had lower CP concentration compared to CD4 and CD5 (258 ± 11.9 g/kg DM). Closing date had a significant effect ($P < 0.001$) on CP; CD2 had a lower CP compared to CD1, CD3 and CD4 (Table 5). CP was significantly affected ($P < 0.05$) by year. Year 1 (258 ± 5.4 g/kg DM) had a greater CP than year 2 and year 3 (240 ± 5.4 g/kg DM).

There was no significant effect of CD or MD on ash content. Ash content was significantly ($P < 0.001$) greater in year 3 (88 ± 1.3 g/kg DM) compared to year 2 (78 ± 1.5 g/kg DM).

There was no MD effect on ADF. Acid detergent fibre was significantly ($P < 0.05$) affected by CD. Acid detergent fibre was lower on CD2 (214 ± 5.0 g/kg DM) compared to CD5 (242 ± 9.2 g/kg DM), and CD1, CD3 and CD4 (230 ± 5.9 g/kg DM) being intermediate. Year also had an effect ($P < 0.001$) on ADF, which was lower in year 2 (216 ± 0.5 g/kg DM) than year 3 (242 ± 3.8 g/kg DM).

Neutral detergent fibre was significantly ($P < 0.05$) affected by CD; CD3 (376 ± 8.5 g/kg DM) was lower than CD1, CD2 and CD5 (401 ± 8.5 g/kg DM) and CD4 (382 ± 8.5 g/kg DM) was intermediate. Year significantly ($P < 0.01$) affected NDF; NDF was greater in year 3 (402 ± 4.8 g/kg DM) than year 1 and year 2 (380 ± 4.8 g/kg DM).

Measurement Period 5

Organic matter digestibility and CP were not affected by CD or year; there was no effect of CD on ash content. Ash content was significantly ($P < 0.001$) lower in year 2 (86 ± 1.7 g/kg DM) compared to year 3 (93 ± 1.74 g/kg DM). Acid detergent fibre and NDF contents were not affected by CD but were significantly ($P < 0.001$) affected by year. Both ADF and NDF were greater in year 2 (ADF − 257 ± 5.6 g/kg DM, NDF − 443 ± 8.3 g/kg DM) compared to year 3 (ADF − 214 ± 6.9 g/kg DM, NDF − 398 ± 10.2 g/kg DM).

Tiller density

There was a significant effect ($P < 0.01$) of CD on PRG tiller density. Closing date 1 had a lower tiller density compared to

CD3 and CD4, and CD2 and CD5 was intermediate to both (Figure 2). Tiller density was significantly (P < 0.001) greater in year 3 (4,039 ± 126.1 tiller/m^2) than years 1 and 2 (average, 2,420 ± 153.6 tiller/m^2). Tiller density was greater (P < 0.001) in spring (+629 plants per m^2) than in autumn. There was no effect of CD on weed grass tiller density. Weed grass tiller density was significantly (P < 0.001) lower in year 1 (1,174 ± 190.3 tiller/m^2) compared to year 2 and year 3 (average 2,173 ± 175.1 tiller/m^2).

Leaf, stem and dead proportion

The proportion of green leaf, stem and dead in the sward was significantly (P < 0.001) affected by CD (Table 6); the green leaf proportion was lowest on CD1 and CD2. Stem and dead proportion were greatest on CD1. Stem proportion in the sward was significantly (P < 0.001) higher in year 1 (0.15 ± 0.011) compared to year 2 (0.11 ± 0.009), and year 3 (0.14 ± 0.010) was intermediate to both.

Leaf, stem and dead mass

Closing date had a significant (P < 0.001) effect on the green leaf mass available (>3.5 cm); CD1 had greater green leaf mass (1,329 ± 72.5 kg DM/ha) compared to CD2 (933 ± 72.7 kg DM/ha), and both were greater than CD3, CD4 and CD5 (727 ± 85.9 kg DM/ha; Figure 3). Year 2 had a significantly (P < 0.001) lower green leaf mass (624 ± 53.9 kg DM/ha) compared to year 1 and year 3 (939 ± 65.1 and 1,102 ± 59.9 kg DM/ha, respectively).

There was significantly (P < 0.001) greater stem mass on CD1 and CD2 (324 ± 23.2 and 288 ± 25.9 kg DM/ha, respectively) compared to CD3, CD4 and CD5 (105 ± 29.9 kg DM/ha). Stem mass was significantly (P < 0.001) greater in year 1 and year 3 (228 ± 23.6 kg DM/ha) compared to year 2 (102 ± 19.0 kg DM/ha).

Closing date had a significant effect on dead mass which was higher on CD1 (319 ± 25.9 kg DM/ha) than CD2, CD3, CD4

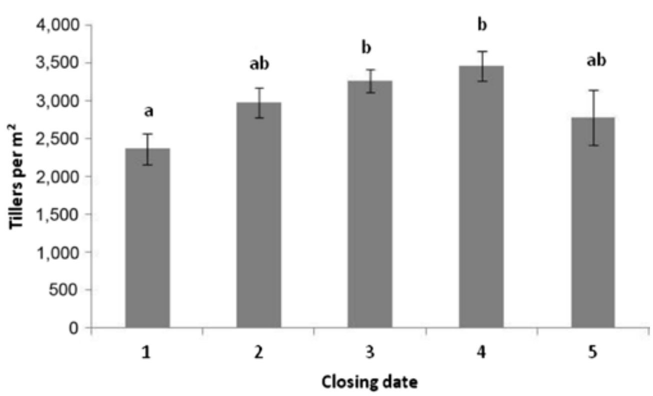

Figure 2. The effect of five autumn closing dates (CD; CD1 [27 Sept–11 Oct], CD2 [12 Oct–26 Oct], CD3 [27 Oct–10 Nov], CD4 [11 Nov–25 Nov] and CD5 [26 Nov–9 Dec]) on perennial ryegrass tiller density (tillers per m^2) in February over 3 yr (year 1 [2016/2017], year 2 [2017/2018] and year 3 [2018/2019]) of measurement. Error bars show the standard error of the mean.

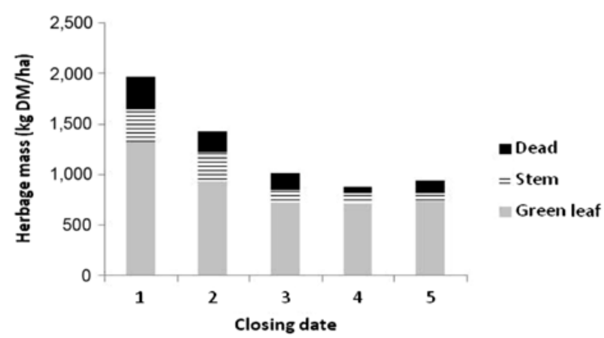

Figure 3. Herbage mass (kg DM/ha), separated into green leaf, stem and dead mass for each autumn closing date (CD; CD1 [27 Sept–11 Oct], CD2 [12 Oct–26 Oct], CD3 [27 Oct–10 Nov], CD4 [11 Nov–25 Nov] and CD5 [26 Nov–9 Dec]) on measurement date 4 [first defoliation in spring] over 3 yr (year 1 [2016/2017], year 2 [2017/2018] and year 3 [2018/2019]).

Table 6: The effect of five autumn closing dates (CD; CD1 [27 Sept–11 Oct], CD2 [12 Oct–26 Oct], CD3 [27 Oct–10 Nov], CD4 [11 Nov–25 Nov] and CD5 [26 Nov–9 Dec]) on the proportion of perennial ryegrass green leaf, stem and dead material on measurement date 4 (first defoliation in spring) over 3 yr (year 1 [2016/2017], year 2 [2017/2018] and year 3 [2018/2019])

Variable	CD1[1]	CD2	CD3	CD4	CD5	S.E.	*P*-value
Leaf proportion[2]	0.68^{a}	0.69^{a}	0.74^{ab}	0.80^{b}	0.80^{b}	0.020	***
Stem proportion[3]	0.16^{ab}	0.17^{a}	0.12^{ab}	0.11^{ab}	0.10^{b}	0.071	*
Dead proportion[4]	0.16^{a}	0.14^{ab}	0.14^{ab}	0.09^{c}	0.10^{bc}	0.015	*

[a,b,c]Within a row, means values with different superscripts differ significantly.
[1]Autumn closing date applied to swards: CD1 = 27 Sept–11 Oct, CD2 = 12 Oct–26 Oct, CD3 = 27 Oct–10 Nov, CD4 = 11 Nov–25 Nov and CD5 = 26 Nov–9 Dec.
[2]Proportion of leaf above 3.5 cm.
[3]Proportion of stem material above 3.5 cm.
[4]Proportion of dead material above 3.5 cm.

and CD5 (140 ± 29.2 kg DM/ha). Dead mass (>3.5 cm) was significantly ($P < 0.001$) lower in years 1 and 2 (153 ± 22.9 and 112 ± 21.1 kg DM/ha, respectively) than in year 3 (264 ± 21.1 kg DM/ha).

Discussion

For each extra day swards were closed from the end of September to the start of December (CD1 to CD5), an additional 16 kg DM/ha was available in spring. This is similar to O'Donovan *et al.* (2002) who reported 15 kg DM/ha, but greater than Lawrence *et al.* (2017) and Ryan *et al.* (2010) who reported 10 kg DM/ha and 12.4 kg DM/ha, respectively. However, lengthening the period of time a sward is closed for can result in an increase in dead and stem material (Lawrence *et al.*, 2017). In the current experiment each additional day closed from late September to early December increased dead mass by 2.5 kg DM/ha per day and stem mass by 2.5 kg DM/ha per day. As a result, only 11 kg DM/ha of the 16 kg DM/ha was green leaf mass. Swards closed in late September and in October (CD1 and CD2) had greater growth rates over winter (MD1 and MD2) than swards closed in late October and November (CD3 and CD4), similar to Ryan *et al.* (2010). In the subsequent spring grazing (second rotation; MD5), swards closed in late November and early December (CD5) had greater growth rates compared to swards closed in late September and October (CD1 and CD2) in the current study. A possible explanation for this is the reduction in tiller density on the earlier closed swards, which decreases the number of growing points (Garay, 1999) in the sward at the initiation of grass growth in spring which might lead to this reduction in growth rate. Although not measured in the current study, in high herbage masses it is also a possibility that there is old leaf or dead material left below the grazing horizon (<4 cm) (Lawrence *et al.*, 2017). This old leaf material is less photosynthetically efficient than new leaf material (Parmenter & Boswell, 1983). Another reason for reduced growth rates in spring for swards closed in late September and October could be lower water-soluble carbohydrate content in the residual (Looney *et al.*, 2019). Water-soluble carbohydrates are required for the supply of energy for growth and function post defoliation (White, 1973). The regrowth is mostly driven by water-soluble carbohydrate reserves at 4 cm above ground level (Donaghy & Fulkerson, 1998), and as such is a fundamental element in the regrowth of swards post defoliation. The increased growth rate in later-closed swards once defoliated in spring, in the current study, is contradictory to Lawrence *et al.* (2017) who reported no effect of CD on subsequent growth rates following initial spring defoliation. This may be a result of the defoliation method; Lawrence *et al.* (2017) mechanically harvested swards which may not accurately reflect the impact of animal grazing on herbage growth (Cashman *et al.*, 2016). Targeting high herbage masses, from swards closed in late September and October, for early defoliation may encourage more green herbage and a lower proportion of dead material in subsequent defoliations (Korte *et al.*, 1984) and counteract reduced growth rates in the subsequent defoliation. Early defoliation will also allow for a lengthier regrowth interval prior to the subsequent defoliation and allow utilisation of applied nitrogen (O'Donovan *et al.*, 2004).

In the current study there was a large year-to-year variation in over-winter growth rates and spring grass availability similar to that reported by Brereton *et al.* (1985), Carton *et al.* (1989) and Hennessy *et al.* (2006). Most likely, the year-to-year variation was a result of climatic conditions. Climatic conditions, particularly soil and air temperature, have the greatest influence on over-winter growth rates (Peacock, 1975). The range in growth rates led to a significant variation in pre-grazing herbage mass on the first spring defoliation (MD4) in the 3-yr study, similar to Hennessy *et al.* (2006). In year 2, there was a lower average pre-grazing herbage mass compared to year 1 and year 3 which can be attributed to the lower average soil and air temperature (−0.8°C). Although there was large year-to-year variation in the study, 50% ($R^2 = 0.5023$) of the variation in spring grass availability was associated with the number of days the sward was closed from grazing. The other 50% of pre-grazing herbage mass in spring was a result of uncontrollable factors such as meteorological conditions, that is, soil and air temperature, solar radiation and moisture. Controllable factors such as fertiliser application, PRG content in autumn and management were accounted for within the experimental design.

In the current study, a higher pre-grazing herbage mass in spring resulted in a reduction in PRG tiller density. Therefore, similar to Laidlaw *et al.* (2000), Hennessy *et al.* (2006) and Lawrence *et al.* (2017), the current study confirms the negative impact of early CD on tiller density. Restricted access to light due to higher herbage masses can cause tiller bud suppression (Hunt, 1978) which can result in the loss of daughter tillers (Korte, 1981). Low light interception at the base of the plant in high pre-grazing herbage mass swards inhibits the production of new tillers (Baker, 1956). Survival of mature tillers at the expense of smaller/younger ones (self-thinning) can occur due to these low light conditions (Laidlaw & Mayne, 2000). When there is a requirement for increased pre-grazing herbage mass in spring, swards closed in late September and October should be defoliated as early as possible in spring to allow light interception at the base of the plant (Brougham, 1960) to promote new tiller production (Kays & Harper, 1974; Laidlaw & Mayne, 2000). This might compensate for the reduction in tiller production over winter in earlier-closed swards. Earlier defoliation of swards in spring with high herbage masses can also result in an improvement in sward quality in subsequent rotations (Garry *et al.*, 2015).

Sward quality in spring is impacted by autumn closing management (Hennessy *et al.*, 2006; Lawrence *et al.*, 2017). A higher pre-grazing herbage mass in spring results in reduced herbage quality as a result of increased dead material (Binnie *et al.*, 2001) in swards closed in late September and October. However, even if OMD, CP and ADF are lower in swards closed in late September and October (CD1 and CD2), nutritional requirements for a dairy cow in early to peak lactation are still met (Kavanagh, 2016) from grazed grass. The quality of PRG in grazed paddocks (average OMD = 826 g/kg DM) closed in late September and early October (CD1 and CD2) reported in this study is still greater than the medium quality silage (DM digestibility [DMD] = 696 g/kg DM) reported by Kennedy *et al.* (2005). Increasing the proportion of grazed grass in the diet in the place of silage, regardless of autumn CD, will increase animal production (Kennedy *et al.*, 2005; Claffey *et al.*, 2019). In this study, after the initial spring grazing, no carryover effect of autumn CD was observed on sward quality in the subsequent spring defoliation (MD5), a result similar to Lawrence *et al.* (2017).

The current study reported that the proportion of green leaf was greater in swards closed in November and early December (CD4 and CD5; +0.12) compared to swards closed in late September and October (CD1 and CD2) similar to Lawrence *et al.* (2017) and Hennessy *et al.* (2006). Likewise, the proportion of dead material in the sward was greatest in swards closed in late September and October, similar to Davies and Simons (1979), Hennessy *et al.* (2006) and Ryan *et al.* (2010). Green leaf is of higher nutritional value than stem and dead material (Binnie *et al.*, 2001; Beecher *et al.*, 2015). Lawrence *et al.* (2017) reported a correlation of R^2 = 0.78 between green leaf proportion and DMD in autumn. In spring, the current study found a correlation of R^2 = 0.61 between green leaf proportion and OMD. The lower correlation reported in the current study could possibly be due to the higher quality of grass in spring compared to autumn (McDonald, 2002). Swards with a greater green leaf proportion have greater nutritional value but the proportion of green leaf does not reflect the quantity of herbage available. In the current study, although swards closed in November and early December had a greater green leaf proportion, swards closed in September and early October had a greater quantity of green leaf mass available in spring. Reporting the proportion and mass of green leaf, stem and dead should give a more accurate representation of the sward morphology available for grazing. Previous research (Beecher *et al.*, 2015) reported that the available OMD is greatest in the leaf compared to stem and dead material. They reported that OMD in February was greatest in the green leaf component (751 g/kg) compared to stem and dead material (658 and 541 g/kg, respectively). In terms of dry organic matter (kg DOM; OMD g/kg DM × kg DM/ha), in the current study there was 52% more available digestible material in earlier-closed swards (CD1; 1,273 kg DOM/ha) compared to later-closed swards (CD4; 664 kg DOM/ha). Although earlier closing of swards can result in an increase in stem and dead material and a reduction in overall sward quality, the available material to grazing animals (<3.5 cm) can have a greater green leaf mass, which, combined with an increase in consumed herbage quality, can increase animal performance. Available green leaf mass combined with DOM should be considered as a means to improving grazing management decisions on farm.

The results of this research have highlighted the success early autumn closing management has on increasing the herbage mass available to meet increased demand for spring grass in an intensive dairy production system. To meet increased feed demand in spring, farmers must adopt an earlier closing of paddocks in autumn. If implemented, this will be beneficial in terms of industry targets to increase production and utilisation of grazed grass, particularly in spring where a deficit has been identified. Successfully managing earlier-closed swards on farm should prioritise early defoliation in spring to help maintain quality and allow a longer regrowth interval to compensate for the lower spring regrowth potential of early closed swards. The year-to-year variation in over-winter growth rates must be considered in grassland management decisions on farm to ensure spring herbage targets are met. A move away from grazing targets based on date, as is currently recommended (Teagasc, 2011), to target pasture cover in autumn will result in a more consistent supply of grass in the following spring. Future research should investigate the impact of different spring defoliation dates on various herbage masses to determine grazing dates that maximise utilisation of swards and reduce carryover effects of autumn closing management into the second rotation.

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