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...
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 (Berereton 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 dates 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 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 (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.

**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

| Treatment | Mean CD | 2-wk interval | No. of days closed |
|-----------|---------|---------------|-------------------|
| 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                |

| Year     | 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**

| Year 1 | Year 2 | Year 3 |
|--------|--------|--------|
| MD1    | 12 Dec | 9 Jan  |
| MD2    | 2 Feb  |        |
| MD3    |        | 13 Dec–9 Jan |
| MD4    | First defoliation (6 Feb–5 April) |        |
| MD5    | Second defoliation (6–30 April) |        |

**Measurement period**

| Year 1 | Year 2 | Year 3 |
|--------|--------|--------|
| 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 |        |

1Treatment 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.
2Mean date for each 2-wk interval per treatment.
3Number of days closed for each closing date between the mean CD and measurement date 3 (2 February).
4Measurement 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.

(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
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):

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

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) (Fibertec™ Systems; Foss, Ballymount, Dublin). Crude protein concentration was determined using an N analyser (Leco FP-428; Leco Australia Pty Ltd, Baulkmah 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

| 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/m²) |
| 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 average¹ | 964 | 560 | 320 | 192 | 249 | 408 | 825 | 1,314 | 604 |

¹Data presented from 2008 to 2016.
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 x 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 m² 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 tillers were cut to ground level and the vertical structure 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. Variables were analysed using the following model:

\[ Y_{ijkl} = \mu + \text{closing date}_j + \text{measurement date}_k + \text{year}_r \times (\text{closing date}_j \times \text{measurement date}_k) + (\text{closing date}_j \times \text{measurement date}_k) \times (\text{year}_r \times \text{closing date}_j) + e_{ijkl} \]

where:
\( \mu \) = mean value for the variable
\( e_{ijkl} \) = residual error term

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 m²) and was greater in year 3 (649 MJ m²).

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 x 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
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.
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

### 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 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.

| Variable         | CD11 | CD2  | CD3  | CD4  | CD5  | S.E. | P-value |
|------------------|------|------|------|------|------|------|---------|
| Leaf proportion  | 0.68a| 0.69a| 0.74ab| 0.80a| 0.80a| 0.020| ***     |
| Stem proportion  | 0.16a| 0.17a| 0.12ab| 0.11ab| 0.10b| 0.071| *       |
| Dead proportion  | 0.16a| 0.14ab| 0.14ab| 0.09c| 0.10bc| 0.015| *       |

*a,b,c*Within a row, means values with different superscripts differ significantly.

1Autumn 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.

2Proportion of leaf area above 3.5 cm.

3Proportion of stem material above 3.5 cm.

4Proportion 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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