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ORIGINAL ARTICLE

Accumulating herbage during autumn to extend the grazing season in pasture-based dairy systems

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[Correction added on 22 September 2021, after first online publication: Some of the abbreviations have been corrected in this version of the article. In addition, some grammatical errors have also been corrected.]

Abstract

A longer grazing season can lower the costs of pasture-based dairy production. Accumulating herbage during autumn increases herbage mass available for grazing in late autumn and the following spring but results in higher pre-grazing herbage mass (PGHM). This could affect sward nutritive value and milk production. The effects of accumulating herbage during autumn on the length of the grazing season, nutritive value, milk production and the supply of herbage mass in the following spring (opening) were examined at systems scale in this study. The dataset was 60 grazing systems from systems comparisons conducted between 2001 and 2018 with spring-calving dairy herds (mean stocking rate 2.4 cows ha^{-1}) at Solohead Research Farm, Ireland. Herbage mass accumulated per system was measured as average herbage mass (AHM; herbage mass >4 cm; average of all paddocks). A higher PGHM (1,783 vs. 1,445 kg dry matter [DM] ha^{-1}, $p < 0.001$, standard error of the mean [*SEM*] 32.5) and peak AHM (highest AHM; 1,345 vs. 1,139 kg DM ha^{-1}, $p = 0.002$, *SEM* 39.2) during late summer and autumn (1 August to end of grazing season [closing]) did not affect herbage nutritive value or milk production ($p > 0.05$). Each increase in peak AHM of 100 kg DM ha^{-1} increased days at pasture per cow in late summer and autumn by 2.2 ± 0.44 ($p < 0.001$, partial $R^2 = 0.46$) and increased closing AHM by 46 ± 6.5 kg DM ha^{-1} ($p < 0.001$, partial $R^2 = 0.42$). Opening AHM in February increased with closing AHM ($p < 0.001$, $R^2 = 0.41$). Accumulating herbage during late summer and autumn facilitated a longer grazing season while not impacting on milk production.

KEYWORDS

autumn, extended grazing, grazing management, grazing season length, herbage accumulation, pasture-based milk production

1 | INTRODUCTION

Rates of herbage growth are highly seasonal in temperate latitudes (Hurtado-Uria et al., 2013). The period when herbage growth meets the demand by grazing dairy cows is limited. In Western Europe herbage deficits due to low growth rates typically occur in late autumn, winter and early spring (March). Hence, in Ireland, dairy cows are compactly calved in February, March and April and are typically dried off and housed during the winter. A long grazing season and a short period of winter housing are key elements of low cost pasture-based dairy production (Finneran et al., 2012; Hanrahan et al., 2018; Läpple et al., 2012).

At moderate stocking densities during August and early September herbage growth rates are sufficient to enable the accumulation of a surplus of herbage mass that can be transferred in situ to meet deficits later in the grazing season. This is typically achieved by ceasing to harvest surplus herbage mass for ensiling, strategic fertilizer input and increasing rotation interval (Hennessy et al., 2008; Laidlaw & Mayne, 2000; Macdonald & Penno, 1998). Accumulating herbage results in increasing average herbage mass (AHM; average herbage mass of all paddocks >4 cm above ground level [AGL]) at farm level. Whereas feed demand by the grazing herd remains more-or-less constant, at some date during the early autumn (typically mid-September in Ireland) growth rate falls below feed demand and, thus, AHM goes into decline. Peak AHM marks the transition between the accumulation and the decline of herbage mass available on the farm. Four timeframes were delineated in the present study: (a) herbage accumulation interval (typically starting 1 August until peak AHM), (b) interval when accumulated herbage was fed to cows (from peak AHM to the end of grazing), (c) the timeframe encompassing (a) and (b), which was denoted ‘late summer and autumn’; (d) the winter or ‘closed’ period when all cows were housed, generally encompassing December and January, which ended with turnout in February. Closing denotes the end of grazing and the beginning of the closed period. The beginning of grazing in the following February was denoted by opening in this study. Hence, the term ‘late summer and autumn’ is used to describe the later part of the grazing season and the later part of lactation in this study, which is somewhat similar to, but not the same as the autumn season which encompasses September, October and November in the Northern hemisphere (Figure 1c).

The magnitude of the peak in AHM is a useful indicator of autumn herbage mass availability. A higher peak AHM means that more herbage mass is available for the interval where accumulated herbage was fed to cows. On the other hand, storing herbage mass in situ involves the risk of (a) self-shading and net senescence particularly in the late autumn (Fulkerson & Donaghy, 2001; Lawrence et al., 2017), (b) poor utilization (Carton et al., 1988), (c) decline in nutritive value (Curran et al., 2010; Holmes et al., 1992) and (d) low ryegrass tiller density that can be carried over into the following spring (Hennessy et al., 2006). Hence, accumulating herbage could negatively impact on sward nutritive value and milk production during late summer and autumn. Delaying the end of the grazing season in autumn could lower the mass of herbage for grazing in the following spring and offset benefits gained by extending the grazing season in autumn.

The concept of accumulating herbage over the autumn period in a grazing system has rarely been described in the scientific literature and no recent studies have examined this question at dairy systems scale. The objective of this study was to examine the implications of

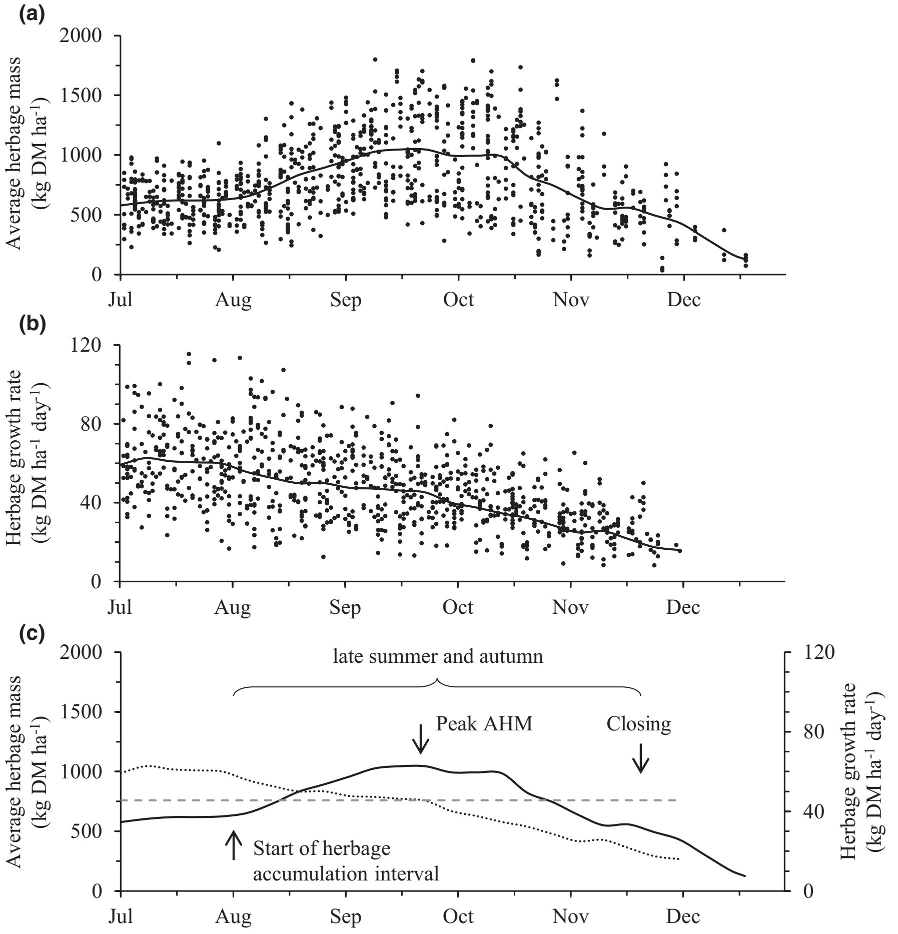

FIGURE 1 (a) Average herbage mass (kg DM ha^{-1}) and (b) daily herbage growth rate (kg DM ha^{-1} day^{-1}) for each grazing system during autumn (1 August to closing) between 2001 and 2018 (●) compared to weekly mean of 2001 to 2018 (——); (c) mean development of average herbage mass (——) and average herbage growth rate (••••••) during late summer and autumn compared to the daily herbage demand for 2.4 cows ha^{-1} (kg DM ha^{-1} day^{-1}, — —); closing date varied between systems (Table 2). DM, dry matter

accumulating herbage during late summer and autumn in terms of herbage production and nutritive value, milk production, the length of the grazing season and herbage mass at opening in the following spring.

2 | MATERIALS AND METHODS

2.1 | Dataset

A dataset was compiled for the purpose of this study from grazing system experiments conducted at Solohead Research Farm (52°30′N, 08°12′W, 95 m above sea level) in south-west Ireland between 2001 and 2018. They were all system studies examining grassland management practices with spring-calving pasture-based dairy herds over an entire grazing season. There were between three and five experimental systems each year resulting in a total of $n = 60$ systems within the 17 years (Table 1).

2.2 | Site description

Soils include poorly drained Gleys (90%) and Grey Brown Podzolics (10%) with a clay loam texture. Topographic relief causes variation in shallow groundwater with a water table depth ranging from 0 to 2.2 m below ground level. The local climate is humid temperate oceanic with a long potential growing season. The land was permanently under grassland with predominantly perennial ryegrass and white clover swards for well over 50 years before the beginning of this study with an average of approximately 5% of the grassland renovated each year during the experimental years.

2.3 | Experimental design

The design and the scale of the experiments were similar in all years. Assignment of cows to herds and paddocks to systems, grazing management and recording of days at pasture was as described

TABLE 1 Details of the 60 grazing systems included in the dataset

Study	Year of study	System name	n	Target PGH (cm)	Cows per system	Stocking rate (cows ha^{-1})	Mineral N^a (kg ha^{-1})	Reference
1	2001–2002	N205	2	6	18	1.75	178	Humphreys et al. (2008)
1	2001–2002	N230	2	6	18	2.10	189	Humphreys et al. (2008)
1	2001–2002	N300	2	6	18	2.50	251	Humphreys et al. (2008)
1	2001–2002	N400	2	6	18	2.50	353	Humphreys et al. (2008)
2	2003–2006	FN	4	6	22–24	2.0–2.2	238	Humphreys et al. (2009)
2	2003–2006	WC	4	6	22–24	2.0–2.2	202	Humphreys et al. (2009)
2	2003–2006	S0	4	6	22–24	2.0–2.2	220	Unpublished
3	2007–2009	6 cm	3	6	18–27	1.99–2.12	189	Phelan et al. (2013a)
3	2007–2009	5 cm	3	5	18–27	1.99–2.12	195	Phelan et al. (2013a)
3	2007–2009	4 cm	3	4	18–27	1.99–2.12	225	Phelan et al. (2013a)
4	2010	S1	1	4	24	2.0	205	Unpublished
4	2010	S2	1	4	24	2.2	205	Unpublished
4	2010	S3	1	4	24	2.2	205	Unpublished
4	2010	S4	1	4	24	2.4	205	Unpublished
5	2011–2012	HF-L	2	4	24	2.35–2.45	196	Tuohy et al. (2014)
5	2011–2012	HF-H	2	4	24	2.56–2.67	305	Tuohy et al. (2014)
5	2011–2012	JX-L	2	4	24	2.39–2.49	197	Tuohy et al. (2014)
5	2011–2012	JX-H	2	4	24	2.64–2.75	307	Tuohy et al. (2014)
6	2013–2015	FT70	3	4	24–25	2.25–2.67	280	Fenger et al. (2020)
6	2013–2015	RA60	3	4	24–25	2.25–2.67	280	Fenger et al. (2020)
6	2013–2015	RA50	3	4	24–25	2.25–2.67	280	Fenger et al. (2020)
7	2017–2018	LC	2	4	24	2.5	235	Unpublished
7/8	2017–2018	GP25	2	4	24	2.5	280	Fenger et al. (2021)
8	2017–2018	GP30	2	4	24	3.0	280	Fenger et al. (2021)
8	2017–2018	GP35	2	4	24	3.5	280	Fenger et al. (2021)
8	2017–2018	GP40	2	4	24	4.0	280	Fenger et al. (2021)

PGH, post-grazing sward height.

[a] Artificial fertilizer and in situ biological nitrogen fixation; not including N deposition from animals and manure application.

by Humphreys et al. (2008, 2009); Phelan et al. (2013a) and Tuohy et al. (2014). Each spring all cows were divided into four main groups on the basis of lactation number (1, 2, 3, and ≥4) and then sub-divided into sub-groups on the basis of calving date (mean 23 February, standard deviation [*SD*] 6.47 days); the number of subgroups being the same as the number of experimental systems in each year. From within each subgroup, one cow was randomly assigned to each herd. Herds were then randomly assigned to each experimental system. This procedure was repeated each spring. The experimental area was grassland used for grazing and production of silage (ensiled herbage) and the mean area per herd was 9.5 ha (range: 6–13.6 ha). At the beginning of each experiment the area was divided into six blocks according to soil type and drainage status and one paddock from each block was randomly assigned to a system and remained in that system until the end of the experiment. Mean paddock size was 1.67 ha (*SD* 0.4 ha).

2.4 | Management of the grazing systems

The management of the grazing systems generally followed a standard set of rules. Each herd was under rotational grazing management. Cows were turned out to graze approximately three days after calving and remained at pasture until they were dried off between mid-November and mid-December. During the main grazing season (from April to 1 August) in all of the systems in this study AHM was measured on a weekly basis and managed to consistently maintain a pre-grazing herbage mass (PGHM; >4 cm AGL) of 1,400 kg ha^{-1}; i.e., an AHM of 700 kg/ha. This was mostly achieved by harvesting surplus herbage mass silage production. Under exceptional circumstances during the main grazing season when herbage growth rates fell below herd demand, cows were supplemented with concentrates once PGHM was less than 1,000 kg ha^{-1}. The rate of supplementation depended on the extent of the herbage deficit. Silage was also fed if the cows had to be housed due to severe herbage deficit due to drought (e.g., 2006 and 2018) or due to excessively wet soil conditions i.e., a volumetric soil moisture content (VSMC m^3 m^{-3}) of between 0.6 and 0.7. The latter tended to be relatively short-term (2 or 3 days) during the main grazing season. Supplementation with concentrates to each herd during the main grazing season and during late summer and autumn was allocated at exactly the same rate within each year. Supplementation with silage was allowed to vary in line with the feed budget for each herd. Supplementation with concentrates and silage varied from year to year depending on weather conditions and their impact on herbage growth and ground conditions.

As a general rule no herbage was harvested for silage production after 1 August. AHM was allowed to increase from a target of 700 kg ha^{-1}, as outlined above, to a target peak of 1,200 kg ha^{-1} in mid-September. Exceptions were made when high herbage growth rates indicated that average herbage masses were going to greatly overshoot the target for mid-September and weather and ground conditions were suitable for harvesting surplus herbage mass for silage production. It happened occasionally that weather and ground conditions were not suitable for harvesting herbage mass for ensiling, particularly later in the season, and AHMs were allowed to overshoot the target, which explains some of the higher peak AHMs in this study. Although some surplus herbage mass was harvested for ensiling in some systems after 1 August, the areas harvested and the quantities of herbage removed from each system were kept to a minimum and were very small relative to the quantities harvested during the main grazing season.

Similar to the main grazing season cows were housed temporarily during late summer and autumn if ground conditions were deemed to be excessively wet. In studies 1 and 2 (Table 1) this decision was made by the farm manager based on experience. From 2007 onwards VSMC was measured using a soil probe (ML2x soil moisture measurement kit; Delta-T Devices Ltd.) and this information was used for decision support. A VSMC of >0.6 (studies 3, 4 and 5), >0.7 (study 6) and between 0.6 and 0.7 (studies 7 and 8; Table 1) was used as a guide for housing the cows between 2007 and 2018.

Closing date marked the end of the grazing season and was defined as the final day in autumn when all cows of each system were housed for the closed period and did not go out to pasture again until the following spring. The target in all studies was to maintain the cows at pasture until at least 1 December while hitting a target AHM of 500 kg ha^{-1} on 1 December. The latter condition was the reason that cows were rarely maintained at pasture until or after 1 December. When the AHM fell below the target of 500 kg ha^{-1} during November, cows were housed in order to allow the swards to grow up to the target. Hence, cows were housed prior to 1 December depending on the current AHM and the expected daily herbage growth rate (based on 10-year averages) between the closing date and 1 December. The other criteria governing the decision to close pastures for the winter were ground conditions as described above and drying off the cows at the end of lactation. In all studies, drying off of the younger and earlier-calving cows generally commenced in late November and was completed in the week before Christmas day (25 December). Hence, a range of closing dates and closing AHMs were recorded across systems.

2.5 | Measurements

2.5.1 | Meteorological data

Meteorological data were recorded at the weather station located on the research farm. Soil temperature was measured daily at a soil depth of 10 cm. Soil moisture deficit (SMD) was calculated for each day of the experimental period of each year using the model developed by Schulte et al. (2005) assuming a poorly drained soil. The number of days when SMD was 0 mm or above was recorded. This has been defined as a threshold for trafficability with bovine livestock (Herbin et al., 2011; Piwowarczyk et al., 2011). In the present study, a high number of days with SMD > 0 mm were used to indicate better soil trafficability and a low number to indicate poorer soil trafficability.

2.5.2 | Herbage production and nutritive value

Immediately before each grazing PGHM was determined on every paddock by harvesting a strip of herbage using (a) a lawnmower (HRH-536 rotary blade, Honda®) between 2001 and 2009 and (b) an Etesia Hydro 124DS, (Etesia UK Ltd.) between 2010 and 2018. All mown herbage from each strip was collected and weighed. A 100 g (fresh weight) subsample was taken and dried for 16 hr at 90°C for determination of dry-matter content, which then was used for determination of PGHM (kg DM ha^{-1}). A second 100-g sub-sample was freeze-dried and milled through a 0.2 mm sieve before analyses for ash content (550°C muffle furnace for 12 hr), crude protein (CP; N content; Leco 528 auto-analyser; Leco Corp.) and in vitro organic matter digestibility (OMD) as described by Morgan et al. (1989). Post-grazing sward height was determined immediately after each grazing using a Filips rising plate meter (Grasstec). Herbage growth rate was determined as the herbage mass grown between two harvests/grazings divided by the number of days in each interval; the rotation interval. Mean rotation interval per system was the mean rotation interval of all paddocks per system of each rotation during late summer and autumn. Mean PGHM and herbage growth rate for each system during late summer and autumn was determined likewise.

2.5.3 | Milk production

Cows were milked at 07.30 and 15.30 hr daily throughout lactation in all years of the study. Individual cow milk yield was recorded at each milking. The composition of milk from each cow was determined for a morning and for an evening milking once per week using a Milkoscan 203 (Foss Electric DK-3400). Mean daily milk yield per cow was the mean yield of all cows per system each day during late summer and autumn and likewise for other milk production variables including milk solids yield, which was the yield of milk fat plus protein per cow. The live weight of each cow was recorded once every two weeks using a weighing scales and the Winweigh software package (Tru-Test Limited). Body condition score (Edmonson et al., 1989; on a scale of 1 to 5) of each cow was recorded once every 2 weeks. The amount of concentrate fed per cow was recorded at each milking (Dairymaster; Causeway, Co. Kerry, Ireland).

2.5.4 | Grazing season length

The length of the grazing season was measured in terms of days at pasture per cow during late summer and autumn. A whole grazing day was defined as when all cows per system were out day and night and not supplemented with silage. One-half day was defined as when all cows were out only by day and supplemented with silage by night. In November and December, when some of the cows were dried off and housed, the proportion of lactating cows out grazing per system was taken into account and the average number of grazing days per cow adjusted accordingly.

2.5.5 | Accumulation of herbage during late summer and autumn and the availability of herbage for grazing in spring

The compressed sward height of each paddock per system was measured using a Filips rising plate meter once per week during each grazing season and on average once per month during the closed period. Compressed sward height was converted into herbage mass which was an estimate of herbage DM >4 cm AGL per paddock using the following formula:

Herbage mass (kg DM ha^{-1}) = (Compressed sward height (cm) − Target post-grazing height (cm)) * Sward density (kg DM cm^{-1} ha^{-1}).

A sward density of 240 kg DM cm^{-1} ha^{-1} was used throughout late summer and autumn of all years. AHM of each system on each measurement date was the sum of the herbage masses of all paddocks of the system divided by the total grazing area. Peak AHM was the highest AHM recorded per system during late summer and autumn in each year. Closing AHM was the AHM measured during the week of the last grazing before the closed period. Opening AHM was the AHM measured at the end of the closed period, that is, when calved cows were turned back out to pasture, which typically took place in early February of the following year. The rate of herbage mass accumulation (growth rate) during the closed period was determined by the difference between closing AHM and opening AHM divided by the number of days during the closed period. Some systems were missing data for either closing AHM (five systems) or opening AHM (four systems) as defined above and were therefore removed from the dataset for the corresponding analysis.

2.5.6 | Statistical analysis

The effect of accumulating herbage during late summer and autumn on herbage production, nutritive value and milk production were subjected to an analysis of variance (ANOVA) using the GLM procedure in SAS (SAS 9.4). For the ANOVA, the dataset was grouped into high and low mean PGHM during late summer and autumn. From within each of the 17 years the systems with the highest and lowest PGHMs were selected and assigned to each group resulting in $n = 34$ systems being compared. Year and PGHM system were fixed factors in the ANOVA to establish the effect of high versus low PGHM within any year.

The full dataset (n = 60 systems) was analysed for associations between milk production variables and peak AHM during late summer and autumn using the CORR procedure in SAS to evaluate associations across all grazing systems. The effect of accumulating herbage during late summer and autumn on the length of the grazing season and the supply of herbage mass in the following spring was analysed in the full dataset ($n = 60$ systems) using multiple regression analysis to identify all factors associated with each dependent variable. Dependent variables were days at pasture during late summer and autumn, closing date, closing AHM and opening AHM in the following spring. Independent variables tested were peak AHM, date of peak AHM, mean PGHM, mean post-grazing height, mean herbage growth rate, days at pasture per cow, stocking rate, amount of concentrate fed and soil trafficability (days with SMD >0 mm) during late summer and autumn, date of the last harvest of herbage mass for ensiling, closing AHM, closing date, mean soil temperature, SMD and herbage growth rate during the closed period. Year was not included as an independent variable in this analysis in order to capture across year effects. Before analysis of each model a test for multicollinearity between independent variables was conducted using PROC CORR and PROC REG in SAS producing Pearson's correlation coefficients (r) and variance inflation factors, respectively. Variables with $r > |0.8|$ or a variance inflation factor >10 were removed from the model. A best fit model was created for each dependent variable using the GLMSELECT procedure. Quadratic terms and interactions of second order between independent variables were considered in the model. A stepwise selection process was applied with a 5% significance level for inclusion and exclusion of variables into the model. Partial R^2 values shown refer to the part of the model R^2 explained by each additional variable in the model when all previous variables are controlled. Therefore, model variables are shown in the order of selection by the GLMSELECT procedure. Results are presented as mean ± standard error.

3 | RESULTS

3.1 | Descriptive statistics

Minimum and maximum values as well as standard deviations for independent and dependent variables demonstrate that a wide range of AHMs during late summer and autumn as well as at opening were encompassed by the dataset (Table 2). Mean AHM during late summer and autumn was 859 ± 33.9 kg DM ha^{-1}. As peak AHM was highly correlated with both mean AHM ($r = 0.96$, $p < 0.001$) and mean PGHM ($r = 0.80$, $p < 0.001$) during late summer and autumn,

TABLE 2 Mean, standard deviation, minimum and maximum of the dependent and independent variables per system in the multi-year dataset (2001–2018) during late summer and autumn (1 August to closing) and the closed period

Variable	Unit	*n*	Mean	*SD*	Min	Max
Late summer and autumn						
Days at pasture	Days per cow	60	96	15.3	68	120
Herbage growth rate	kg DM ha^{-1} day^{-1}	60	46.6	10.25	25.4	72.9
Peak herbage mass[a]	kg DM ha^{-1}	60	1,226	349.0	634	1,800
Date of peak herbage mass	Date	60	17 September	19.3[f]	08 August	29 October
Pre-grazing herbage mass	kg DM ha^{-1}	60	1,609	459.0	785	2,953
Post-grazing sward height	cm	49	5.6	1.19	3.9	7.7
Rotation interval	Days	53	35.7	6.87	23	54
Stocking rate	Cows ha^{-1}	60	2.4	0.47	1.7	4.0
Soil moisture deficit >0 mm[b]	Days	60	56	23.8	13	96
The closed period						
Closing date	Date	60	23 November	9.4[f]	07 November	17 December
Closing herbage mass[c]	kg DM ha^{-1}	55	424	189.6	36	846
Herbage growth rate in closed period	kg DM ha^{-1} day^{-1}	51	2.75	2.59	−4.06	7.07
Soil moisture deficit in December	mm	60	−8.02	1.78	−9.98	−3.56
Soil temperature in closed period[d]	°C	60	5.60	1.42	3.02	7.80
Opening herbage mass[e]	kg DM ha^{-1}	56	581	265.1	118	1,191

DM, dry matter; SD, standard deviation.

[a] Highest average herbage mass per system between 1 August and closing.

[b] Number of days where SMD was 0 mm or above.

[c] Average herbage mass at the beginning of the closed period.

[d] Soil temperature measured at 10 cm soil depth.

[e] Average herbage mass at the end of the closed period (early February).

[f] *SD* in days.

peak AHM was used as the main indicator of the mass of herbage accumulated during late summer and autumn. The variation in weekly AHM and herbage growth rate is shown in Figure 1a and b. The mean of the latest date per system on which herbage mass was harvested for ensiling was 26 July ± 2.9 days. Figure 1c shows the mean development of AHMs during late summer and autumn. Peak AHM occurred when herbage growth rate declined below demand.

3.2 | Herbage production, nutritive value and milk production

The high PGHM systems had higher ($p < 0.001$) PGHM (1,783 vs. 1,445 kg DM ha^{-1}, standard error of the mean [*SEM*] 32.5), a longer ($p = 0.002$) rotation interval (37 vs. 34 days, *SEM* 0.7), a higher ($p = 0.02$) herbage growth rate (50 vs. 44 kg DM ha^{-1} day^{-1}, *SEM* 1.4) and a higher ($p = 0.002$) peak AHM (1,345 vs. 1,139 kg DM ha^{-1}, *SEM* 39.2) during late summer and autumn. Post-grazing height was not significantly different between PGHM systems (5.6 ± 0.09 cm, $p > 0.05$). Nutritive value of the herbage was not affected by PGHM ($p > 0.05$) in terms of OMD (803 ± 2.8 g kg DM^{-1}), CP (210 ± 5.0 g kg DM^{-1}) and ash (112 ± 0.6 g kg DM^{-1}). Milk yield, milk solids yield, milk fat content, milk protein content and milk lactose content was not affected by PGHM ($p > 0.05$; Table 3). Likewise, the correlation analysis showed no association between peak AHM and milk yield or milk solids yield.

3.3 | Grazing season length, closing and opening AHM

Days at pasture per cow during late summer and autumn were positively associated with peak AHM per system, date of peak AHM, herbage growth rate per system and soil trafficability ($p < 0.01$) as well as negatively associated with stocking rate per system ($p < 0.001$), explaining 77% of the variation (Table 4). Within the associated variables only peak AHM and stocking rate were controlled by grassland management. The variation in peak AHM explained the largest part of the variation in days at pasture per system (partial $R^2 = 0.46$, Figure 2a). On average over the 17 years, each increase in peak AHM of 100 kg DM ha^{-1} increased the length of the grazing season by 2.2 ± 0.44 days, whereas each increase in stocking rate of one cow ha^{-1} decreased the number of days at pasture by 11.7 ± 2.25. A later closing date was associated with a higher peak AHM, higher SMD in December and better soil trafficability during late summer and autumn ($R^2 = 0.63$; $p < 0.01$; Table 4).

Closing AHM was positively associated with peak AHM and date of peak AHM ($p < 0.01$) and negatively associated with days at pasture ($p < 0.001$), which explained 59% of the variation in closing AHM (Table 4). The variation in peak AHM explained the largest part of the variation in closing AHM (partial $R^2 = 0.42$, Figure 2b). On average, each increase in peak AHM of 100 kg DM ha^{-1} increased closing AHM by 46 ± 6.5 kg DM ha^{-1}. Increasing closing AHM by 100 kg DM ha^{-1} increased opening AHM by 82 ± 14.2 kg DM ha^{-1} ($p < 0.001$, $R^2 = 0.41$, Table 4). There were moderate associations between mean soil temperature during the closed period and both opening AHM ($r = 0.38$, $p = 0.003$) and herbage growth rate during the closed period ($r = 0.32$, $p = 0.02$).

4 | DISCUSSION

4.1 | The effect of PGHM on herbage production, nutritive value and milk production during late summer and autumn

During the autumn perennial ryegrass swards are in a vegetative state and accumulate herbage up to a ceiling mass at which new leaf growth and senescence are in balance (Parsons & Chapman, 2000). With decreasing light intensity and air temperature towards the end of the growing season senescence rate can exceed the rate of new leaf growth resulting in a net loss of herbage mass and

TABLE 3 Mean, standard deviation, minimum and maximum of milk production variables per system in the multi-year dataset (2001–2018) from 1 August to drying off

Variable	Unit	*n*	Mean	*SD*	Min	Max
Daily milk yield	kg cow^{-1} day^{-1}	60	16.3	2.07	12.0	19.5
Daily yield of fat and protein	kg cow^{-1} day^{-1}	60	1.39	0.167	0.98	1.67
Milk fat content	g kg^{-1}	60	45.6	4.89	32.4	54.4
Milk protein content	g kg^{-1}	60	39.8	1.94	36.7	44.1
Milk lactose content	g kg^{-1}	60	46.0	0.95	44.1	47.9
Body weight	kg cow^{-1}	60	576	37.84	469	625
Body condition score		60	2.96	0.09	2.81	3.20
Mean dry off date	Date	60	4 December	5.8[a]	13 November	11 Decemebr
Concentrate feeding	kg fed cow^{-1}	60	193	151.4	0	566

SD, standard deviation.

[a] *SD* in days.

TABLE 4 Summary of the stepwise selection process from the multiple regression analysis of factors associated with days at pasture during late summer and autumn (1 August to closing), closing date, closing AHM and opening AHM (February) in the multi-year dataset (2001–2018)

Dependent variable	Step	Independent variable	Estimate (*SE*)	Partial R^2	Model
Days at pasture[a]	0	Intercept	10.1 (17.22)		$R^2 = 0.77$
(days per cow)	1	Peak AHM[d,e] (kg DM ha^{-1})	2.20 (0.44)***	0.46	*RMSE* = 7.57
	2	Stocking rate[a] (cows ha^{-1})	−11.7 (2.25)***	0.16	*n* = 60
	3	Soil trafficability[a,f] (days)	0.18 (0.04)***	0.08	
	4	Date of peak AHM (day in year)	0.23 (0.06)***	0.04	
	5	H. growth rate[a] (kg DM ha^{-1} day^{-1})	0.38 (0.13)**	0.04	
Closing date	0	Intercept	324.7 (4.92)***		$R^2 = 0.63$
(day in year)	1	Peak AHM[d,e] (kg DM ha^{-1})	1.48 (0.22)***	0.32	*RMSE* = 5.89
	2	SMD in December (mm)	2.57 (0.43)***	0.24	*n* = 60
	3	Soil trafficability[a,f] (days)	0.11 (0.03)**	0.07	
Closing AHM[b]	0	Intercept	−357.6 (232.37)		$R^2 = 0.59$
(kg DM ha^{-1})	1	Peak AHM[d,e] (kg DM ha^{-1})	45.5 (6.52)***	0.42	*RMSE* = 124.7
	2	Days at pasture[a] (days per cow)	−7.22 (1.66)***	0.09	*n* = 55
	3	Date of peak AHM (day in year)	3.54 (1.06)**	0.09	
Opening AHM[c]	0	Intercept	278 (64.5)***		$R^2 = 0.41$
(kg DM ha^{-1})	1	Closing AHM[b,e] (kg DM ha^{-1})	82.2 (14.2)***	0.41	*RMSE* = 191.8 *n* = 51

AHM, average herbage mass (average herbage DM >4 cm above ground level; average of all paddocks per system); DM, dry matter; RMSE, root mean square error; SE, standard error; SMD, soil moisture deficit.

[a] from 1 August to closing.

[b] AHM at the beginning of the closed period.

[c] AHM at the end of the closed period (early February).

[d] Highest AHM per system recorded between 1 August and closing.

[e] Increase of 100 kg DM ha^{-1}.

[f] Number of days where SMD was above 0 mm.

$^{**}p < 0.01$.; $^{***}p < 0.001$.

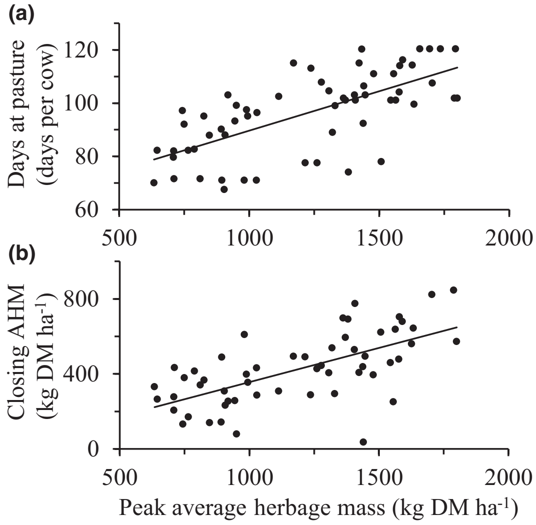

FIGURE 2 Relationship between amount of herbage accumulation (peak average herbage mass) during late summer and autumn (1 August to closing) and (a) days at pasture ($R^2 = 0.43$, $p < 0.001$) and (b) closing average herbage mass ($R^2 = 0.38$, $p < 0.001$) in the 60 grazing systems in the multi-year dataset (2001–2018). See Table 4 for regression estimates

associated negative effects on nutritive value of the herbage (Lawrence et al., 2017). In the present study, there was no evidence that higher PGHM was associated with net loss of herbage mass during the late summer and autumn. Indeed, in the comparison of high and low PGHM swards the high PGHM had a positive effect on herbage growth rate, which clearly indicates that ceiling mass had been not surpassed. In previous plot-based studies with perennial ryegrass swards net loss of herbage mass occurred when rotation intervals were longer than 84 days (from 9 August to 11 November; ceiling mass of 3,185 kg DM ha^{-1}; Lawrence et al., 2017) or 61 days (from 20 September to 20 November; ceiling mass 2,460 kg DM ha^{-1}; Hennessy et al., 2006). In a study with grass-clover swards between 2 July and 23 September highest herbage growth rates were reported with a rotation interval of 42 days compared to 56 or 84 days (daily growth rates of 59, 45 and 40 kg DM ha^{-1}, respectively; Phelan et al., 2013b). In the same study between 24 September and 16 December herbage growth rate was highest at 56 days rotation interval (daily growth rates of 17 vs. 10 and 8 kg DM ha^{-1} for 42 and 84 days respectively). The mean rotation interval of the high PGHM systems examined in the present study was 37 days. Hence, the rotation intervals in the present study were shorter than those likely to be subject to net senescence of herbage mass.

There was no indication that higher PGHM negatively affected utilization of grazed swards during late summer and autumn because there was no difference in post-grazing heights between the PGHM swards. Furthermore, PGHM had no effect on herbage nutritive value, milk and milk solids yield in the present study, similar to that recorded by Bryant and MacDonald (1983). In agreement with the present study, Dillon et al. (1998) found no difference in post-grazing height, nutritive value (OMD and CP) or milk yield from swards grazed at different average PGHMs (1,930 vs. 2,314 kg DM ha^{-1}) between 21 August and 6 December. Curran et al. (2010) also found no difference in post-grazing height and milk production of swards differing in PGHM (1,600 vs. 2,400 kg DM ha^{-1}, grazed at a daily herbage allowance of 15 kg DM cow^{-1}) between 21 July and 31 October. Although, in the latter study, Curran et al. (2010) reported higher OMD and higher CP in the lower PGHM swards. Nevertheless, the absence of a difference in milk yield in the present and previous studies clearly indicates that the nutritive value of both high and low PGHM swards were sufficient to meet the dietary requirements of spring calving dairy cows in mid and late lactation.

4.2 | The effect of accumulating herbage during late summer and autumn on the length of the grazing season and the supply of herbage mass in spring

The results of this study show that accumulating herbage during late summer and autumn can effectively extend the grazing season and increase the proportion of grazed herbage in the diet of dairy cows. Peak AHM and stocking rate explained a greater part of the variation in days at pasture than soil trafficability. Similarly, peak AHM explained a greater part of the variation in closing date than SMD during December and soil trafficability during late summer and autumn. Cows mostly had to be housed at closing due to a deficit in herbage mass rather than poor soil trafficability.

The main period in autumn when the grazing season can be extended (and the proportion of grazed herbage in the diet increased) was during the interval between peak AHM and closing. At the mean stocking rate in this study of 2.4 cows ha^{-1}, and with the type of cow involved in this study the daily feed demand was approximately 50 kg DM ha^{-1}. Hence, each additional 100 kg DM ha^{-1} increased the length of the grazing season by approximately 2 days. This relationship also explains why a higher stocking rate decreases the number of days at pasture during late summer and autumn because there is a higher daily feed demand by the grazing herd.

Higher peak AHM was associated with higher closing AHM, which concomitantly resulted in higher opening AHM in the following spring. Hence, accumulating herbage during late summer and autumn facilitated extending the grazing season in autumn and in the following spring. This is likely to improve profitability due to lower feed costs and a lower requirement for housing and management of slurry etc. (Hanrahan et al., 2018; Läpple et al., 2012). Previous studies focused on increasing herbage mass at turnout in early spring by closing swards earlier before the winter, which consequently meant fewer days at pasture and a shorter grazing season during autumn. It has been shown that later closing resulted in lower herbage mass for grazing in spring and vice versa (Claffey et al., 2020; Lawrence et al., 2017; Ryan et al., 2010). The results of the present study demonstrate that accumulating herbage during late summer and autumn can provide a double dividend of more days at pasture during autumn and a higher opening AHM. Nevertheless, the low predictability of opening AHM from closing AHM and the association with soil temperature during the closed period in the present study demonstrates that the grazing management during the preceding autumn does not always directly impact on the mass of herbage in the following spring, which is somewhat similar to that found by Bryant and MacDonald (1983). Low temperatures and inclement weather during the closed period can cause loss of the accumulated herbage mass. Hennessy et al. (2006) and Claffey et al. (2020) reported that following the imposition of closing treatments (early vs. late closing dates) the mass of herbage in the subsequent spring did not follow a consistent pattern in successive years. This was attributed to variations in meteorological conditions and herbage growth rates during the closed period.

4.3 | Implications for grassland management

Peak AHM is an indicator of the mass of herbage accumulated during late summer and autumn. It has been used in guidelines for autumn grassland management in pasture-based systems; at a stocking rate of 2.5 cows ha^{-1} a peak AHM of 1,130 kg DM ha^{-1} on 15 September has been recommended by Kennedy et al., (2016). This is similar to the mean peak (1,139 kg DM ha^{-1}) of the low PGHM systems in the present study. While it is not possible to clearly identify an optimum peak AHM based on the results of this study it is clear that there were only benefits from increasing peak AHM from 1,139 to 1,345 kg DM ha^{-1}, which was the mean peak AHM in the high PGHM systems in the present study.

Herbage growth rate during late summer and autumn was variable as it was mainly dependent on weather conditions (Figure 1b). In years with high herbage growth rate during the herbage accumulation interval a moderate peak AHM can be achieved by harvesting surplus herbage mass for silage production. Ensilage is associated with losses of dry matter and nutritive value of the herbage (Borreani et al., 2018) and an increase in production costs (Finneran et al., 2012). There may be an upper limit for peak AHM where the difference in production cost between storing herbage mass in situ and ensiling excess herbage mass does not compensate for losses due to net senescence. Identifying such upper limits for peak AHM at different stocking rates would be useful for developing practical guidelines for optimally extending the grazing season while avoiding excessive net senescence of accumulated herbage.

5 | CONCLUSIONS

Higher mean PGHM (1,783 vs. 1,445 kg DM ha^{-1}) and a higher than commonly recommended mean peak AHM (1,345 vs. 1,139 kg DM ha^{-1}) did not negatively impact on herbage growth rate, herbage utilisation, nutritive value of the herbage or milk production of spring-calving dairy cows during late summer and autumn in the present study. Higher peak AHM increased herbage growth rate and days at pasture per cow during autumn, and closing AHM. A higher closing AHM was associated with a higher opening AHM in February. Therefore, the results of the present study show that the length of the grazing season and the proportion of grazed herbage in the diet of dairy cows can be increased by accumulating herbage during late summer and autumn. This has potential to lower costs of production in pasture-based dairy systems.

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AUTHOR CONTRIBUTIONS

Friederike Fenger: Conceptualization (equal); data curation (lead); formal analysis (lead); investigation (equal); methodology (lead); validation (equal); visualization (lead); writing – original draft (lead); writing – review and editing (equal). **Imelda Casey:** Formal analysis (supporting); funding acquisition (equal); methodology (supporting); project administration (lead); resources (supporting), supervision (lead); validation (supporting); writing – review and editing (supporting). **James Humphreys:** Conceptualization (equal); data curation (supporting); formal analysis (supporting); funding acquisition (equal); investigation (lead); methodology (supporting); project administration (supporting); resources (lead); supervision (supporting); validation (equal); writing – review and editing (equal).

DATA AVAILABILITY STATEMENT

Research data are not shared.

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