The Journal of Agricultural Science

cambridge.org/ags

Animal Research Paper

Cite this article: Doyle PR, McGee M, Moloney AP, Kelly AK, O'Riordan EG (2023). Effect of pre-grazing herbage mass and post-grazing sward height on herbage production and intake and performance of suckler-bred steers within a weanling-to-beef production system. *The Journal of Agricultural Science* **161**, 297–312. https://doi.org/10.1017/S0021859623000217

Received: 30 September 2022
Revised: 18 January 2023
Accepted: 20 March 2023
First published online: 24 March 2023

Keywords:
Grass-fed beef; grazing behaviour; live-weight gain; pasture allowance; residual sward height; rotation length

Corresponding author:
P. R. Doyle;
Email: Peter.Doyle@teagasc.ie;
E. G. O'Riordan,
E-mail: Edward.ORiordan@teagasc.ie

Effect of pre-grazing herbage mass and post-grazing sward height on herbage production and intake and performance of suckler-bred steers within a weanling-to-beef production system

P. R. Doyle[1,2], M. McGee[1], A. P. Moloney[1], A. K. Kelly[2] and E. G. O'Riordan[1]

[1]Teagasc, Animal & Grassland Research Centre and Innovation Centre, Grange, Dunsany, Co. Meath, Ireland and [2]School of Agriculture and Food Science, University College Dublin, Belfield, Dublin 4, Ireland

Abstract

The current study investigated the effects of pre-grazing herbage mass (PGHM, 1500 or 2500 kg dry matter (DM)/ha) and post-grazing sward height (PGSH, 4 or 6 cm) on herbage production and its nutritive value and DM intake, grazing behaviour and growth of Charolais steers ($n = 96$; 12 months of age; 396 ± 19.0 kg) during a 222-day grazing season, and the subsequent effect of an indoor finishing diet (grass silage alone or supplemented with concentrates) for 146 days, on performance and carcass traits. Steers were assigned to one of 12 grazing groups and group was assigned to a 2 (PGHM) × 2 (PGSH) factorial arrangement of treatments. At the end of the grazing season, live-weight was 16 kg heavier for PGHM-1500 than PGHM-2500 and 34 kg heavier for PGSH-6 than PGSH-4. After indoor finishing, there was no difference in carcass weight between PGHM treatments, but PGSH-6 had a 19 kg heavier carcass than PGSH-4. Herbage production was 881 and 517 kg DM/ha greater for PGHM-2500 than PGHM-1500 and for PGSH-4 than PGSH-6, respectively. Grazing stocking rate did not differ between PGHM treatments but PGSH-4 carried 1.35 more steers/ha than PGSH-6. Supplementing concentrates during the indoor period increased carcass weight (42 kg) and fat score (2.10 units). In conclusion, grazing to 6 rather than 4 cm, increased individual carcass weight but not carcass weight gain/ha. Compared to PGHM-2500, grazing PGHM-1500 increased steer live-weight gain at pasture, but did not affect carcass weight following indoor finishing.

Introduction

Suckler beef systems in temperate climates are designed to offer a high inclusion (92%) of grazed and conserved herbage in the animal's diet (Drennan and McGee, 2009), as grazed pasture is the cheapest prevalent feed source (Finneran *et al.*, 2012). Consequently, increasing individual animal live-weight gain and stocking rate from grazed pasture, coupled with minimizing the use of expensive feedstuffs, especially concentrates, are key profit drivers in grass-based beef production systems (Finneran and Crosson, 2013; Taylor *et al.*, 2018). In this regard, grazing management technologies need to be investigated to further improve the stocking rate and animal live-weight gain from pasture within these low-cost beef systems (Sitienei *et al.*, 2015).

In grass-based weanling-to-beef suckler steer systems, spring-born single-suckled calves are weaned at 7 months of age. After weaning calves are offered grass silage and a low level of supplementary concentrates during an indoor 'store' feeding period. This is followed by a 'second' grazing season to take advantage of compensatory growth, and lastly an indoor finishing period based on grass silage plus concentrates before slaughter at 24 months of age (Drennan and McGee, 2009; Herron *et al.*, 2021). The rising popularity of 100% 'grass-fed' beef (Sitienei *et al.*, 2015) has encouraged the development of forage-only systems, without any supplementary concentrates. However, achieving a commercially acceptable carcass fat score (fat score ≥6.0, scale 1–15) on forage-only systems can be difficult with late-maturing breed suckler steers, the predominant genotype in Ireland (Regan *et al.*, 2018). In this context, strategies to maximize animal growth at pasture and thus subcutaneous fat accretion are critical as the use of concentrates is precluded during the 'finishing' phase (Doyle *et al.*, 2021).

Within technically efficient rotational grazing systems, pre-grazing herbage mass (PGHM) and post-grazing sward height (PGSH) influence pasture allocations and sward nutritive value (Frame and Laidlaw, 2011; Donaghy *et al.*, 2021), and individually they have been shown to influence live-weight gain and stocking rate of beef cattle at pasture (Doyle *et al.*, 2021, 2022). Compared to lactating dairy cows, grazing guidelines for beef cattle on rotational grazing temperate pasture are much less developed. Dairy cow studies in temperate climates recommend a PGSH of ca. 3.5–4 cm to optimize herbage production, sward nutritive value, stocking rate and animal output/ha (Ganche *et al.*, 2013; McCarthy *et al.*, 2013, 2014; Donaghy *et al.*, 2021). Additionally, a PGHM of ca. 1500 kg DM/ha (measured above 4 cm) is commonly recommended to optimize grazing to a PGSH of 4 cm and in order to maintain high herbage nutritive value (Curran *et al.*, 2010; McCarthy *et al.*, 2014; Donaghy *et al.*, 2021). However, these grazing recommendations for dairy cows normally encompass strategic concentrate supplementation to ensure that milk solids production per hectare is maintained (Curran *et al.*, 2010; McCarthy *et al.*, 2013). Although these 'dairy derived' grazing guidelines are now recommended for beef cattle (Maher, 2017), they may not be directly relevant to beef grazing systems, because most commercial beef farms have substantially lower stocking rates (1.6 livestock units/ha) than commercial dairy farms (2.1 livestock units/ha) (Teagasc, 2020a, 2020b) and concentrate supplementation at pasture is generally not an inherent practice recommended for technically efficient beef grazing systems (Taylor *et al.*, 2018). Increasing PGSH from ca. 4.0 to ca. 6.0 cm can increase individual intake of beef cattle resulting in greater growth rate equivalent to 30 kg live-weight during a ca. 200-day grazing season (O'Riordan *et al.*, 2011b, 2011c; Doyle *et al.*, 2021). Furthermore, increasing PGHM is reported to increase (Doyle *et al.*, 2022) (1500 *v.* 2000 kg DM/ha) or have no impact (Humphreys *et al.*, 2001) (2000 *v.* 3500 kg DM/ha) on steer live-weight gain. However, to the authors' knowledge, there are no published peer-reviewed studies that have examined the interactive effect of PGHM and PGSH on the sward nutrient concentration, beef animal grazing behaviour and their associated effect on animal dry matter intake (DMI) and live-weight gain at grass, and this information is required. Similarly, the residual impact of grazing management practices on steer performance during the subsequent indoor finishing period and on carcass traits needs to be determined.

Additionally, the impact of the interactive effect of PGHM and PGSH on herbage production in grass-based weanling-to-beef suckler systems needs to be quantified (Doyle *et al.*, 2021). Increasing PGSH above 4 cm reduces herbage production (Frame and Hunt, 1971; Doyle *et al.*, 2021) and consequently grazing stocking rate or the quantity of grass silage preserved for the indoor winter feeding period (Doyle *et al.*, 2021). On the other hand, increasing PGHM above 1400–1500 kg DM/ha, whilst maintaining a constant PGSH of 4 cm, increases annual herbage production (Wims *et al.*, 2014; Doyle *et al.*, 2022). Increasing PGSH to increase animal live-weight gain and increasing PGHM to increase herbage production could potentially increase live-weight gain/ha of grazing systems and this requires investigation.

Therefore, using suckler bred steers operated in a weanling-to-beef production system, the objectives of the current study were to investigate the effects of PGHM and PGSH on (1) the accumulation and nutritive value of herbage, (2) grazing behaviour, DMI and growth of suckler-bred steers grazing these pastures, (3) the subsequent impact of indoor finishing diet on performance and carcass characteristics and (4) the overall carcass gain/ha of these grazing systems.

Materials and methods

The current study was conducted at Teagasc, Grange Research Centre, Ireland (longitude 6°40'W; latitude 53°30′N; elevation 92 m a.s.l.) between October 2018 and April 2020, on a moderately well-drained brown earth with gleying and clay loam texture soil type. A total of 660 mm of rain and a soil temperature (50 mm depth) of 13.1°C were recorded at the Centre during the 2019 grazing season (March to October). This compares to a 13-year average of 568 mm and 12.9°C, respectively. Annual herbage growth at the Centre during the 2019 grazing season was comparable to the 13-year average, with spring grass growth above average, i.e. 'earlier' (Fig. 1).

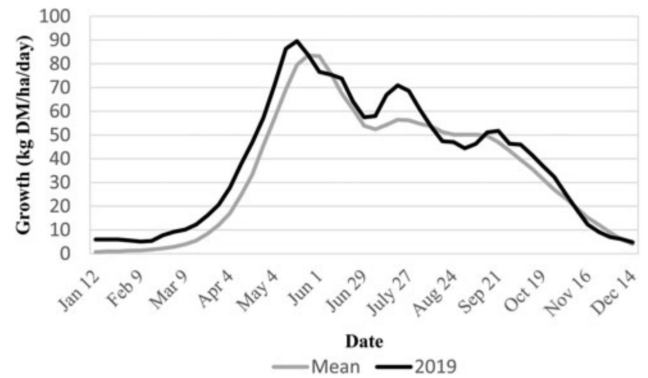

Figure 1. Daily grass growth for 2019 compared to the previous 13-year average at Teagasc Grange.

Animal procedures performed in this experiment were approved by the Teagasc Animal Ethics Committee and were conducted in accordance with the European Communities Regulation 2002 and 2005.

Production system, animal management and experimental design

Animals were produced within a suckler weanling-to-beef production system and slaughtered at 24 months of age as described previously (Regan *et al.*, 2018). Ninety-six spring-born, Charolais-sired recently weaned bulls (351 ± 16.5 kg) bred from suckler crossbred dams were sourced from commercial livestock marts in Ireland and transferred to Grange Research Centre in mid-October, at 7.5 months of age. Following arrival at the Centre, and subsequently as required, animals were treated for internal and external parasites (Ivermectin and Closantel, Closamectin, Norbrook Laboratories, Monaghan, Ireland; 1 ml/10 kg of live-weight), and vaccinated against Clostridial (Covexin 10, Zoetis, Dublin, Ireland; 2 ml per animal, administered twice) and respiratory diseases (Rispoval 3 and Rispoval IBR, Zoetis, Dublin, Ireland; 4 and 2 ml per animal, respectively, administered twice). At 8 months of age, animals were castrated with a 'burdizzo' by a veterinarian and returned immediately to pasture, where they remained there for 4 weeks before housing. For the 'first' winter steers (360 ± 21.3 kg) were housed in slatted floor pens in groups of seven (lying area = 2.84 m^2/animal) and fed grass silage only (*in vitro* DM digestibility (DMD), 751 g/kg) *ad libitum*, plus a mineral and vitamin supplement for 129 days. Mean steer daily silage DMI and daily live-weight gain was 5.53 kg DM and 0.34 kg during this period, respectively.

In early-March prior to turnout to pasture, steers were weighed indoor on two consecutive days, blocked on descending live-weight, and from within block randomly assigned to one of 12 grazing groups. Groups were randomly assigned to a two (PGHM > 4 cm: 1500 or 2500 kg DM/ha) × two (PGSH: 4 or

https://doi.org/10.1017/S0021859623000217 Published online by Cambridge University Press

6 cm compressed height) factorial arrangement of treatments, with three replicate groups of eight steers per treatment. Steers were turned out to pasture on 21 March 2019, where they rotationally grazed *Lolium perenne*-dominant swards in their replicate grazing groups for 222 days.

At the end of the grazing season (29 October), steers (534 ± 35.6 kg) were housed in concrete slatted floor pens in their respective sub-groups (lying area = 2.68 m^2/animal) for the finishing period. Within grazing group, steers were blocked on live-weight and randomly assigned to one of two indoor finishing diets offered individually for 146 days; (1) grass silage (752 g/kg DMD) *ad libitum* (proportionately 0.1 in excess of daily intake) supplemented with 3.75 kg concentrate DM (SC) or (2) grass silage only (SO) *ad libitum* plus a mineral-vitamin supplement. The concentrate was a coarse mixture comprised of 862 g/kg fresh weight rolled barley, 60 g/kg soyabean meal, 50 g/kg molasses and 28 g/kg mineral-vitamin and, following gradual introduction over 10 days, was offered once daily on top of the silage. The general-purpose mineral-vitamin supplement (calcium 25.0%, sodium 12.4%, vitamin A 500 000 IU/kg, vitamin D3 100 000 IU/kg, vitamin E 1500 mg/kg, vitamin B12 750 mg/kg and vitamin B1 250 mg/kg) was offered to SO on top of the silage at a rate equivalent to that offered in the concentrates for SC. At the start of the indoor finishing period, all animals were administered a copper bolus based on blood test results. At all times, animals had continuous access to clean, fresh water. At the end of the indoor finishing period, animals were slaughtered in a commercial abattoir at ca. 24 months of age.

Pasture management

The experimental area was a 27.4 ha permanent grassland area (20 years) that was initially divided equally between grazing and silage production. Based on expected annual herbage supply and animal feed demand, a global stocking rate of 3.51 steers/ha (2.46 livestock units/ha) was set across the grazing and silage production area and mean turn-out stocking rate was 2776 kg live-weight/ha on the grazing area. The grazing area comprised of five adjacent land blocks totalling 60 permanent paddocks (0.228 ha each) and from within land block, paddocks were assigned to one of 12 equal-sized 1.14 ha grazing area farmlets (balanced for starting herbage supply). Farmlet was randomly assigned to a grazing group. Each permanent paddock was further divided into three sub-paddocks (15 sub-paddocks per grazing group on the grazing area). At the beginning of the grazing season, a 'base' or 'starting' sub-paddock was assigned to each farmlet. For every grazing rotation, each grazing group grazed their base sub-paddock first and the grazing rotation cycle finished when the pasture supply on their respective base sub-paddock had returned to the assigned PGHM. Paddocks not grazed in each cycle were harvested as baled silage; yield of herbage removed was determined via lawnmower cuts (as below). During any periods of feed deficit (when the next sub-paddock to be grazed was below the assigned PGHM), a grazing group moved to their respective silage area farmlet (see below), and returned to their respective grazing area farmlet when the next sub-paddock attained the assigned PGHM. The herbage yield and area grazed on the silage farmlet was determined. PGSHs were checked twice daily using a rising plate meter (Jenquip, Feilding, New Zealand) and cattle remained in the sub-paddock until the assigned PGSH was achieved. Therefore, sub-paddock residency time varied between treatments. Daily herbage allowance per steer was calculated as [(PGHM/daily area grazed)/no. of animals].

The allocated silage production area consisted of four separate land parts, each of which was sub-divided into four equal-sized plots (ca. 0.855 ha), which were randomly assigned to the four grazing treatments. Collectively, this resulted in four separate silage farmlets (3.42 ha), which provided grass silage for the indoor winter periods (of which area and yield were determined via lawnmower cuts (as below)), and were used as an additional grazing area during periods of feed deficit, especially during the latter part of the grazing season when grass growth naturally declined.

Grazing paddocks were not mechanically topped, except when removing herbage in excess of grazing needs (as silage). Each farmlet received 150 kg chemical nitrogen/ha up to the end of August on the grazing area. On each of the silage production areas, 128, 99 and 84 kg nitrogen/ha (totalling 311 kg nitrogen/ha) were applied prior to the first, second and third silage cuts, respectively, which were harvested correspondingly on 11 May, 24 June and 12 August. The application rates of phosphorus and potassium fertilizers were determined by soil recommendations (Alexander *et al*., 2008).

Pasture measurements

A rising plate meter was used to measure pre- and post-grazing compressed sward height, where 30 random heights in each sub-paddock (∼395 heights/ha) were recorded. PGHM (kg DM/ha) (>4 cm) was estimated based on these heights using the equation of O'Riordan *et al*. (1997). PGHM was directly determined from 4 and 6 cm, as appropriate, with a rotary lawnmower as described by Doyle *et al*. (2021). Additionally, in the swards grazed to 6 cm, herbage mass was measured monthly in the 4–6 cm horizon using a lawnmower, to determine herbage mass between 4 and 6 cm, to facilitate measuring PGHM, herbage accumulation, growth, utilization, excess herbage mass removed at each silage cut, herbage mass removed and grazing group DMI from a constant height (4 cm) for all treatments. Herbage growth, annual herbage accumulation, herbage mass removed, herbage utilization and grazing group DMI were calculated according to Doyle *et al*. (2021). Canopy density (above the assigned PGSH), rotation (or stocking) cycle and rest period were calculated as specified by Allen *et al*. (2011). On the grazing area, sward leaf, stem and dead herbage mass and proportion were measured above the allotted PGSH (4 or 6 cm, as appropriate) according to Doyle *et al*. (2021).

The vertical distribution of the sward biomass and chemical composition were estimated throughout the grazing season. In the 'base' sub-paddock of each grazing group, 15 pre-grazing herbage 'grab' samples were taken randomly from ground level using a scalpel in May (vegetative stage), June (reproductive stage) and September (post-reproductive stage). Samples were composited in the laboratory while still maintaining their straight vertical distribution. A 500 g sub-sample was placed under a guillotine blade and cut from ground level to the grazing horizon (4 or 6 cm) and cut into 4 cm layers thereafter until the top of the canopy was reached, where layer 1 represented the bottom of the plant. Thus, PGSH-6 was cut into layers of 0–6 cm (layer 1), 6–10 cm (layer 2), 10–14 cm (layer 3), 14–18 cm (layer 4), 18–22 cm (layer 5) and 22–26 cm (layer 6), etc. Each layer was dried at 40°C to a stable weight, for chemical analysis and DM yield determination, with yield being corrected for ash content. The first five layers (from ground level) were individually ground

https://doi.org/10.1017/S0021859623000217 Published online by Cambridge University Press

and the remaining layers were composited and ground through a Wiley mill (1 mm aperture; Arthur H. Thomas, Philadelphia, PA, USA) in preparation for chemical analysis.

Cutting plots

The effect of PGHM and PGSH on herbage growth and accumulation was also determined separately in *L. perenne*-dominant experimental plots (5 m × 2 m) representative of the grazing area, between 17 April 2019 and 29 October 2019. The simulated grazing treatments were replicated four times in a fully randomized complete block design. All four replicate plots were cut to their respective PGSH (4 or 6 cm) (using a lawnmower; 0.53 m × 5 m strip) throughout the grazing season when they attained their targeted PGHM, which was estimated via rising plate meter. Herbage growth and accumulation for the cutting plots were calculated as described by Doyle *et al.* (2021). Furthermore, on 17 April 2020, all 16 cutting plots were cut to their assigned PGSH to determine the preceding winter and early spring growth of the respective treatments.

Animal measurements

During both indoor winters, individual animal intake was measured using electronically controlled Calan gates (American Calan Inc., Northwood, NH, USA) as described previously (Doyle *et al.*, 2021).

The RumiWatch noseband sensor (Itin & Hoch GmbH, Liestal, Switzerland) (Werner *et al.*, 2018) was used to monitor each steer's grazing behaviour for four consecutive days between 12 and 30 August (day 144–162 of the grazing season). The RumiWatch converter V.0.7.3.36 was used to convert the grazing behaviour data into 1 h summaries (Itin & Hoch GmbH) (Werner *et al.*, 2018; Norbu *et al.*, 2021). During this 4-day measurement period, herbage was offered to each grazing treatment group on a 48 h schedule, allowing each grazing treatment group to graze their respective PGHM to PGSH twice. Grazing behaviour was successfully measured on all 96 animals over 3 weeks.

Live-weight was recorded every 2 weeks during the trial using a calibrated scales (Tru-Test XR3000, load bars XHD 10 000, Auckland, New Zealand) and recorded on two consecutive days at important time points as detailed in Doyle *et al.* (2021). All grazing groups were moved to a new-sub-paddock the evening before weighing in an effort to equalize gut fill between the different treatments. After weighing, steers returned to their original sub-paddock if they had not attained their PGSH the evening before. Indoors, steers were weighed at 8 a.m. prior to their morning feeding. The cumulative live-weight over a specific length of time was used to determine live-weight gain.

Using an automatic real-time scanner (model – ECM ExaGo Veterinary scanner, with a 3.5 MHz linear transducer, IMV imaging, Meath, Ireland), animals were ultrasonically scanned at turnout to pasture, housing for the finishing period and pre-slaughter to determine M. longissimus and back fat depth as outlined by Lenehan *et al.* (2017).

Post-slaughter, cold carcass weight was estimated as 0.98 of hot carcass weight. Kill-out proportion was determined by dividing the cold carcass weight by pre-slaughter live-weight. Carcasses were graded mechanically for conformation and fat score on a continuous 15-point scale according to the EU beef carcass classification system (Mezgebo *et al.*, 2017).

Systems output/ha measurements

Grazing area used per rotation and the area of excess herbage removed per rotation (from the grazing area only) were calculated using the same equations as Wims *et al.* (2014). Stocking rate, live-weight gain/ha, total silage demand for a weanling-to-beef steer system and total silage preserved were calculated using the same equations as Doyle *et al.* (2021).

Feed sampling and analysis

Herbage samples were obtained from every pre-grazing cut and pooled into monthly samples for each grazing group. Representative samples of supplied grass silage and concentrates were collected twice weekly at feed out and pooled into bi-weekly and monthly samples, respectively. Sample processing, *in vitro* organic matter digestibility (OMD), neutral cellulose plus gammanase digestibility, chemical analysis (crude protein (CP); neutral detergent fibre (NDF); acid detergent fibre (ADF); water soluble carbohydrates (WSC); ash) and estimated Unité Fourragère Viande (UFV) of grazed herbage, grass silage and concentrates was conducted using the methods reported by Doyle *et al.* (2021). The DM, DMD, NDF, CP and UFV concentration of the grass silage offered during the first winter were 313 g/kg, 0.762 DMD, 438, 156 g/kg DM and 0.828 kg DM, respectively. Corresponding values during the finishing period were 287 g/kg, 0.752 DMD, 455, 166 g/kg DM and 0.816 kg DM. The concentrate DM, neutral cellulase gammanase digestibility, NDF, CP and UFV concentration were 788 g/kg, 934, 143, 141 g/kg DM and 1.20 kg DM, respectively.

Statistical analysis

Model assumptions (constant variance and normal distribution) were checked using residual diagnostics. Animal data pertaining to the grazing season, grazing behaviour for each of the two consecutive 24 h measurement periods and systems output/ha (stocking rate, live-weight gain/ha, silage preserved, etc.) were statistically analysed using the MIXED procedure of statistical analysis software (SAS, version 9.4) (SAS Institute; Cary, NC, USA) where the experimental unit was grazing group or farmlet, as appropriate (grazing model). The grazing model contained fixed effects for PGHM, PGSH and their interactions. Differences between means were tested for significance using the PDIFF statement and adjusted by Tukey, as appropriate. Animal data pertaining to the finishing period and post-slaughter characteristics were analysed using a similar model except the experimental unit was the sub-group (finishing diet) within the previous PGHM × PGSH grazing group and the statistical model contained PGHM, PGSH, finishing diet and their interactions as fixed effects, and the interaction between grazing group, PGHM and PGSH as a random effect.

Herbage nutritive values were analysed using the grazing model with repeated measures used for each month of the grazing season. Vertical herbage distribution data were analysed using the grazing model for each of the three monthly measurement periods and sward horizon layer was added to the model as a fixed effect.

Data for all other measurements pertaining to pasture measurements, herbage production and rotation cycles were analysed using the MIXED procedure of SAS, with the sub-paddock as the experimental unit. The structure of the paddocks did not allow a full randomization of the sub-paddocks because sub-paddocks within paddock shared a common treatment. To take possible spatial correlation between sub-paddocks within treatment into account, a spatial correlation model was added to the analysis model. The spatial model was fitted with a repeated statement in the MIXED procedure of SAS. Data averaged per sub-paddock were weighted for frequency of grazing (i.e. the number of times the sub-paddock was defoliated). Differences between means were tested for significance using the PDIFF statement and adjusted by Tukey. For total silage produced on the grazing area, the assumption of normal distribution was not met due to the presence of excess null values (i.e. a lot of paddocks were not cut for silage), so a distribution-free approach using randomization analysis from the macro code of Cassell (2002) was used. For repeated measures over time, a third dimension was added to the spatial model to capture correlations over time. Repeated measures were broken into early- (spring vegetative stage in March, April and May), mid- (reproductive phase in June and July) and late- (autumn vegetative stage in August, September and October) season growth. The number of data points in each season differed. Data were considered statistically significant when $P < 0.05$ and considered a tendency towards statistical significance when $P < 0.10$.

Results

Sward characteristics

There was no PGHM × PGSH interaction ($P > 0.05$) for structural characteristics or characteristics relating to pasture supply (daily herbage allowance and daily area grazed) except for excess herbage mass removed at each silage cut on the grazing area ($P < 0.001$), where 1500-4 was the same as 1500-6 but 2500-4 was greater than 2500-6 (Table 1). Compared to PGHM-1500,

Table 1. Effect of pre-grazing herbage mass (PGHM – 1500 or 2500 kg dry matter (DM)/ha) and post-grazing sward height (PGSH – 4 or 6 cm) on sward structural characteristics, sward morphology and herbage feed allowance

PGHM	1500		2500			*P* value		
PGSH	4	6	4	6	S.E.M.	PGHM	PGSH	PGHM × PGSH
Structural characteristics								
PGHM (kg DM/ha)[1]	1691	1682	2719	2648	77.4	0.001	0.433	0.466
Early-season growth[1]	2162	2167	2574	2635	83.0	0.001	0.998	0.782
Mid-season growth[1]	1592	1596	2884	2949	85.8	0.001	0.998	0.659
Late-season growth[1]	1578	1625	2828	2669	78.2	0.001	0.975	0.358
Pre-grazing height (cm)	9.9	9.9	13.9	13.9	0.17	0.001	0.948	0.818
Canopy density (kg DM/cm/ha)[2]	271	261	266	249	4.2	0.045	0.001	0.392
PGSH (cm)	4.1	5.9	4.3	6.0	0.03	0.001	0.001	0.147
Post-grazing herbage mass (kg DM/ha)[1]	185	633	228	656	8.2	0.001	0.001	0.220
Herbage mass removed (kg DM/ha)[1]	1488	1064	2436	2005	70.1	0.001	0.001	0.678
Grazing utilization (%)[1]	89	62	91	75	0.5	0.001	0.001	0.001
Sward morphology (%)[2]								
Leaf	73[a]	69[a,b]	62[b]	67[a,b]	1.8	0.009	0.787	0.050
Stem[3]	20[b]	22[b]	30[a]	21[b]	1.5	0.013	0.038	0.008
Dead	7	10	7	12	1.3	0.354	0.034	0.367
Leaf:stem	3.6[a]	3.3[a]	2.1[b]	3.2[a]	0.25	0.012	0.172	0.016
Pre-grazing leaf mass (kg DM/ha)[2]	1253	943	1711	1525	40.6	0.001	0.001	0.166
Pre-grazing stem mass (kg DM/ha)[2]	344[b,c]	296[c]	832[a]	480[b]	38.5	0.001	0.001	0.004
Pre-grazing dead mass (kg DM/ha)[2]	129	130	206	275	25.7	0.003	0.205	0.225
Feed allowance								
DHA (kg DM/animal/day)[2,4]	6.8	8.2	6.8	7.9	0.18	NS	0.001	0.482
Daily area grazed (m^2/steer/day)	40	62	24	35	1.6	0.001	0.001	0.502
Average residency time (days)	2.7	1.7	4.4	3.1	0.10	0.001	0.001	0.130
Excess herbage mass removed at each silage cut on the grazing area (kg DM/ha)[1,5]	2608[c]	2614[c]	4011[a]	3443[b]	147	0.001	0.001	0.001

S.E.M., standard error of the mean for PGHM × PGSH.
[1]Measured above 4 cm only. The measured herbage mass between 4 and 6 cm grazing horizon is 495 kg DM/ha.
[2]Measured from the height of the assigned PGSH (4 or 6 cm).
[3]PGHM × time interaction for stem proportion ($P = 0.035$), values for spring, summer and autumn were 21, 31 and 17 and 22, 43 and 16% for PGHM-1500 and PGHM-2500, respectively.
[4]DHA, daily herbage allowance is as a result of systems effect and was not an imposed management tool.
[5]Excess herbage mass is the average yield of silage removed per cut from the grazing area only (excluding silage area).
a,b,c means within a row with different superscripts differ ($P < 0.05$).

PGHM-2500 had a greater ($P < 0.001$) PGHM, sward height, herbage mass removed, grazing utilization and residency time, and a lower ($P < 0.001$) daily area grazed. Compared to PGSH-4, PGSH-6 had a similar PGHM (above 4 cm) and sward height, and a lower canopy density ($P < 0.001$), herbage mass removed ($P < 0.001$) and grazing utilization ($P < 0.001$). Further, PGSH-6 had a greater ($P < 0.001$) daily herbage allowance and daily area grazed, and consequently, a shorter ($P < 0.001$) residency time.

There was a PGHM × PGSH interaction for leaf ($P = 0.050$) and stem ($P = 0.008$) proportions, and leaf:stem ratio ($P = 0.016$), whereby 1500-6 and 2500-6 did not differ but 2500-4 had a lower leaf proportion and leaf:stem ratio, and greater stem proportion than 1500-4 (Table 1). There was also a PGHM × PGSH interaction for pre-grazing stem mass ($P = 0.004$) whereby 1500-4 and 1500-6 did not differ, but 2500-4 was greater than 2500-6 (Table 1). There was a PGHM × time interaction for stem proportion ($P = 0.035$), whereby PGHM treatments did not differ in early- and late-season but PGHM-2500 was greater than PGHM-1500 in mid-season. Proportion of dead material did not differ between PGHM treatments but was greater ($P = 0.034$) for PGSH-6 than PGSH-4.

Sward nutritive value

There were no PGHM × PGSH × month or PGSH × month interactions for grazed herbage DM, *in vitro* digestibility and chemical composition (Table 2). There was a PGHM × month interaction for OMD ($P = 0.027$), CP ($P < 0.001$), NDF ($P = 0.018$), ADF ($P < 0.001$) and WSC ($P = 0.038$) concentrations, whereby differences between PGHM treatments for OMD, CP, NDF and ADF concentration were lowest pre-reproductive stage (April and May) and largest at the end of the reproductive stage in August. There was a PGHM × PGSH interaction for CP ($P = 0.004$) and NDF ($P = 0.049$) concentrations. For NDF concentrations, 2500-4 was greater than 1500-4, but 1500-6 and 2500-6 did not differ. For CP concentration, 2500-6 was greater than 2500-4, but 1500-4 and 1500-6 did not differ (Table 2). *In vitro* OMD and ADF concentration did not differ between PGSH treatments.

Sward vertical distribution

The vertical distribution of *in vitro* digestibility and chemical composition of the herbage for the grazing season is presented in Table 3 (monthly values are presented in Supplementary Table 1).

OMD and CP concentration decreased and NDF, ADF and ash concentrations increased ($P < 0.001$) from the top (layer 6) to the base (layer 1) of the plant (Table 3). There was a PGHM × layer interaction ($P = 0.022$) for ADF concentration, whereby concentration did not differ between PGHM treatments below the grazing horizon (layer 1), but was greater ($P < 0.001$) for PGHM-2500 than PGHM-1500 above the grazing horizon (layer 2 to 6). There were PGSH × layer interactions ($P = 0.034$) for ADF concentration, whereby PGSH-6 had a greater ($P = 0.021$) ADF concentration than PGSH-4 below the grazing horizon (layer 1), but did not differ above the grazing horizon (layer 2 to 6).

Grazing and ruminating behaviour

During the 48 h grazing behaviour measurement period, there were no PGHM × PGSH interactions or effect of PGHM ($P > 0.05$) on DMI, bite mass and intake rate (Table 4); however, PGHM-2500 tended to have a lower ($P = 0.067$) eating time per kg DMI and had a greater ($P = 0.040$) DMI per grazing bout than PGHM-1500. Compared to PGSH-4, PGSH-6 had a greater DMI, intake rate and DMI per grazing bout ($P < 0.001$), tended to have a greater bite mass ($P = 0.083$) and had a lower ($P < 0.001$) eating time per kg DMI. For rumination parameters, there was a PGHM × PGSH interaction for ruminating mastications per kg DMI ($P = 0.0046$), ruminating time ($P = 0.019$), mastications ($P = 0.019$), mastication rate ($P = 0.041$), number of boli ($P = 0.012$) and boli per ruminating bout ($P = 0.017$), whereby 1500-4 was lower than 2500-4, but 1500-6 and 2500-6 did not

Table 2. Effect of pre-grazing herbage mass (1500 or 2500 kg dry matter (DM)/ha) and post-grazing sward height (4 or 6 cm) on DM concentration, *in vitro* digestibility and chemical composition of grazed herbage

PGHM	1500		2500			*P* value				
PGSH	4	6	4	6	S.E.M.	PGHM	PGSH	PGHM × PGSH	Month	PGHM × Month
DM (g/kg)[1]	182	184	187	182	2.2	0.956	0.967	0.991	0.009	0.928
DM composition										
OMD[1]	0.801^{a}	0.793^{a}	0.765^{b}	0.782^{a,b}	0.0059	0.004	0.472	0.058	0.003	0.027
CP (g/kg DM)[1]	182^{a}	177^{a}	150^{c}	159^{b}	2.1	0.001	0.343	0.004	0.001	0.001
NDF (g/kg DM)[1]	400^{c}	405^{b,c}	438^{a}	422^{a,b}	4.6	0.001	0.256	0.049	0.001	0.018
ADF (g/kg DM)[1]	226^{b}	225^{b}	240^{a,b}	253^{a}	3.8	0.001	0.120	0.067	0.001	0.001
WSC (g/kg DM)[1]	164	156	171	170	5.0	0.071	0.461	0.467	0.001	0.038
Ash (g/kg DM)[1]	98	96	97	90	2.6	0.165	0.102	0.316	0.009	0.258

OMD, in vitro organic matter digestibility; CP, crude protein; NDF, neutral detergent fibre; ADF, acid detergent fibre; WSC, water soluble carbohydrates; Ash, crude ash.
[1]Measured from the height of the assigned PGSH (4 or 6 cm).
S.E.M. = standard error of the mean for PGHM × PGSH.
a,b,c means within a row with different superscripts differ ($P < 0.05$).

Table 3. Effect of pre-grazing herbage mass (1500 or 2500 kg dry matter (DM)/ha) and post-grazing sward height (4 or 6 cm) on the vertical distribution of *in vitro* digestibility and chemical composition of the sward

	Grazing treatment					Layer							*P* value[5]			
	1500-4	1500-6	2500-4	2500-6	S.E.M.[3]	1	2	3	4	5	6	S.E.M.[4]	PGHM	PGSH	Layer	PGHM × PGSH
OMD	0.788[a]	0.777[ab]	0.773[b]	0.779[ab]	0.004	0.677	0.776	0.795	0.810	0.810	0.817	0.005	0.126	0.607	0.001	0.038
CP (g/kg OM)	167	176	139	142	3.4	114	124	150	171	185	192	4.2	0.001	0.096	0.001	0.404
NDF (g/kg OM)	472[a]	522[b]	538[b]	536[b]	5.4	587	547	516	500	488	465	6.7	0.001	0.001	0.001	0.001
ADF (g/kg OM)[1,2]	255[a]	283[b]	297[c]	295[c]	2.2	325	305	290	276	258	237	2.7	0.001	0.001	0.001	0.001
WSC (g/kg OM)	195[a]	178[b]	190[ab]	194[ab]	4.9	175	192	194	191	189	195	6.0	0.264	0.177	0.178	0.030
Ash (g/kg OM)	113	112	104	105	2.4	167	107	99	99	92	88	2.9	0.001	0.932	0.001	0.669

Layer 1; ground level to the base of the grazing horizon; layer 6, top of the plant.
OMD, *in vitro* organic matter digestibility; CP, crude protein; NDF, neutral detergent fibre; ADF, acid detergent fibre; WSC, water soluble carbohydrates; Ash, crude ash.
[1]PGHM × layer interaction ($P = 0.022$): values of 320 *v.* 330, 293 *v.* 318, 275 *v.* 305, 264 *v.* 288, 245 *v.* 272, 218 *v.* 256 for PGSH-4 *v.* PGSH-6 in layers 1, 2, 3, 4, 5 and 6, respectively.
[2]PGSH × layer interaction ($P = 0.034$): values of 310 *v.* 340, 296 *v.* 314, 284 *v.* 296, 272 *v.* 280, 251 *v.* 265, 235 *v.* 239 for PGHM-1500 *v.* PGHM-2500 in layers 1, 2, 3, 4, 5 and 6, respectively.
[3]S.E.M. = standard error of the mean for PGHM × PGSH.
[4]S.E.M. = standard error of the mean for layer.
[5]There were no PGHM × PGSH × Layer interactions.
a,b,c means within a row with different superscripts differ ($P < 0.05$).

differ. Rumination parameters for the first and second 24 h of the 48 h allocation are outlined in Supplementary Table 2.

During the first 24 h of the 48 h allocation, there was a PGHM × PGSH interaction for grazing bites/day ($P = 0.051$), whereby 1500-6 was lower than 2500-6, but 1500-4 and 2500-4 did not differ (Table 5). During the first 24 h, compared to PGHM-1500, PGHM-2500 had a lower number of grazing bouts per day ($P = 0.005$), longer grazing bout duration ($P = 0.014$) and a greater bite rate ($P = 0.044$) (Table 5). Grazing behaviour parameters did not differ ($P > 0.05$) between PGSH treatments during the first 24 h.

During the second 24 h there was a PGHM × PGSH interaction for grazing bites/day ($P = 0.027$), whereby 1500-6 was greater than 1500-4, but 2500-4 and 2500-6 did not differ. PGHM-2500 had a lower ($P = 0.026$) eating time and tended to have a lower bite rate ($P = 0.096$) than PGHM-1500. Eating time and grazing bouts did not differ between PGSH treatments; however, PGSH-6 had a greater bite rate than PGSH-4 ($P < 0.001$). Grazing behaviour data derived from the RumiWatch harnesses averaged over the 48 h measurement period are reported in Supplementary Table 2.

Steer intake, growth and carcass characteristics

There were no PGHM × PGSH or PGSH × finishing diet interactions ($P > 0.05$) for steer intake, growth or live-weight (Table 6). There were PGHM × PGSH × finishing diet interactions for DMI expressed per unit of live-weight ($P = 0.048$), ADG ($P = 0.013$) and carcass weight ($P = 0.034$); however, these interactions were deemed not to be biologically (practically) important (see footnote in Table 6).

Grazed herbage DMI did not differ between PGHM but was higher ($P < 0.001$) for PGSH-6 than PGSH-4. There was a quadratic response in live-weight gain during the grazing season for all treatments (Fig. 2). Mid-way through the grazing season (day 119; 18 July) live-weight did not differ (503 kg, Fig. 2(*a*)) between PGHM treatments, but at the end of the grazing season, PGHM-2500 were 16 kg lighter ($P = 0.006$) than PGHM-1500. For PGSH, mid-way through the grazing season, PGSH-4 were 19 kg lighter ($P = 0.049$) than PGSH-6 (494 *v.* 513 kg, Fig. 2(*b*)), and this difference increased to 34 kg by the end of the grazing season.

During the finishing period, DMI did not differ within PGHM and PGSH treatments. Finishing period ADG was greater ($P = 0.036$) for PGHM-2500 than PGHM-1500, but did not differ between PGSH treatments. There was a PGHM × finishing diet interaction for feed conversion ratio ($P = 0.050$), whereby PGHM did not differ on SC, but PGHM-2500 was lower ($P = 0.045$) than PGHM-1500 on SO. Overall, ADG from the first winter to slaughter, pre-slaughter live-weight and carcass weight did not differ between PGHM treatments but were greater ($P = 0.029$) for PGSH-6 than PGHS-4. Carcass conformation and fat score did not differ between grazing treatments.

Within finishing diet, SC had a greater DMI, ADG, pre-slaughter live-weight, carcass weight, carcass fat score ($P < 0.001$), carcass conformation score ($P = 0.005$) and kill-out proportion ($P = 0.022$) compared to SO.

There were no PGHM × PGSH × finishing diet interactions ($P > 0.05$) for ultrasonic measurements of body composition. There was no difference ($P > 0.05$) in ultrasonic fat and muscle depth measurements between PGHM treatments at the end of the grazing season or pre-slaughter, whereas, PGSH-6 had a

https://doi.org/10.1017/S0021859623000217 Published online by Cambridge University Press

Table 4. Effect of pre-grazing herbage mass (1500 or 2500 kg dry matter (DM)/ha) and post-grazing sward height (4 or 6 cm) on estimated herbage DM intake (DMI), bite mass, intake rate and ruminating behaviour during a 48-h allocation

PGHM	1500		2500			*P* value		
PGSH	4	6	4	6	s.e.m.	PGHM	PGSH	PGHM × PGSH
Grazing behaviour								
Steer DMI (kg/day)[1]	5.2	7.2	5.4	7.2	0.36	0.808	0.001	0.817
Pre-hension time per kg DMI (min)[2]	95	68	83	67	3.1	0.060	0.001	0.115
Eating time per kg DMI (min)[3]	114	81	98	80	3.8	0.067	0.001	0.109
DMI per grazing bout (kg)	0.65	0.92	0.80	1.04	0.055	0.040	0.002	0.687
Bite mass (g)	0.25	0.29	0.26	0.29	0.017	0.587	0.083	0.839
Intake rate (g/min)[2]	10.5	14.7	12.1	15.0	0.62	0.173	0.001	0.297
Ruminating behaviour								
Ruminating time (min/d)	314[b]	415[a]	437[a]	458[a]	13.7	0.001	0.002	0.019
Ruminating bouts (n/d)	12.5	13.1	13.7	13.6	0.31	0.027	0.372	0.301
Ruminating bout duration (min/bout)	27	33	33	36	1.1	0.003	0.003	0.147
Ruminating mastications (n/d)	18 665[b]	27 136[a]	27 417[a]	30 240[a]	971.9	0.001	0.001	0.019
Ruminating mastication rate (chews/min)	60[c]	65[a]	63[b]	66[a]	0.6	0.009	0.001	0.041
Ruminating boli (n/d)	347[b]	460[a]	499[a]	517[a]	14.8	0.001	0.003	0.012
Ruminating mastications per bolus (n/bolus)	52	59	54	57	1.1	0.718	0.003	0.244
Ruminating boli per ruminating bout (n/bout)	28[b]	35[a]	37[a]	38[a]	1.0	0.001	0.002	0.017
Ruminating time per kg DMI (min)	60	58	81	65	3.3	0.003	0.022	0.067
Ruminating mastications per kg DMI (n)	3586[b]	3788[b]	5086[a]	4258[a,b]	218.1	0.002	0.189	0.046

s.e.m., standard error of the mean for PGHM × PGSH.
[1]DMI during the grazing behaviour measurement period only.
[2]Pre-hension time only includes eat down time on the RumiWatch system.
[3]Eating time includes eat up + eat down time on the RumiWatch system.
[4]Intake rate is calculated as (DMI × 1000)/pre-hension time.
a,b,c means within a row with different superscripts differ ($P < 0.05$).

greater rib fat depth (2.66 *v.* 2.34 mm; $P = 0.049$), lumbar fat depth (2.17 *v.* 2.03 mm; $P = 0.069$) and muscle depth (61.95 *v.* 58.70 mm; $P = 0.010$) at the end of the grazing season but not at slaughter, compared to PGSH-4. SC had greater pre-slaughter ultrasonic measures of fat (4.85 *v.* 3.67 mm; $P = 0.028$) and muscle depth (71.58 *v.* 67.69 mm; $P < 0.001$) compared to SO.

Herbage accumulation on the grazing area and cutting plots

There was no PGHM × PGSH interaction ($P > 0.05$) for regrowth interval, herbage growth and herbage accumulation on the grazing and silage area (Table 7) or cutting plots (Table 8). On the grazing area and cutting plots, regrowth interval, grazing rotation cycle length, average growth rate and herbage production (kg DM/ha) were greater for PGHM-2500 than PGHM-1500 ($P < 0.001$) and for PGSH-4 than PGSH-6 ($P < 0.05$). Herbage production differences within PGHM and PGSH treatments were proportionately greater on the cutting plots (0.17 and 0.12, respectively) than the grazing area (0.08 and 0.05, respectively).

On the grazing area, the quantity of herbage consumed/ha through grazing did not differ within PGHM and PGSH treatments, but more herbage was consumed for PGSH-6 than PGSH-4 on the silage area ($P < 0.001$). The quantity of excess herbage removed/ha as silage did not differ between PGHM treatments but was lower for PGSH-6 than PGSH-4 on the grazing ($P = 0.017$) and silage ($P < 0.001$) area. Overall, across the grazing and silage area, closing farmlet pasture supply was greater for PGHM-2500 than PGHM-1500 and for PGSH-4 than PGSH-6.

Systems output/ha

There was no PGHM × PGSH interaction ($P > 0.05$) for stocking rate, live-weight output/ha or for grass silage demand and supplied for the indoor winter period (Table 9). PGHM had no effect on the average grazing area required per rotation, stocking rate or overall grass silage demand and supplied for the indoor winter period per animal unit. However, the maximum area required per rotation (during September) was lower ($P = 0.050$) for PGHM-2500 than PGHM-1500. Live-weight gain/ha at pasture was lower ($P = 0.012$) for PGHM-2500 than PGHM-1500, but live-weight gain/ha and carcass weight gain/ha from weaning-to-slaughter did not differ between PGHM.

Compared to PGSH-4, PGSH-6 had a greater ($P < 0.001$) average and maximum grazing area required per rotation, and subsequently had a lower ($P < 0.001$) grazing stocking rate or amount of grass silage preserved per animal unit and consequently, a greater ($P = 0.003$) grass silage deficit (supply *v.* demand) for the indoor winter period. PGSH had no effect on live-weight gain/ha at pasture and live-weight gain/ha and carcass weight gain/ha from weaning-to-slaughter.

Table 5. Effect of pre-grazing herbage mass (1500 or 2500 kg dry matter (DM)/ha) and post-grazing sward height (4 or 6 cm) on grazing behaviour during the first and second 24 h of a 48 h allocation

PGHM	1500		2500			*P* value		
PGSH	4	6	4	6	S.E.M.	PGHM	PGSH	PGHM × PGSH
First 24 h								
Eating time (min/d)[1]	691[a]	623[a]	611[a]	675[a]	19.7	0.512	0.924	0.010
Pre-hension time (min/d)[2]	593[a]	525[a]	518[a]	579[a]	18.0	0.591	0.846	0.007
Grazing bouts (n/d)	8.3	8.3	6.3	6.5	0.49	0.005	0.863	0.921
Grazing bout duration (min/bout)	90	80	100	109	6.2	0.014	0.908	0.184
Grazing bites (n/d)	27 900[b]	27 652[b]	28 225[a,b]	33 144[a]	1151.2	0.035	0.077	0.051
Bite rate (bites/min)[3]	47	53	55	57	2.5	0.044	0.126	0.572
Second 24 h								
Eating time (min/d)[1]	492	542	446	466	22.4	0.026	0.157	0.539
Pre-hension time (min/d)[2]	401	455	371	378	22.4	0.043	0.209	0.327
Grazing bouts (n/d)	8.1	7.2	7.1	7.4	0.41	0.346	0.515	0.189
Grazing bout duration (min/bout)	68	81	71	72	6.1	0.623	0.334	0.359
Grazing bites (n/d)	13 971[b]	22 621[a]	12 814[b]	16 009[b]	1012.9	0.005	0.001	0.027
Bite rate (bites/min)[3]	35	50	35	42	2.1	0.096	0.001	0.126

S.E.M., standard error of the mean for PGHM × PGSH.
[1]Eating time includes eat up + eat down time on the RumiWatch system.
[2]Pre-hension time only includes eat down time on the RumiWatch system.
[3]Bite rate is calculated as (number of grazing bites/pre-hension time) (not eating time).
a,b,c means within a row with different superscripts differ ($P < 0.05$).

Discussion

Grass-based beef systems aim to maximize animal performance from cheaper grazed pasture and reduce the reliance on more expensive feedstuffs (Finneran and Crosson, 2013; Taylor *et al.*, 2018). Grazing management practices, including PGHM and PGSH, can be major determinants of the growth, nutritive value and DMI of grazed herbage, which are key contributing factors to performance of livestock grazing pasture (Frame and Laidlaw, 2011; Donaghy *et al.*, 2021). Recent studies have separately evaluated the effects of PGHM (Doyle *et al.*, 2022) and PGSH (Doyle *et al.*, 2021) on herbage and animal production within a suckler steer weanling-to-beef system. The overall objective of this experiment was to obtain a greater understanding of the interactive effects of PGHM and PGSH on sward structure, nutritive value and herbage production, the plant–animal interface, consequential steer live-weight gain at pasture, the residual impact on subsequent animal performance during the indoor finishing period and overall animal production output per hectare. True grazing group and farmlet replication was maintained throughout the experiment and represents a relatively novel design in grazing system experiments.

Effect of post-grazing sward height on steer performance

The 'recommended' PGSH guideline of ca. 4 cm, currently used for lactating dairy cows (Ganche *et al.*, 2013; Chapman *et al.*, 2014; Donaghy *et al.*, 2021), is unsuitable for growing cattle grazing pasture as it restricted animal growth at pasture by 0.16 kg/day, compared to a PGSH of 6 cm. The resulting 34 kg live-weight difference in favour of PGSH-6 at the end of the grazing season, is of similar magnitude to previous studies grazing beef cattle for a ~200-day grazing season, with similar PGSH differences (21 kg, Doyle *et al.*, 2021; 27 kg, O'Riordan *et al.*, 2011b; 33 kg, O'Riordan *et al.*, 2011c). Correspondingly, greater milk solids production was found in dairy cows grazing high (4.2–8.7 cm) compared to low (2.7–4.9 cm) PGSH in studies in Ireland (Mayne *et al.*, 1987; Ganche *et al.*, 2013) and New Zealand (MacDonald *et al.*, 2008).

The greater live-weight gain for PGSH-6 than PGSH-4 can be largely attributed to the consistently higher DMI across the grazing season, as nutrient concentration did not differ within grazing horizon layers between PGSH treatments. Consequently, differences in live-weight between PGSH treatments continued to diverge as the grazing season progressed. Similarly, previous studies have shown that a higher PGSH is associated with a higher DMI in beef (Difante *et al.*, 2010; Euclides *et al.*, 2016; Doyle *et al.*, 2021) and dairy cattle (MacDonald *et al.*, 2008; Ganche *et al.*, 2013; McCarthy *et al.*, 2013). The lower DMI for PGSH-4 is mainly accredited to the lower bite mass and intake rate compared to PGSH-6. Both of these parameters decrease linearly with sward depletion height (Chacon and Stobbs, 1976; Barrett *et al.*, 2001) due to a lower bite depth (Carvalho, 2013). This DMI 'restriction' was more evident during the second 24 h of the 48 h allocation, whereby PGSH-4 had a lower bite rate and fewer grazing bites, implying little desire to select out small quantities of herbage (Chacon and Stobbs, 1976). Under the circumstances of this rotational stocking experiment, steer grazing behaviour at the end (PGSH) rather than the beginning (PGHM) of the graze-down process had a larger impact on steer DMI. It should be

https://doi.org/10.1017/S0021859623000217 Published online by Cambridge University Press

Table 6. Effect of pre-grazing herbage mass (PGHM – 1500 or 2500 kg dry matter (DM)/ha), post-grazing sward height (PGSH – 4 or 6 cm) and finishing diet (diet – grass silage only (SO) or grass silage supplemented with 3.75 kg concentrate DM (SC)) on dry matter intake (DMI), average daily gain (ADG), live-weight and carcass traits of suckler-bred steers during the first winter, grazing season and finishing period

PGHM	1500		2500		Diet		S.E.M.		*P* value			
PGSH	4	6	4	6	SO	SC	Grazing	Diet	PGHM	PGSH	Diet	Interaction[a]
Dry matter intakes (DMI)												
Pasture DMI (kg/day)	6.1	6.8	6.3	7.1	–	–	0.14	–	0.120	0.001	–	0.945
Finishing period silage DMI (kg/day)	7.4	7.4	7.3	7.7	8.6	6.4	0.17	0.10	0.605	0.334	0.001	0.070
Finishing period SC DMI (kg/day)	9.3	9.3	9.2	9.6	8.6	10.2	0.17	0.10	0.602	0.332	0.001	0.072
Pasture DMI (g/kg live-weight)	13.2	14.2	14.0	15.1	–	–	0.29	–	0.027	0.005	–	0.802
Finishing DMI (g/kg live-weight)[b]	15.9	15.1	16.0	15.7	14.7	16.6	0.31	0.17	0.330	0.172	0.001	0.048
Pasture FCR[c]	10.3	9.6	12.4	10.3	–	–	0.44	–	0.012	0.012	–	0.156
Finishing period FCR[c,d]	12.9	13.8	10.9	11.1	14.3	10.0	0.80	0.48	0.025	0.503	0.001	0.142
Average daily gain (kg)												
Grazing season	0.59	0.71	0.50	0.69	–	–	0.021	–	0.028	0.001	–	0.162
Finishing period[e]	0.83	0.77	0.94	0.90	0.66	1.06	0.047	0.029	0.036	0.354	0.001	0.013
First winter to slaughter	0.59	0.64	0.59	0.66	0.57	0.67	0.021	0.013	0.600	0.029	0.001	0.124
Live-weight (kg)												
Turn-out to pasture[f]	394	400	397	392	–	–	2.5	–	0.256	0.473	–	0.891
End of grazing season[f]	525	559	509	544	535	534	4.3	2.3	0.006	0.001	0.791	0.134
Slaughter	646	672	645	676	631	689	8.3	5.3	0.838	0.009	0.001	0.076
Post-slaughter measurements												
Carcass weight (kg)[g]	367	387	367	384	355	398	4.7	2.7	0.840	0.004	0.001	0.034
Kill-out proportion (%)	56.8	57.5	56.9	56.8	56.3	57.7	0.38	0.32	0.488	0.378	0.022	0.995
Carcass conformation score (1–15)	8.6	9.1	9.5	9.3	8.6	9.7	0.30	0.20	0.139	0.692	0.005	0.560
Carcass fat score (1–15)	7.8	8.1	7.9	8.1	6.9	9.0	0.34	0.27	0.859	0.451	0.001	0.882

S.E.M. Grazing, standard error of the mean for PGHM × PGSH.
S.E.M. Diet, standard error of the mean for finishing diet.
[a]PGHM × PGSH × diet interaction.
[b]PGHM × PGSH × diet interaction: values of 14.2 *v.* 16.3, 13.3 *v.* 15.8, 14.2 *v.* 16.5, 14.3 *v.* 15.9 for SO *v.* SC, for 1500-4, 1500-6, 2500-4, 2500-6, respectively.
[c]FCR = feed conversion ratio (kg DM/kg ADG).
[d]PGHM × diet interaction ($P = 0.050$): values of 15.4 *v.* 11.9 and 10.2 *v.* 9.2 for PGHM-1500 *v.* PGHM-2500 in SO and SC, respectively.
[e]PGHM × PGSH × diet interaction: values of 0.65 *v.* 1.01, 0.54 *v.* 1.00, 0.65 *v.* 1.22, 0.79 *v.* 1.01 for SO *v.* SC, for 1500-4, 1500-6, 2500-4, 2500-6, respectively.
[f]Live-weight recorded indoors on a silage-only diet.
[g]PGHM × PGSH × diet interaction: values of 347 *v.* 386, 363 *v.* 411, 342 *v.* 393, 369 *v.* 400 for SO *v.* SC, for 1500-4, 1500-6, 2500-4, 2500-6, respectively.

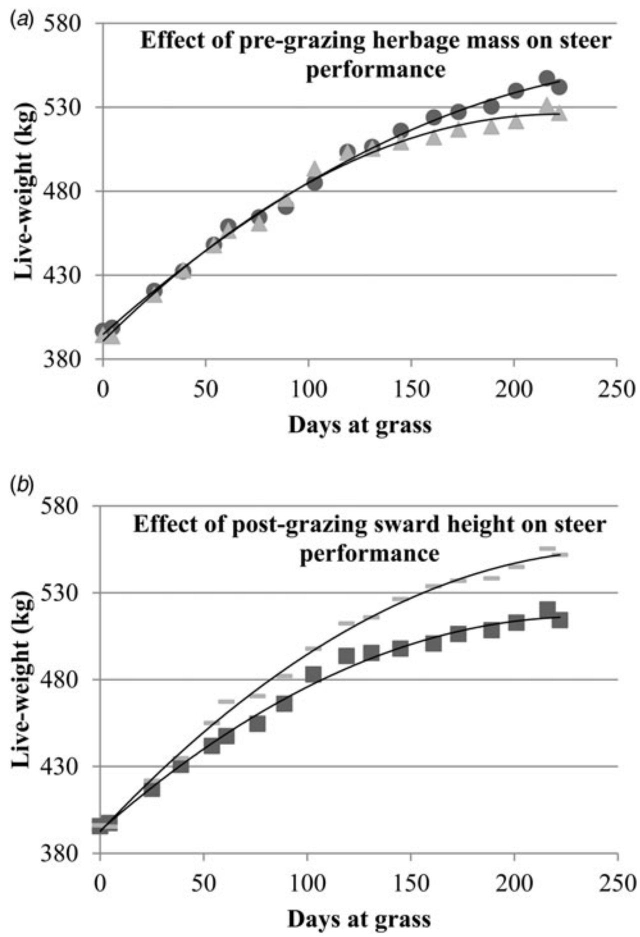

Figure 2. Effect of (*a*) pre-grazing herbage mass (1500 kg DM/ha ● and 2500 kg DM/ha ▲), and (*b*) post-grazing sward height (4 cm ■ and 6 cm —) on steer live-weight gain over the grazing season. Respective regression lines were (*a*) pre-grazing herbage mass (1500 kg DM/ha: $y = -0.0019x^2 + 1.0892x + 394.73$; $R^2 = 0.9962$, and 2500 kg DM/ha: $y = -0.0027x^2 + 1.2149x + 390.76$; $R^2 = 0.9934$), and (*b*) post-grazing sward height (4 cm: $y = -0.0022x^2 + 1.0514x + 393.08$; $R^2 = 0.9934$, and 6 cm: $y = -0.0025x^2 + 1.2681x + 392.49$; $R^2 = 0.996$).

noted that although herbage utilization was greater for PGSH-4 than PGSH-6, herbage utilization was measured from 4 cm for all treatments.

The absence of an effect of PGSH on *in vitro* digestibility measured above the grazing horizon agrees with previous studies (2.7 *v.* 4.2 cm PGSH, Ganche *et al.*, 2013; 2.7 *v.* 4.8 cm PGSH, Ganche *et al.*, 2015; 4.0 *v.* 6.0 cm PGSH, Doyle *et al.*, 2021). The PGSH × layer interaction for ADF concentration, whereby concentration was greater for PGSH-6 than PGSH-4 below, but not above, the grazing horizon, suggests that fresh herbage regrows from the defoliation point. This implies that animals were grazing only 'fresh' herbage regrowth that had gathered since the previous grazing cycle and thus were not consuming the older, lower nutritive value herbage accumulated below the grazing horizon (Ganche *et al.*, 2015). In practical terms, this means a PGSH between 4 and 6 cm does not negatively impact the nutrient value of consumed herbage; however, it is acknowledged that a compressed PGSH greater than 7 cm can reduce herbage digestibility (Donaghy *et al.*, 2021). It should be noted that mechanical 'topping' did not occur during in the current study.

If animals were slaughtered at the end of the grazing season, theoretically PGSH-6 would have a ca. 22 kg heavier carcass than PGSH-4. This growth superiority would be beneficial to heifer production systems where slaughter at ca. 19 months of age prior to the second winter is more common (Teagasc, 2020a), or where producers sell live animals at the end of the grazing season. However following housing, the differences in animal live-weight in favour of PGSH-6 at the end of the grazing season were retained throughout the indoor finishing period and the resulting 19 kg heavier carcass is consistent with the 11 kg difference in carcass weight for PGSH-6 compared to PGSH-4 reported by Doyle *et al.* (2021). It is surprising that compensatory growth did not occur for PGSH-4 during the indoor finishing period, as evident in other studies where beef cattle were more 'restricted' at pasture (O'Riordan *et al.*, 2011a). If steers were drafted for slaughter based on slaughter weight (rather than at the same time point), it is estimated that PGSH-4 steers would require an additional 58 and 24 days on SO on SC, respectively, to obtain the same carcass weight as PGSH-6 steers, which is in accord with Doyle *et al.* (2021). Reducing slaughter age of cattle and concentrate input can substantially lower greenhouse gas emissions and winter feed costs, respectively, in beef production systems (Finneran and Crosson, 2013; Taylor *et al.*, 2020).

Effect of pre-grazing herbage mass on steer performance

The current study showed that compared to PGHM-2500, PGHM-1500 improved steer performance at pasture resulting in a 16 kg heavier animal at housing, but the superior growth was only manifested in the second half of the grazing season. Similarly with dairy cows, Tuñon *et al.* (2011) compared a PGHM of 1500 and 2300 kg DM/ha and reported no difference between treatments in the first half of the grazing season but increased daily milk solids in the second half of the grazing season for the lower PGHM. In contrast, other studies have reported that a higher PGHM increased (1500 *v.* 2000 kg DM/ha, Doyle *et al.*, 2022) or had no effect (2000 *v.* 3500 kg DM/ha, Humphreys *et al.*, 2001) on steer ADG, or no effect on individual dairy cow milk production as determined in recent experimental (1400 *v.* 2000 kg DM/ha, Wims *et al.*, 2014) studies and in the meta-analysis reviewed by Pérez-Prieto and Delagarde (2012). This discrepancy in animal performance may be attributed to the relatively small differences found in herbage OMD between PGHM in these studies compared to the current experiment. Avoiding excessively high PGHM (> ca. 2000 kg DM/ha) particularly during and after the reproductive plant growth phase (McEvoy *et al.*, 2009; Wims *et al.*, 2014; Doyle *et al.*, 2022) can reduce the differences in herbage OMD, and thus differences in animal performance, between PGHM treatments.

The lower nutritive value (OMD) of the herbage for PGHM-2500 than PGHM-1500, and particularly for 2500-4 *v.* 1500-4, in the second half of the grazing season, was due to greater stem elongation in the summer, onset of senescence in the autumn (Holmes, 1989) and the absence of mechanical 'topping' (McDonald, 1986). It could be postulated that if mechanical topping had occurred, the herbage nutritive differences may well be reduced. The significantly lower CP concentration for PGHM-2500 compared to PGHM-1500, coupled with the similar DMI between PGHM, implies lower nitrogen excretion for PGHM-2500 (Owens *et al.*, 2008; O'Connor *et al.*, 2019), which is important in terms of reducing nitrogen loss in beef production systems.

Table 7. Effect of pre-grazing herbage mass (PGHM – 1500 or 2500 kg dry matter (DM)/ha) and post-grazing sward height (PGSH – 4 or 6 cm) on grazing rotations and herbage growth rate on the grazing area and herbage accumulation on the grazing and silage area

PGHM	1500		2500			*P* value[a]	
PGSH	4	6	4	6	S.E.M.	PGHM	PGSH
Grazing rotation cycles							
Number of grazing rotation cycles	6.2	7.6	3.8	4.7	0.11	0.001	0.001
Average rest period (days)	32	27	52	45	0.8	0.001	0.001
Average grazing rotation cycle length (days)	34	28	57	49	0.9	0.001	0.001
Early-season	37	33	51	43	1.9	0.001	0.006
Mid-season	27	22	44	36	0.8	0.001	0.001
Late-season	40	33	66	56	0.7	0.001	0.001
Herbage growth rate (kg DM/ha/day)[b]							
Average growth rate	49	46	55	53	1.1	0.001	0.012
Early-season	59	55	65	55	2.4	0.888	0.075
Mid-season	56	52	66	68	2.1	0.001	0.999
Late-season	39	34	44	41	2.0	0.023	0.291
Herbage accumulation on the grazing area (kg DM/ha)[b]							
Total herbage accumulation	11 506	10 688	12 095	11 861	179.8	0.001	0.004
Grazed	8421	8254	8751	8748	461.4	0.203	0.583
Removed as silage	2633	1608	2487	1926	338.0	0.564	0.017
Closing cover[b]	452	826	857	1187	69.5	0.001	0.001
Herbage accumulation on the silage area (kg DM/ha)[b]							
Total herbage accumulation	12 275	11 912	12 189	11 712	76.5	0.189	0.001
Grazed	986	2523	1277	2595	267.9	0.517	0.001
Removed as silage	10 060	9031	9734	8565	205.3	0.091	0.001
Closing cover[c]	1229	358	1177	552	172.9	0.692	0.002

S.E.M., standard error of the mean for PGHM × PGSH.
[a]There were no PGHM × PGSH interactions.
[b]Measured from 4 cm only. The measured herbage mass between 4 and 6 cm grazing horizon is 495 kg DM/ha.
[c]The pasture supply remaining in the pasture at the end of the year.

Although, daily DMI did not differ between PGHM treatments due to the similar bite mass and bite rate, it is noteworthy that PGHM-2500, and particularly 2500-6, had a greater DMI during the first 24 h (indicated by greater grazing bites, bite rate and grazing bout duration) which is consistent with previous observations (Piña *et al.*, 2020), and a lower DMI in the second 24 h (indicated by a lower grazing time, number of grazing bites and bite rate) compared to PGHM-1500. The lower DMI for PGHM-2500 in the second 24 h can be due to the greater bite force required due to the greater ADF concentration in the lower layers of the grazing horizon (Tharmaraj *et al.*, 2003) and reduced bite rate as steers try to avoid stem and select leaves (Amaral *et al.*, 2013). As a higher PGHM is accompanied by a higher stem mass, particularly in lower layers of the grazing horizon (Griffiths *et al.*, 2003); as indicated by the higher ADF concentration in these layers.

If animals were slaughtered at the end of the grazing season hypothetically PGHM-1500 would have a ca. 10 kg heavier carcass, which would be practically significant for production systems selling animals at the end of the grazing season as outlined earlier. However, after the indoor finishing period, the live-weight gain advantage for the lower PGHM was dissipated on both the SO and SC diet, due to compensatory growth (Hornick *et al.*, 2000; O'Riordan *et al.*, 2011a). This implies that a greater range of PGHM levels (1500–2500 kg DM/ha) can be implied without interfering with animal performance in the circumstances of a suckler weanling-to-beef production system that incorporates a final indoor finishing period.

Effect of finishing diet on steer performance

Despite the lower carcass weight and fat score of SO, 83% of steers in this forage-only system achieved a commercially acceptable carcass fat score of 6.0 or greater. The carcass weight (355 kg) and fat score (6.9) achieved by forage-only steers were higher than Regan *et al.* (2018) (319 kg carcass; 6.1 fat score) and Doyle *et al.* (2022) (332 kg carcass; 5.78 fat score), but similar to Doyle *et al.* (2021) (353 kg carcass; 6.8 fat score). It is noteworthy to consider that these forage-only systems require a target live-weight of ca. >535 kg at the end of the grazing season and highly digestible grass silage (>750 g/kg DMD) offered during the indoor finishing

Table 8. Effect of pre-grazing herbage mass (PGHM – 1500 or 2500 kg dry matter (DM)/ha) and post-grazing sward height (PGSH – 4 or 6 cm) on regrowth interval, herbage growth rate and herbage accumulation on the cutting plots

PGHM	1500		2500			*P* value[a]	
PGSH	4	6	4	6	s.e.m.	PGHM	PGSH
Regrowth interval (days)	28	24	42	36	.	.	.
Number of rotation cycles	7	8	5	6	.	.	.
Pre-cut height (cm)	10.2	10.1	14.1	13.8	0.27	0.001	0.453
Pre-cut herbage mass (kg DM/ha)[b]	1665	1639	2597	2539	64.5	0.001	0.525
Average growth rate (kg DM/ha/day)[c]	52	47	63	56	1.3	0.001	0.001
Early-season	57	54	72	63	2.0	0.001	0.138
Mid-season	59	50	72	66	2.0	0.001	0.024
Late-season	39	34	55	42	2.0	0.001	0.010
Winter[d]	17	17	16	15	2.0	0.438	0.567
Herbage accumulation (kg DM/ha)[c,e]	12 228	10 672	14 148	12 643	299.8	0.001	0.001

s.e.m., standard error of the mean for PGHM × PGSH.
[a]There were no PGHM × PGSH interactions.
[b]Estimated via plate meter from 4 cm only.
[c]Measured from the height of the assigned PGSH (4 or 6 cm).
[d]Growth rate from 13/11/2019 to 17/04/2020.
[e]Accumulation over the grazing season only, did not include herbage accumulation over the winter.

Table 9. Effect of pre-grazing herbage mass (PGHM – 1500 or 2500 kg dry matter (DM)/ha) and post-grazing sward height (PGSH – 4 or 6 cm) on stocking rate and live-weight output/ha at pasture, and grass silage demand and supply for the indoor winter period

PGHM	1500		2500			*P* value[a]	
PGSH	4	6	4	6	s.e.m.	PGHM	PGSH
Stocking rate and live-weight output/ha							
Average grazing area required per rotation (ha)[b]	0.93	1.14	1.00	1.15	0.025	0.166	0.001
Max grazing area required per rotation (ha)[b]	1.20	1.72	1.08	1.38	0.103	0.050	0.004
Stocking rate (steers/ha)	8.6	7.0	8.1	7.0	0.26	0.115	0.001
Grazing season live-weight gain/ha (kg)[c]	1132	1118	903	1063	44.0	0.012	0.135
Live-weight gain/ha (kg)[d]	1107	1081	1073	1115	38.1	0.995	0.839
Carcass weight gain/ha (kg)[d]	628	622	611	634	21.6	0.906	0.701
Grass silage demand and supply for the indoor winter period (kg/animal unit)[e]							
Grass silage preserved per animal unit[f,g]	1809	1516	1742	1495	43.2	0.339	0.001
Grass silage demand in a forage-only system[h]	2519	2476	2470	2596	37.5	0.367	0.296
Grass silage demand in a silage + concentrate system[h]	2093	2132	2104	2121	43.3	1.000	0.547
Grass silage demand *v.* supply in a forage-only system	−710	−960	−729	−1101	56.8	0.204	0.001
Grass silage demand *v.* supply in a silage + concentrate system	−285	−616	−363	−626	65.0	0.463	0.003

s.e.m., standard error of the mean for PGHM × PGSH.
[a]There were no PGHM × PGSH interactions.
[b]Includes area grazed on both the assigned grazing and silage area.
[c]Live-weight gained at pasture over the average grazing area required per rotation.
[d]Group live-weight or carcass gain from the start of the first winter to pre-slaughter over the average grazing area required per rotation + the assigned silage area.
[e]Animal unit is considered to include both a weanling steer (ca. 350 kg, 10 months of age) and finishing steer (ca. 650 kg, 22 months of age) during the indoor winter period.
[f]Inlcudes silage removed from both the grazing and silage area.
[g]Measured from 4 cm only.
[h]Total silage consumed during first winter and indoor finishing period and corrected for ensilage and feed out loss.

period (Doyle *et al.*, 2021) to increase the chances of achieving a commercially acceptable carcass fat score by 24 months of age. As expected, concentrate supplementation in the finishing period significantly increased carcass weight and fatness (Regan *et al.*, 2018; Doyle *et al.*, 2021, 2022); consequently, all of SC animals were adequately 'finished'.

https://doi.org/10.1017/S0021859623000217 Published online by Cambridge University Press

Herbage production and output/ha

In grass-based systems, herbage production on the farm has a positive impact on key profit drivers such as stocking rate and live-weight gain/ha (Clarke *et al.*, 2013). Consistent with other studies (Binnie and Chestnutt, 1991; Binnie *et al.*, 1997; O'Riordan, 1997; Tuñon, 2013; Wims *et al.*, 2014) regrowth interval was longer for PGHM-2500 than PGHM-1500, which proportionately increased herbage accumulation by 0.08 (+881 kg DM/ha) and 0.17 (+1946 kg DM/ha) on the grazing area and cutting plots, respectively, and could potentially reduce the requirement for fertilizer nitrogen inputs (O'Riordan, 1997). It is hypothesized that the lower herbage production differences on the grazing plots than cutting plots could be attributed to the longer residency time for PGHM-2500 on the grazing area, which can negatively influence herbage production (Fulkerson and Donaghy, 2001).

The greater herbage production for PGHM-2500 mainly resulted in a greater closing cover at the end of the year, which can lengthen the grazing season in the autumn (Hennessy and Kennedy, 2009) or increase grass availability in spring (Claffey *et al.*, 2020). However, this excess herbage production for PGHM-2500 did not affect average grazing area used per rotation and consequently stocking rate (Doyle *et al.*, 2022) or silage preserved per animal unit (Humphreys *et al.*, 2001; Wims *et al.*, 2014; Doyle *et al.*, 2022). Although pasture live-weight gain/ha was higher for PGHM-1500, carcass gain and live-weight gain/ha from weaning to slaughter was similar, due to the compensatory growth that occurred during the indoor finishing period for PGHM-2500. In contrast, increasing PGHM from 1500 to 2000 kg DM/ha increased live-weight gain/ha (+5%) (Doyle *et al.*, 2022) and milk solids yield/ha (+8%) (Wims *et al.*, 2014), in other studies.

Previous research has reported that post-grazing residuals varying from 4 to 8 cm have relatively little effect on pasture yield (Lee *et al.*, 2008). Similarly, in the current study, the greater annual herbage accumulation for PGSH-4 compared to PGSH-6 was relatively small at 526 kg DM/ha which is consistent with previous studies (3 *v.* 6 cm, Frame and Hunt, 1971; 4 *v.* 6 cm, Doyle *et al.*, 2021). Although not significant, Tuñon *et al.* (2014) also reported a 463 kg DM/ha greater herbage accumulation for a PGSH of 4.2 cm compared to 4.9 cm. Nonetheless, the superior herbage growth for PGSH-4 can be attributed to a number of factors including, a lower quantity of old leaf material left behind after grazing (Chapman *et al.*, 2014), increased herbage density (Frame and Hunt, 1971; Chapman *et al.*, 2014) and a longer regrowth interval (Ferraro and Oesterheld, 2002).

The greater herbage supply (herbage production) and lower herbage demand (DMI per steer and area grazed per day) in favour of PGSH-4, consequently decreased the grazing area required per rotation which is consistent with the literature (Ganche *et al.*, 2015; Costa *et al.*, 2021; Doyle *et al.*, 2021). This lower grazing area required can either increase the sum of excess herbage removed as silage or increase the grazing stocking rate. PGSH-4 conserved 270 kg DM (proportionately 0.07) more silage per animal unit than PGSH-6, resulting in 16 days more feeding per animal unit during the indoor period (assuming a combined daily demand of 16.6 kg DM for both a weanling and finishing steer when assuming an edible silage recovery of 0.78 (field to fed losses) (Keating and O'Kiely, 2000). In the SO system, the extra 16 days of grass silage supply for PGSH-4 could result in a 5.8 kg heavier carcass weight. This greater silage supply is consistent with some (Minchin and McGee, 2010; Doyle *et al.*, 2021) but not all (Ganche *et al.*, 2013, 2015) studies. Ganche *et al.* (2013) (2.7 *v.* 4.2 cm) and Ganche *et al.* (2015) (2.7 *v.* 4.8 cm) found PGSH to have no effect on cumulative silage yield as they compared severe PGSH (ca. 4 cm or lower) and as a result reported the higher PGSH (ca. 4 cm) to produce more herbage.

The 14% higher stocking rate on the grazing area (not the whole farmlet) for PGSH-4 than PGSH-6 is consistent with the literature (Mayne *et al.*, 1987; Ganche *et al.*, 2015; Costa *et al.*, 2021; Doyle *et al.*, 2021). Nonetheless, live-weight gain/ha at pasture or carcass gain/ha from weaning to slaughter did not differ between PGSH treatments, which is similar to Doyle *et al.* (2021). The closing cover was greater for PGSH-4 than PGSH-6 (combined across the grazing and silage area), which offers the same benefits for those described above for PGHM-2500 (lengthen the grazing season).

Lastly, it is important to consider the effect that finishing diet had on overall grass silage demand from the grazing system. The grass silage deficit was greater on the SO than SC system, due to a higher daily demand for grass silage on SO. Consequently, where a forage-only grazing system is being implemented, extra land (or a lower stocking rate) will be required to produce extra grass silage for the winter. Therefore, producers must consider that although grazing to 6 cm is more favourable in a forage-only system to increase steer performance at pasture, there is increased risk of a forage deficit over the winter due to less area available for silage production when grazing to 6 cm (assuming fixed animal numbers and land area), coupled with the higher demand for silage consumption in a forage-only system.

Practical implications

Although the PGSH-4 grazing system increased stocking rate or grass silage supply than PGSH-6, the inferior individual animal performance means greater concentrate supplementation would be required during the subsequent indoor finishing winter to achieve a similar carcass weight as PGSH-6, which would result in greater feed costs per animal (Finneran and Crosson, 2013). Considering most commercial beef production systems do not have excessively high stocking rates (Teagasc, 2020a), on the basis of this and other studies (Doyle *et al.*, 2021) it is recommended therefore to graze to a PGSH of 6.0 cm to increase individual steer performance at pasture (cheapest feed resource) and reduce reliance on concentrates. Although the quantity of grass silage produced for winter feeding was lower for PGSH-6 compared to PGSH-4, the former requires a shorter indoor feeding period due to the heavier live-weight at the end of the grazing season, and thus, a lower quantity of grass silage to achieve a target carcass weight.

Conclusion

In the context of a late-maturing breed, weanling-to-beef suckler steer system, it has been shown that, at the individual animal level, grazing 'tightly' (PGSH-4 *v.* PGSH-6), and grazing a high pasture mass (PGHM-2500 *v.* PGHM-1500), in a rotationally stocked system has a negative impact on animal live-weight gain at pasture. The negative effect of 'tight' grazing, but not PGHM, was still evident at the end of an indoor finishing period in terms of a lighter carcass. Nevertheless, overall carcass output/ha was similar between treatments due to compensatory growth during the indoor finishing period for PGHM-2500 compared to

https://doi.org/10.1017/S0021859623000217 Published online by Cambridge University Press

PGHM-1500, and due to a greater grazing area required for PGSH-6 compared to PGSH-4.

Due to concentrate supplementation during the indoor finishing period, all steers on SC achieved a commercially acceptable carcass fat score; whilst, the majority (83%) of SO steers achieved this target.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S0021859623000217

Data availability statement. The datasets used and analysed during the current study are unavailable.

Acknowledgements. The authors acknowledge Dennis Bonnin, Joe Munroe, M.J. Kelly and work placement students for their technical assistance and Francis Collier, Pat Whelan and Patsy Martin for their care of the experimental animals. Also thanks to the staff of Grange laboratories for feed analysis and to Dr Jim Grant for his assistance with statistical analysis. The financial support of Teagasc is gratefully acknowledged.

Author contributions. Conceptualization, P. R. D., M. M., A. P. M., A. K. K. and E. G. O.; methodology, P. R. D., M. M., A. P. M., A. K. K. and E. G. O.; formal analysis, P. R. D., M. M., A. P. M., A. K. K. and E. G. O.; investigation, P. R. D. and E. G. O.; resources, P. R. D., M. M., A. P. M., A. K. K. and E. G. O.; data curation, P. R. D. and E. G. O.; writing – original draft preparation, P. R. D.; writing – review and editing, M. M., A. P. M., A. K. K. and E. G. O.; supervision, E. G. O.; project administration, E. G. O.; funding acquisition, E. G. O. All authors have read and agreed to the published version of the manuscript.

Financial support. The work was supported by Teagasc.

Conflict of interest. None.

Ethical standards. Animal procedures performed in this experiment were approved by the Teagasc Animal Ethics Committee and were conducted in accordance with the European Communities Regulation 2002 and 2005.

References

Alexander S, Black A, Boland A, Burke J, Carton OT, Coulter BS, Culleton N, Dillon P, Hackett R and Humphreys J (2008) Major and micro nutrient advice for productive agricultural crops. 50th anniversary edition ed: Teagasc, Johnstown Castle, Co Wexford.

Allen VG, Batello C, Berretta E, Hodgson J, Kothmann M, Li X, McIvor J, Milne J, Morris C and Peeters A (2011) An international terminology for grazing lands and grazing animals. *Grass and Forage Science* **66**, 2.

Amaral MF, Mezzalira JC, Bremm C, Da Trindade JK, Gibb MJ, Suñe RWM and de F. Carvalho PC (2013) Sward structure management for a maximum short-term intake rate in annual ryegrass. *Grass and Forage Science* **68**, 271–277.

Barrett PD, Laidlaw AS, Mayne CS and Christie H (2001) Pattern of herbage intake rate and bite dimensions of rotationally grazed dairy cows as sward height declines. *Grass and Forage Science* **56**, 362–373.

Binnie R and Chestnutt D (1991) Effect of regrowth interval on the productivity of swards defoliated by cutting and grazing. *Grass and Forage Science* **46**, 343–350.

Binnie R, Kilpatrick D and Chestnutt D (1997) Effect of altering the length of the regrowth interval in early, mid and late season on the productivity of grass swards. *The Journal of Agricultural Science* **128**, 303–309.

Carvalho PCF (2013) Can grazing behaviour support innovations in grassland management? *Proceedings of the 22nd International Grassland Congress*, September 2013 Sydney Australia, pp. 1134–1148.

Cassell D (2002) A randomization test wrapper for SAS PROCs (paper 251–27). Proceedings of the 27th Annual SAS Users Group International Conference. SAS Institute, Cary, NC, 2002.

Chacon E and Stobbs TH (1976) Influence of progressive defoliation of a grass sward on the eating behaviour of cattle. *Australian Journal of Agricultural Research* **27**, 709–727.

Chapman D, McCarthy S and Wims C (2014) Maximising leaf availability using pasture growth principles. *Grazing management the root to success – DairyNZ Technical Series issue* 23. Hamilton, New Zealand.

Claffey A, Delaby L, Boland T and Egan M (2020) Implications of adapting autumn grazing management on spring herbage production – the effect on late lactation milk production and the subsequent response in early lactation animal performance. *Livestock Science* **231**, 103870.

Clarke AM, Brennan P and Crosson P (2013) Life-cycle assessment of the intensity of production on the greenhouse gas emissions and economics of grass-based suckler beef production systems. *The Journal of Agricultural Science* **151**, 714.

Costa CM, Difante GS, Costa ABG, Gurgel ALC, Ferreira Jr MA and Santos GT (2021) Grazing intensity as a management strategy in tropical grasses for beef cattle production: a meta-analysis. *Animal: An International Journal of Animal Bioscience* **15**, 100192.

Curran J, Delaby L, Kennedy E, Murphy JP, Boland TM and O'Donovan M (2010) Sward characteristics, grass dry matter intake and milk production performance are affected by pre-grazing herbage mass and pasture allowance. *Livestock Science* **127**, 144–154.

Difante GD, Euclides VPB, do Nascimento D, da Silva SC, Barbosa RA and Torres RAD (2010) Performance and feed conversion of beef cattle steers on Tanzania guineagrass under two grazing intensities and rotational stocking. *Revista Brasileira De Zootecnia-Brazilian Journal of Animal Science* **39**, 33–41.

Donaghy D, Bryant R, Cranston L, Egan M, Griffiths W, Kay J, Pembleton K and Tozer K (2021) Will current rotational grazing management recommendations suit future intensive pastoral systems? *NZGA: Research and Practice Series* **17**, 225–242.

Doyle PR, McGee M, Moloney AP, Kelly AK and O'Riordan EG (2021) Effect of post-grazing sward height, sire genotype and indoor finishing diet on steer intake, growth and production in grass-based suckler weanling-to-beef systems. *Animals* **11**, 2623.

Doyle PR, McGee M, Moloney AP, Kelly AK and O'Riordan EG (2022) Effect of pre-grazing herbage mass on pasture production and performance of suckler-bred steers during the grazing season and subsequent indoor finishing period. *Livestock Science* **256**, 104814.

Drennan MJ and McGee M (2009) Performance of spring-calving beef suckler cows and their progeny to slaughter on intensive and extensive grassland management systems. *Livestock Science* **120**, 1–12.

Euclides VPB, da Conceição Lopes F, do Nascimento Junior D, da Silva SC, dos Santos Difante G and Barbosa RA (2016) Steer performance on Panicum maximum (cv. Mombaça) pastures under two grazing intensities. *Animal Production Science* **56**, 1849–1856.

Ferraro DO and Oesterheld M (2002) Effect of defoliation on grass growth. A quantitative review. *Oikos* **98**, 125–133.

Finneran E and Crosson P (2013) Effects of scale, intensity and farm structure on the income efficiency of Irish beef farms. *International Journal of Agricultural Management* **2**, 226–237.

Finneran E, Crosson P, O'Kiely P, Shalloo L, Forristal PD and Wallace M (2012) Stochastic simulation of the cost of home-produced feeds for ruminant livestock systems. *The Journal of Agricultural Science* **150**, 123–139.

Frame J and Hunt I (1971) The effects of cutting and grazing systems on herbage production from grass swards. *Grass and Forage Science* **26**, 163–172.

Frame J and Laidlaw AS (2011) *Improved Grassland Management*. Marlborough: Crowood Press.

Fulkerson W and Donaghy D (2001) Plant-soluble carbohydrate reserves and senescence-key criteria for developing an effective grazing management system for ryegrass-based pastures: a review. *Australian Journal of Experimental Agriculture* **41**, 261–275.

Ganche E, Delaby L, O'Donovan M, Boland TM, Galvin N and Kennedy E (2013) Post-grazing sward height imposed during the first 10 weeks of lactation: influence on early and total lactation dairy cow production, and spring and annual sward characteristics. *Livestock Science* **157**, 299–311.

Ganche E, O'Donovan M, Delaby L, Boland TM and Kennedy E (2015) Does post-grazing sward height influence sward characteristics, seasonal herbage dry-matter production and herbage quality? *Grass and Forage Science* **70**, 130–143.

Griffiths W, Hodgson J and Arnold G (2003) The influence of sward canopy structure on foraging decisions by grazing cattle. II. Regulation of bite depth. *Grass and Forage Science* **58**, 125–137.

Hennessy D and Kennedy E (2009) Extending the grazing season. *UK Vet Livestock* **14**, 27–31.

Herron J, Curran TP, Moloney AP, McGee M, O'Riordan EG and O'Brien D (2021) Life cycle assessment of pasture-based suckler steer weanling-to-beef production systems: effect of breed and slaughter age. *Animal: An International Journal of Animal Bioscience* **15**, 100247.

Holmes W (1989) Grass: its production and utilization Blackwell Scientific Publications.

Hornick JL, Van Eenaeme C, Gérard O, Dufrasne I and Istasse L (2000) Mechanisms of reduced and compensatory growth. *Domestic Animal Endocrinology* **19**, 121–132.

Humphreys J, O'Riordan EG and O'Kiely P (2001) Maximising annual intake of grazed grass for beef production, Meath, Ireland, Teagasc.

Keating T and O'Kiely P (2000) Comparison of old permanent grassland, *Lolium perenne* and *Lolium multiflorum* swards grown for silage: 1. Effects on beef production per hectare. *Irish Journal of Agricultural and Food Research* **39**, 1–24.

Lee J, Donaghy D and Roche J (2008) Effect of defoliation severity on regrowth and nutritive value of perennial ryegrass dominant swards. *Agronomy Journal* **100**, 308–314.

Lenehan C, Moloney AP, O'Riordan EG, Kelly A and McGee M (2017) Comparison of rolled barley with citrus pulp as a supplement for growing cattle offered grass silage. *Advances in Animal Biosciences* **8**, 33–37.

MacDonald KA, Penno JW, Lancaster JAS and Roche JR (2008) Effect of stocking rate on pasture production, milk production, and reproduction of dairy cows in pasture-based systems. *Journal of Dairy Science* **91**, 2151–2163.

Maher J (2017) Lessons learned from the beef finalists of the Teagasc Grass10 Farmer of the Year Competition. Teagasc, *National Beef Conference* 2017 *'Planning for Healthy Profits'*, 2017 Tullamore, Ireland. Teagasc, 15–20.

Mayne CS, Newberry RD, Woodcock SCF and Wilkins RJ (1987) Effect of grazing severity on grass utilization and milk production of rotationally grazed dairy cows. *Grass and Forage Science* **42**, 59–72.

McCarthy B, Pierce KM, Delaby L, Brennan A, Fleming C and Horan B (2013) The effect of stocking rate and calving date on grass production, utilization and nutritive value of the sward during the grazing season. *Grass and Forage Science* **68**, 364–377.

McCarthy S, Wims C, Kay J, Chapman D and MacDonald K (2014) Grazing management-striking a balance. *Grazing management the root to success – DairyNZ Technical Series issue* 23. Hamilton, New Zealand.

McDonald RC (1986) Effect of topping pastures 1. Pasture accumulation and quality. *New Zealand Journal of Experimental Agriculture* **14**, 279–289.

McEvoy M, O'Donovan M, Kennedy E, Murphy JP, Delaby L and Boland TM (2009) Effect of pregrazing herbage mass and pasture allowance on the lactation performance of Holstein-Friesian dairy cows. *Journal of Dairy Science* **92**, 414–422.

Mezgebo GB, Moloney AP, O'Riordan EG, McGee M, Richardson RI and Monahan FJ (2017) Comparison of organoleptic quality and composition of beef from suckler bulls from different production systems. *Animal: An International Journal of Animal Bioscience* **11**, 538–546.

Minchin W and McGee M (2010) Effect of post-grazing sward height on grass production and performance of four beef heifer genotypes. *Advances in Animal Biosciences* **1**, 324–324.

Norbu N, Alvarez-Hess P, Leury B, Wright M, Douglas M, Moate P, Williams S, Marett L, Garner J and Wales W (2021) Assessment of RumiWatch noseband sensors for the quantification of ingestive behaviors of dairy cows at grazing or fed in stalls. *Animal Feed Science and Technology* **280**, 115076.

O'Connor A, Moloney AP, O'Kiely P, Boland TM and McGee M (2019) Effects of fertiliser nitrogen rate to spring grass on apparent digestibility, nitrogen balance, ruminal fermentation and microbial nitrogen production in beef cattle and in vitro rumen fermentation and methane output. *Animal Feed Science and Technology* **254**, 114198.

O'Riordan EG (1997) Effect of nitrogen application rate and grass regrowth interval on annual herbage production. *Agricultural Research Forum*, 133–134.

O'Riordan EG, Devaney S and French P (1997) Sward height as a measure of pasture herbage supply. *Irish Journal of Agricultural & Food Research* **36**, 107.

O'Riordan EG, Crosson P and McGee M (2011a) Finishing male cattle from the beef suckler herd. *Irish Grassland Association Journal* **45**, 131–146.

O'Riordan EG, Keane MG and McGee M (2011b) Effects of turn-out date to pasture in spring and post-grazing sward height on performance of dairy crossbred steers during the grazing season. *Agricultural Research Forum*, 86.

O'Riordan EG, McNamee A, Keane MG, Buckley F and McGee M (2011c) Performance and Carcass traits of Holstein-Friesian, Jersey × Holstein-Friesian and Norwegian Red × Holstein-Friesian steers; effect of turnout date and post-grazing sward height. *Agricultural Research Forum,* 106.

Owens D, McGee M and Boland T (2008) Intake, rumen fermentation, degradability and digestion kinetics in beef cattle offered autumn grass herbage differing in regrowth interval. *Grass and Forage Science* **63**, 369–379.

Pérez-Prieto LA and Delagarde R (2012) Meta-analysis of the effect of pregrazing pasture mass on pasture intake, milk production, and grazing behavior of dairy cows strip-grazing temperate grasslands. *Journal of Dairy Science* **95**, 5317–5330.

Piña LF, Balocchi OA, Keim JP, Pulido RG and Rosas F (2020) Pre-Grazing herbage mass affects grazing behavior, herbage disappearance, and the residual nutritive value of a pasture during the first grazing session. *Animals* **10**, 212.

Regan M, McGee M, Moloney AP, Kelly AK and O'Riordan EG (2018) Grass-based suckler steer weanling-to-beef production systems: effect of breed and slaughter age. *Grassland Science in Europe* **23**, 488–490.

Sitienei I, Gillespie J and Scaglia G (2015) Producer perceptions of the importance of challenges currently facing the United States grass-finished beef industry. *The Professional Animal Scientist* **31**, 315–323.

Taylor RF, Crosson P, Kelly AK and McGee M (2018) Benchmarking technical and economic performance of beef cow-calf to finishing production systems in Ireland. *The Professional Animal Scientist* **34**, 421–434.

Taylor RF, McGee M, Kelly AK and Crosson P (2020) Bioeconomic and greenhouse gas emissions modelling of the factors influencing technical efficiency of temperate grassland-based suckler calf-to-beef production systems. *Agricultural Systems* **183**, 102860.

Teagasc (2020a) 2027 Sectoral road map: beef. Available at https://www.teagasc.ie/media/website/publications/2020/2027-Sectoral-Road-Map---Beef.pdf (Accessed 29/01/2021).

Teagasc (2020b) 2027 Sectoral road map: dairy. Available at https://www.teagasc.ie/media/website/publications/2020/Road-Map-2027-Dairy-201120.pdf (Accessed 29/01/2021).

Tharmaraj J, Wales W, Chapman D and Egan A (2003) Defoliation pattern, foraging behaviour and diet selection by lactating dairy cows in response to sward height and herbage allowance of a ryegrass-dominated pasture. *Grass and Forage Science* **58**, 225–238.

Tuñon G (2013) Improving the use of perennial ryegrass swards for dairying in Ireland (Ph.D. thesis). Massey University, Palmerston North, New Zealand.

Tuñon G, Lopez-Villalobos N, Kemp P, Kennedy E, Hennessy D and O'Donovan M (2011) Effect of pre-grazing herbage mass on grazing behaviour, grass dry matter intake and milk production of dairy cows. *Proceedings of the New Zealand Society of Animal Production* **2011**, 28–32.

Tuñon G, Kennedy E, Horan B, Hennessy D, Lopez-Villalobos N, Kemp P, Brennan A and O'Donovan M (2014) Effect of grazing severity on perennial ryegrass herbage production and sward structural characteristics throughout an entire grazing season. *Grass and Forage Science* **69**, 104–118.

Werner J, Viel J, Niederhauser J, O'Leary N, Umstatter C and O'Brien B (2018) Validation of new algorithms for the RumiWatch noseband sensor to detect grazing behaviour of dairy cows. *Grassland Science in Europe* **23**, 917–919.

Wims CM, Delaby L, Boland TM and O'Donovan M (2014) Effect of pre-grazing herbage mass on dairy cow performance, grass dry matter production and output from perennial ryegrass (*Lolium perenne* L.) pastures. *Animal: An International Journal of Animal Bioscience* **8**, 141–151.