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Corresponding author:
Michael Egan;
Email: Michael.egan@teagasc.ie

The effect of spring grass availability and silage supplementation on dairy cow performance and dry matter intake during early lactation

Sarah Walsh[1,2], Luc Delaby[3], Michael Kennedy[1], Zoe McKay[4], Michael O'Donovan[1], Christina Fleming[1] and Michael Egan[1]

[1]Teagasc, Animal & Grassland Research and Innovation Centre, Moorepark, Fermoy, Co. Cork Ireland; [2]School of Agriculture and Food Science, University College Dublin, Belfield, Dublin 4, Ireland; [3]INRAE, Institut Agro, UMR Physiologie, Environnement et Génétique pour l'Animal et les Systèmes d'Elevage, 35590 Saint-Gilles, France and [4]School of Agriculture and Food Science, University College Dublin, Lyons Farm, Lyons Estate, Celbridge, Naas, Co. Kildare, Ireland

Abstract

The objectives of this study were to investigate the effect of level and timing of silage supplementation during early lactation on animal performance and dry matter intake (DMI). Two farm-lets were established with a high (1253 kg DM/ha) and low (862 kg DM/ha) grass availability at turnout. In spring, cows were assigned to one of two treatments as they calved over 2 years; high grass (HG) and low grass (LG). During period 1 (week 1–6), cows on the HG treatment were offered a high daily herbage allowance (DHA) with low silage and the LG treatment were offered a low DHA with high silage. In period 2 (week 7–12), half of the cows from the HG treatment in P1 switched to the LG treatment in P2 and vice versa as 20 LG cows in P1 switched to the HG treatment in P2. Cows on the HG treatment in P2 received a high DHA with no silage and the LG treatment received a low DHA with 3 kg DM/cow silage. Grass DMI was significantly higher for the HG treatment during both periods (+1.6 and +3.4 kg DM/cow/day, respectively). The HG treatment produced +0.9 kg milk/cow/day and had a higher protein concentration (+1.1 g/kg milk) compared to cows on the LG treatment during period 2. Differences in animal performance observed in period 2 were maintained throughout the 8-week carryover period.

Introduction

Pasture-based dairy production systems have a competitive advantage to increase farm profitability with improved grass utilization (Hanrahan *et al.*, 2018) and extending the grazing season (Läpple *et al.*, 2012). Rising input prices (fertilizer and concentrate) in recent years have increased feed costs on Irish dairy farms, with the cost of grazed grass increasing by 29% in 2022 (Doyle *et al.*, 2022). Increasing supplementation results in an increase in overall feed cost, with concentrate and grass silage costing 73 and 41% more compared to grazed grass, respectively (Doyle *et al.*, 2022). Grazed grass still remains to be the cheapest feed source available on Irish grassland farms (Finneran *et al.*, 2012; Doyle *et al.*, 2022). Spring grass has a high nutritive value and can meet the majority of the requirements of early lactation dairy cows (Sayers and Mayne, 2001) and as such the proportion of grazed grass in the diet in spring should be maximized (Kennedy *et al.*, 2005). The seasonality of grass growth limits grass availability during winter and spring, resulting in the need for grass silage supplementation to meet herd demand. Inclement and wet weather in spring can also increase the need for grass silage supplementation in order to reduce pasture damage while grazing.

The adaption of autumn grazing management (Claffey *et al.*, 2020a; Looney *et al.*, 2021) can somewhat negate the need for additional supplementation in spring as grass is allowed to accumulate over the winter period (Looney *et al.*, 2021). Claffey *et al.* (2020a) reported earlier housing in autumn led to increases in grass dry matter intake (DMI) during the subsequent spring as a result of higher opening farm cover (OFC – herbage mass available on farm at turnout (kg DM/ha)) which facilitates greater daily herbage allowance (DHA), while having no negative impact on animal production the previous autumn (Claffey *et al.*, 2020a). Previous studies have reported an increase in milk production, when DHA was increased from 15 to 17 kg DM/cow/day with 3 kg/cow/d concentrate supplementation (Kennedy *et al.*, 2005; McEvoy *et al.*, 2008; Claffey *et al.*, 2020a) with McEvoy *et al.* (2008) reporting the benefits of increasing DHA during early lactation were still evident in mid-lactation.

The spring rotation planner (SRP) is a grazing tool utilized in the Irish pasture-based system which allocates a set area to be grazed each day throughout the first rotation in order to ensure grass in the diet (Teagasc, 2017). Previous research investigated the SRP targets by utilizing varying DHA with no silage supplementation (Claffey *et al.*, 2020b) and comparing cows offered *ad libitum* silage with cows on a grass-only diet during early lactation (Dillon *et al.*, 2002; Kennedy *et al.*, 2005). There is limited research on the effect of including low levels of grass silage in the diet to extend the first rotation when grass supply is inadequate. It is important that cows are not over allocated areas above the SRP targets as it can lead to a reduction in grass supply for the second rotation (Claffey *et al.*, 2019a), as a result, grass silage may need to be offered to animals in spring to ensure animal intake requirements are met. On–off grazing strategies as described by Kennedy *et al.* (2011) can also be implemented in spring, whereby cows graze for a few hours each day, to increase grass DMI during early lactation (Dillon *et al.*, 2002; Kennedy *et al.*, 2011). The rate and timing of silage supplementation warrants investigation as climatic conditions and grass growth are highly variable in spring and across years.

In order to ensure spring grass availability, dairy cows are housed indoors during the winter period to allow grass to accumulate over winter and are turned out to pasture after calving (Ramsbottom *et al.*, 2020). The use of a 6–8-week compact calving season in the Irish grass based system increases the risk of restriction during early lactation as grass growth does not meet demand at this time. Dairy cows diets, particularly during early lactation, can have a significant impact on animal performance (Kennedy *et al.*, 2007). Restricting DMI during early lactation has been shown to have a negative impact on subsequent milk production (Claffey *et al.*, 2019b). Claffey *et al.* (2020a) reported an increase in milk production of 0.38 kg milk/cow/day per kg DM increase in DHA. Lewis *et al.* (2011) reported that an all grass diet can meet dairy cow's nutritive requirements (with a peak milk yield of 25 kg/cow/day) from week four of lactation onwards; however, inadequate grass supply and inclement weather at this time can limit Irish dairy farms from achieving this (Hurtado-Uria *et al.*, 2013).

The current study investigated the effect of introducing grass silage supplementation immediately after calving, as previous research has investigated silage supplementation from week three of lactation onwards (Dillon *et al.*, 2002; Kennedy *et al.*, 2011). The objective of this experiment was to investigate the effect of quantity and timing of silage supplementation during early lactation, on subsequent animal performance and its impact on individual DMI.

Materials and methods

Experimental site and design

This experiment was conducted at the Teagasc Animal & Grassland Research and Innovation Centre, Moorepark, Fermoy, Co. Cork (52°7′3′′N, 8°16′42′′W; 49 m above sea level). The experiment was carried out from 1 February to 12 June 2021 (year 1) and 1 February to 18 June 2022 (year 2). The soil type was a free draining, acid brown soil with a sandy loam to loam texture. Soils had a pH of 6.8 (±0.2), P Index of 3.8 (±0.4) and K Index of 3.3 (±0.8; scale 1–4; 1 = deficient, 4 = no response to application of nutrient; Alexander *et al.*, 2008). Daily rainfall (mm), air temperature (°C) and soil temperature to a depth of 100 mm (°C) were recorded daily at the experimental site. The swards mainly consisted of perennial ryegrass (PRG) (*Lolium perenne* L; PRG > 85%), while the remainder consisted of meadow grasses and white clover (*Poa*, *festuca pratensis* and *trifolium repens* L., cv. Chieftain). Two farm-lets of 15.3 ha were established with 23 paddocks per treatment. Paddocks remained on the same treatment for the 2 years of the experiment. Two levels of spring grass availability were established (high and low grass) using different closing grazing strategies during the previous autumn. The final rotation for the high grass paddocks began on 28 September 2020 (year 1) and 27 September 2021 (year 2), while the final rotation for the low grass paddocks began on 12 October 2020 (year 1) and 11 October 2021 (year 2). The final rotation for both treatments was 45 days. The OFC achieved in year 1 (1 February) and year 2 (28 January) were 1080 (high) and 800 (low) kg DM/ha and 1426 (high) and 923 (low) kg DM/ha, respectively.

A total of 80 spring calving Holstein Friesian and Holstein Friesian × Jersey cows (60 multiparous and 20 primiparous) were randomized based on the previous year's milk production (multiparous) or dam's first lactation (primiparous), parity, breed, bodyweight and body condition score (BCS) at calving (Table 1). Cows were randomly assigned to one of four treatments and placed into one of two grazing groups as they calved; high grass (HG) or low grass (LG). Cows calved indoors and were then placed in the Moorepark general herd, during this time they were allocated fresh grass (10 kg/cow) with 3 kg concentrate/cow/day. The experimental period began on 1 February in both years and cows were turned out to graze in their respective treatment 3 days after calving. A high-order cross-over design was

Table 1. Initial herd characteristics for the animals used in the experiment in year 1 (2021) and year 2 (2022)

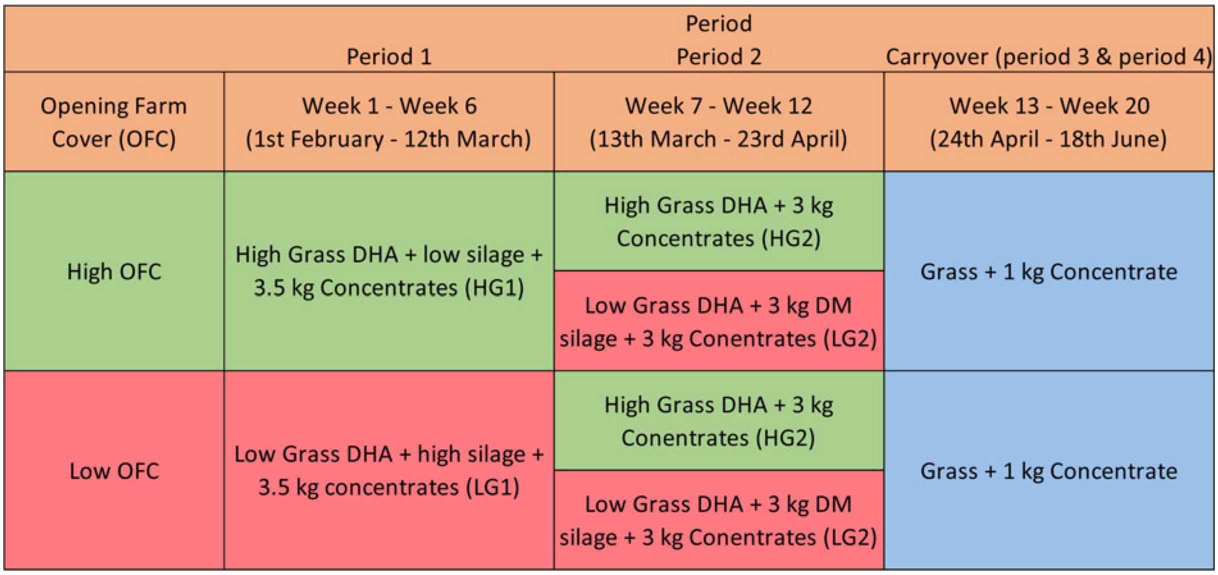
Variable	Mean (2021)	S.D. (2021)	Mean (2022)	S.D. (2022)
Calving date	12 Feb	±17	18 Feb	±20
Breed (Holstein/HF × Jersey)	10[a]/10[b]	-	7[a]/13[b]	-
Lactation number	3	±2.0	3	±1.9
Daily milk yield (kg/cow)	20	±4.1	17	±3.4
Milk protein concentration (g/kg milk)	3	±2.5	38	±2.3
Milk fat concentration (g/kg milk)	50	±5.4	54	±6.1
Daily milk solids yield (kg/cow)	1.7	±0.35	1.5	±0.31
Pre-experimental body weight (kg/cow)	598	±76.7	496	±62.0
Pre-experimental body condition score	3.2	±0.28	3.1	±0.37

[a] Holstein,
[b] Holstein × Jersey.

implemented which has previously been referred to as Balaams design (Balaam, 1968; Hughes *et al*., 2003; Verdon *et al*., 2018) which can be used to reduce variation and bias due to half of the experimental units (individual animal) remaining on the same treatment throughout the experiment (Rezaei, 1997). Two dietary treatments were utilized in four possible sequences whereby 40 cows remained on either the HG or LG treatment (20 per treatment) throughout P1 and P2 while the remaining 40 animals ($n = 20$) crossed over treatments after P1 for the remainder of the experimental period (P2) (Fig. 1).

The experimental period was divided into two periods; period 1 (P1 = week 1–6 of the experiment) and period 2 (P2 = week 7–12 of the experiment) (Fig. 1). During P1 cows on the HG treatment (HG1) were offered a high DHA, which was calculated daily, and adjusted using the previous days post-grazing sward height, with low silage supplementation while cows on the LG treatment (LG1) were offered a lower DHA with high silage supplementation. At the end of the first 6-week period (P1), 20 cows from the HG treatment changed over to the LG treatment, while the other 20 cows remained on the HG treatment for P2, similarly 20 of the cows on the LG treatment in P1 changed over to the HG treatment, while the other 20 cows remained on the LG treatment for P2. During P2, cows on the HG treatment (HG2) were offered a high DHA with no silage supplementation while cows on the LG treatment (LG2) were offered a lower DHA with 3 kg DM silage/day. All cows were offered the same concentrate supplementation throughout P1 (3.5 kg/cow) and P2 (2.9 kg/cow) for years 1 and 2, and this was offered during morning and evening milking each day. The concentrate was made up of soybean meal (300 g/kg of fresh weight), beet pulp/molasses (155 g/kg), barley (150 g/kg), maize (130 g/kg), maize distillers (120 g/kg), rapeseed meal (75 g/kg), Megalac (33 g/kg; Volac Wilmar Feed Ingredients Ltd, Hertfordshire, UK), maize/beet (25 g/kg), acid buff (7 g/kg) and salt (5 g.kg); the UFL content of the concentrate was 0.92 and the CP content was 14%.

During P1 and P2, cows were offered a DHA which was calculated using the pre-grazing herbage mass (preGHM) to a target post-grazing sward height (postGSH) of 4 cm. Fresh pasture was offered after morning and evening milking each day and back fences were used to avoid re-grazing previous allocations. Cows on the LG1, HG1 and LG2 treatments were allocated their grass silage supplementation indoors after morning milking and were allowed out to pasture at 11.00 h. Fresh silage was offered daily to the cows using a Keenan diet feeder (Keenan Holdings limited, Borris, Co. Carlow, Ireland) to ensure the silage was evenly distributed along the feed barrier. The feed face was 12 m in length, with each cow having 0.3 m of head space for feeding as recommended by Teagasc (Teagasc, 2016). During periods of heavy rainfall, animals on the LG1, HG1 and LG2 treatments were allowed access to pasture before receiving their silage allocation in order to minimize damage by reducing time spent in the paddock. During periods of extreme weather events during P1, cows were fully housed with silage supplementation (4 days in year 1 and 1 day in year 2). Grass silage offered to cows in years 1 and 2 of the study was first cut silage and harvested on 20 May 2020 and 28 May 2021 at a pre-cutting herbage mass of 5350 and 5050 kg DM/ha, respectively. Swards used for silage mainly consisted of PRG (>85%; *cv. Fintona*, *Moira* and *Astonconqueror*) while the remainder consisted of meadow grasses (*Poa*, *festuca pratensis*). Fresh grass was cut and allowed to wilt for 24 h to ensure adequate DM content (>30%) was achieved at harvesting. All silage was harvested using a self-propelled precision chop harvester to a chop length of 25–50 mm, before being stored and ensiled in a silage clamp. Anaerobic conditions were created to allow for fermentation to occur by removing all air and covering the silage clamp with a thick polythene sheet. The silage used for both treatments throughout the experimental period was taken from the same silage pit in each year to ensure silage quality remained consistent throughout the experimental period.



		Period	
	Period 1	Period 2	Carryover (period 3 & period 4)
Opening Farm Cover (OFC)	Week 1 - Week 6 (1st February - 12th March)	Week 7 - Week 12 (13th March - 23rd April)	Week 13 - Week 20 (24th April - 18th June)
High OFC	High Grass DHA + low silage + 3.5 kg Concentrates (HG1)	High Grass DHA + 3 kg Concentrates (HG2)	Grass + 1 kg Concentrate
		Low Grass DHA + 3 kg DM silage + 3 kg Conentrates (LG2)	
Low OFC	Low Grass DHA + high silage + 3.5 kg concentrates (LG1)	High Grass DHA + 3 kg Conentrates (HG2)	Grass + 1 kg Concentrate
		Low Grass DHA + 3 kg DM silage + 3 kg Conentrates (LG2)	

Figure 1. Experimental design illustrating the diets offered to the high grass (HG) and low grass (LG) grazing groups throughout the experimental period. During period 1 (P1) cows on the HG treatment (HG1) were offered a high DHA with low silage supplementation while cows on the LG treatment (LG1) were offered a lower DHA with high silage supplementation. At the end of the first 6-week period (P1), 20 cows from the HG treatment changed over to the LG treatment, while the other 20 cows remained on the HG treatment for period 2 (P2), similarly 20 of the cows on the LG treatment in P1 changed over to the HG treatment, while the other 20 cows remained on the LG treatment for P2. Both treatments received the same DHA and concentrates with no silage supplementation during the carryover period (periods 3 and 4).

At the end of the 12-week experimental period (P1 and P2), there was an 8-week carryover period (weeks 13–20 in years 1 and 2), during which all animals were managed similarly. The carryover period was divided into two sub-periods of 4 weeks; period 3 (P3 = weeks 13–16) and period 4 (P4 = weeks 17–20). During P3 and P4, animals remained in two grazing groups which both received the same DHA to a postGSH of 4 cm (≈17 kg DM/cow/day) using 24 h allocations of fresh pasture and 1 kg concentrate supplementation. Average rotation length was 24 days for P3 and 21 days for P4 for both groups. Silage was not offered to either group during P3 or P4.

Sward measurements

Pre-grazing herbage mass (>4 cm) was determined in each paddock ($n = 23$) prior to grazing at each grazing rotation ($n = 4$) using an Etesia mower (Etesia UK Ltd, Warwick, UK) to cut two strips (1.2 × 10 m). Grass height was measured before and after harvesting each strip using a rising plate meter (Jenquip rising plate meter, New Zealand), in order to calculate sward density. All of the mown herbage was collected and weighed and a sample (300 g) was collected. A sub-sample (100 g) of the herbage sample was dried for 16 h at 90°C to determine the DM content. Pre-grazing herbage mass was calculated using the following equation (O'Donovan *et al.*, 2002):

$$\text{Pre-grazing herbage mass (kg DM/ha)} = \left(\frac{Weight\ (kg)}{Area\ (Length\ \times 1.2)} \times 10,000\right) \times \frac{DM\ \%}{100}$$

Sward density was then calculated using the following equation:

$$\text{Sward density (kg DM/cm/ha)} = \frac{Herbage\ mass\ (kg\ DM/ha)}{Pre-cutting\ height - Post-cutting\ height}$$

Pre-grazing herbage mass was corrected to 4 cm using the following equation:

$$\text{Pre-grazing herbage mass} > 4\ \text{cm (kg DM/ha)} =$$

$$Pre-cutting\ height\ (cm) - 4\ \times sward\ density\ (kg\ DM/cm/ha)$$

Pre-grazing sward height (preGSH) (>4 cm) and postGSH were measured daily by taking 40 measurements diagonally across the allocation before and after grazing using a rising plate meter (Jenquip Rising Plate Meter, New Zealand).

Herbage removed was determined daily to estimate apparent DMI of the treatment groups during the carryover period using the following equation:

$$(([PreGSH\ (cm) - PostGSH\ (cm)]\ \times sward\ density)$$
$$\times\ daily\ grazing\ area\ /no.\ animals$$

Silage DM content was determined weekly by taking a 100 g sub sample and drying it for 16 h at 90 °C. The silage DM content was used to calculate the daily fresh weight allocation using the following calculation: (Number of cows × kg DM offered)/DM %. Silage samples were also taken weekly to determine silage quality. A 100 g sub sample was taken from silage that was offered to the cows and dried at 40 °C for 48 h before being milled through a 1 mm sieve and stored for analysis.

Wet chemistry was used to determine the chemical composition of grazed herbage and grass silage. Herbage was taken from each paddock prior to grazing and dried at 60°C for 48 h before being milled through a 1 mm sieve. Samples were bulked for each treatment by week, and were subsequently analysed for DM, organic matter digestibility (OMD), acid detergent fibre (ADF), neutral detergent fibre (NDF), crude protein (CP) and crude ash. In vitro neutral detergent cellulose method (Morgan *et al.*, 1989) (FibertecTM Systems; Foss, Ballymount, Dublin) was used to estimate OMD and calculated with the equation described by Garry *et al.* (2018). The ADF and NDF concentrations were determined using a fibre analyser (AOAC, 1995, method 973.18) based on the method described by Van Soest *et al.* (1991). CP concentration was determined using a nitrogen (N) analyser (Leco FP-428; Leco Australia Pty Ltd., Baulkham Hills, NSW, Australia) based on the AOAC method 990-03 (AOAC International, 1990). Crude ash concentration was estimated by burning a subsample in a muffle furnace at 500 °C for 12 h (AOAC, 1995, method 942.05). Silage samples for the 12-week experimental period were also bulked by week for both treatments, and analysed using wet chemistry for DM, OMD, ADF, NDF, CP and crude ash concentrations as described previously. The OMD content of the silage was determined in vitro after samples were dried at 40 °C for 48 h and milled using a 1 mm sieve.

Animal measurements

Animals were milked twice daily during the experimental period at 7.00 and 15.00 h. Milk yields (kg) for each cow were recorded at morning and evening milking (Dairymaster, Causeway, Co. Kerry). Fat and protein concentrations were determined weekly by taking milk samples from one successive morning and evening milking, and analysed using Milkoscan 203 (Foss Electric DK-3400, Hillerød, Denmark).

Bodyweight and BCS were measured weekly throughout the experimental period. Cows were weighed using an electronic portable weighing scales and Winweigh software package (Tru-test Limited, Auckland, New Zealand). BCS was recorded by an experienced independent observer using a scale ranging from 1 to 5, where 1 = emaciated and 5 = extremely fat, with 0.25 increments (Edmondson *et al.*, 1989).

Individual total DMI were measured for both treatments on weeks 2, 4, 6, 8, 10 and 12 of the experimental period (during P1 and P2) using the n-alkane technique as described by Mayes *et al.* (1986) and modified by Dillon and Stakelum (1989). Average total DMI were calculated for the HG and LG treatments during P1 and P2. All cows were dosed for 11 days before morning and evening milking with a paper bullet (Carl Roth, GmbH, Karlesruhe, Germany) containing 500 mg of dotriacontane (C32, alkane). On days 7–11 of dosing, faecal samples were collected from all cows morning and evening before milking and stored at −20°C. Faecal samples were thawed and bulked by cow (14.4 g/sample, 144 g total) once all samples were collected. Bulked faeces samples were dried for 72 h at 60°C and milled through a 1 mm sieve and stored for analysis for alkane concentration. Herbage samples representative of the next day's grazing were taken during the sampling period. Two herbage samples of ~15 individual grass snips were manually collected using

Gardena hand shears on days 5–9 for both treatment groups. The herbage was stored at −20°C, bowl chopped (Muller, typ MKT 204 Special, Saabrücken, Germany) and freeze dried at −50°C for 72 h before being milled through a 1 mm sieve and stored for analysis of alkane concentration. Dry matter intake was estimated using the equation described by Mayes *et al.* (1986):

$$DMI(kg) = \frac{(Fi/Fj\,) \times Dj}{Hi - ((Fi/Fj) \times Hj)}$$

where F_i is the concentration (mg/kg DM) of the C31 (odd number of carbon atoms) natural alkanes in faeces, F_j is the concentration in faeces of the C32 (even number of carbon atoms) from the dosed synthetic C32 alkane external marker, H_i is the concentration of C31 in herbage, H_j is the concentration of C32 in the herbage and D^j is the daily dose of C32 (mg/day).

Statistical analysis

Statistical analysis was carried out using SAS version 9.4 (SAS Institute Inc., Cary, NC, USA, 2002). Pre-grazing herbage mass, preGSH and postGSH were analysed using PROC MIXED in SAS. Paddock was the experimental unit and week of experiment was the repeated measure. The variables included in the model were year, treatment, week and the interaction between treatment and year. Herbage variables were analysed separately for periods 1, 2, 3 and 4. These variables were analysed using the following model:

$$Y_{abcd} = \mu + T_a + Y_b + W_c + (Y_b x T_a) + e_{abcd}$$

where Y_{abcd} is the response of herbage d in treatment a, in year b, in week c; μ, mean; T_a, treatment ($a = 1$ or 2); Y_b, year ($b = 1$ or 2); W_c, week of experiment ($c = 1$–20); $Y_b \times T_a$, interaction between year and treatment; e_{abcd}, the residual error term.

Average daily milk yield, weekly milk fat and protein concentration, milk fat and protein yield and daily milk solids were analysed using PROC MIXED in SAS. The individual cow was the experimental unit and week of experiment was the repeated measure. Pre-experimental milk production, bodyweight, days in milk at the start of the experiment and BCS were used as co-variates in the model. The experiment was split into two periods (P1 = weeks 1–6 and P2 = weeks 7–12) and the carryover was also split into two periods (P3 = weeks 13–16 and P4 = weeks 17–20).

Each period was analysed separately to investigate the effect of treatment in P1 and P2 on animal performance during the experimental and carryover periods. The interaction between the treatment applied in P1 and treatment applied in P2 was analysed to determine the impact of treatment within and across periods. All non-significant interactions ($P > 0.05$) were removed from the model. The change in bodyweight from the start of P1 to the end of P2 and the end of P4 was also analysed. The model contained terms associated with production including breed, parity, days in milk, year and treatment.

Data was analysed using the following model for P1:

$$Y_{hijklmn} = \mu + B_h + P_i + T_j + Y_l + W_m + (W_m x T_j) + X_{hijklm} + DIM_{hijklm} + e_{hijklm}$$

where $Y_{hijklmn}$ is the response of the animal n of breed h, in parity i, in treatment j or k, in year l and in week m; μ, mean; B_h, breed ($h = 1$ or 2); P_i, parity ($i = 1$, 2 or 3); T_j, treatment in period 1 ($j = 1$ or 2); Y_l, year ($l = 1$ or 2); W_m, week of experiment ($m = 1$–6); $W_m \times T_j$, interaction between week and treatment in period 1; X_{hijklm}, pre-experimental milk production or bodyweight variables; DIM_{hijklm}, days in milk at the start of the experiment; e_{hijklm}, the residual error term.

Data were analysed using the following model for P2 and the carryover periods (P3 and P4):

$$Y_{hijklmn} = \mu + B_h + P_i + T_j + T_k + Y_l + W_m + (T_j x T_k) + (W_m x T_j) + (W_m x T_k) + X_{hijklm} + DIM_{hijklm} + e_{hijklm}$$

where $Y_{hijklmn}$ is the response of the animal n of breed h, in parity i, in treatment j or k, in year l and in week m; μ, mean; B_h, breed ($h = 1$ or 2); P_i, parity ($i = 1$, 2 or 3); T_j, treatment in period 1 ($j = 1$ or 2); T_k, treatment in period 2 ($k = 1$ or 2); Y_l, year ($l = 1$ or 2); W_m, week of experiment ($m = 7$–12 for P2, 13–16 for P3 and 17–20 for P4); $T_j \times T_k$, interaction between treatment in period 1 and treatment in period 2; $W_m \times T_j$, interaction between week and treatment in period 1; $W_m \times T_k$, interaction between week and treatment in period 2; X_{hijklm}, pre-experimental milk production or bodyweight variables; DIM_{hijklm}, days in milk at the start of the experiment; e_{hijklm}, the residual error term.

Results

Meteorological data

Meteorological data for the experimental period (February to June, 2021 and 2022, respectively named years 1 and 2) are presented in Table 2. There was a higher air temperature during the winter of year 2 which resulted in higher levels of herbage for the HG and LG treatments compared to year 1. There was large variability in the amount of rainfall in spring between years with 62.6 mm more rainfall in February and March of year 1 compared to year 2. There was 43.8 mm more rain during February and March of years 1 and 2 of the study compared to the previous 10-year average (2011–2020).

Herbage parameters

There was a significant effect of year on OFC as OFC was significantly higher in year 2 ($P < 0.05$) compared to year 1 for the HG and LG treatments (+346 and +123 kg DM/ha, respectively).

Period 1 (weeks 1–6)

Herbage variables

Treatment had a significant effect ($P > 0.05$) on preGHM and preGSH as both were higher for the HG1 treatment compared to the LG1 treatment (+366 kg DM/ha and +0.57 cm, respectively) (Table 3). Mean chemical composition for grazed grass and grass silage offered to the HG1 and LG1 treatments is reported in Tables 4 and 5, respectively.

Dry matter intake

As planned, treatment had a significant effect ($P < 0.05$) on grass and silage DMI (Table 6). The HG1 treatment had a higher grass DMI compared to the LG1 treatment (+1.6 kg DM/cow) and silage DMI was significantly higher for the LG1 treatment (+2 kg DM/cow). There was no difference in total DMI (13.9 kg DM/cow/day) between the HG1 and LG1 treatments. There was a

Table 2. Meteorological data measured at the experimental site during the experimental (1 February–23 April) and carryover (24 April–18 June) period for years 1 and 2 in contrast to the 10-year average (2011–2020)

		February	March	April	May	June	Mean
Mean air temp (°C)	Year 1	6.3	7.5	7.4	9.8	14.4	9.1
	Year 2	7.4	6.7	9.1	12.4	13.8	9.9
	10-yr avg.	6.0	6.6	8.8	11.5	13.9	9.3
Total rainfall (mm)	Year 1	189.9	52.7	22.5	130.8	26.9	84.6
	Year 2	96.9	83.1	69.3	43.6	73.4	73.3
	10-yr avg.	95.9	71.6	75.1	63.0	80.7	77.3
Mean soil temp (°C) @ 100 mm depth	Year 1	7.0	7.8	9.4	11.1	14.1	9.9
	Year 2	8.2	8.0	9.7	12.5	14.2	10.5
	10-yr avg.	7.0	7.6	9.4	11.6	14.2	10.0

Table 3. The effect of the high grass (HG) and low grass (LG) treatments on pre- and post-grazing sward height and pre-grazing herbage mass during periods 1 and 2 in years 1 and 2 of the experiment

	Period 1[a]		Period 2[b]			*P*-value		
	HG1	LG1	HG2	LG2	S.E	Year	Treatment	Year × treatment
PreGSH (cm)	9.0	8.4	11.9	11.3	0.39	0.044	0.062	0.041
PostGSH (cm)	3.99	3.96	4.02	3.94	0.093	<0.001	0.453	0.726
PreGHM (kg DM/ha)	1469	1103	1906	1895	81.3	<0.001	0.055	0.270

HG1, high grass daily herbage allowance (DHA) with low silage supplementation during period 1; LG1, low grass DHA with high silage supplementation during period 1; HG2, high DHA with no silage supplementation during period 2; LG2, low DHA with silage supplementation during period 2; PreGSH, pre-grazing sward height; PostGSH, post-grazing sward height; PreGHM, pre-grazing herbage mass.

[a] Period 1 = 1 February–12 March (weeks 1–6).

[b] Period 2 = 13 March–23 April (weeks 7–12).

Table 4. Mean sward composition for the high grass (HG) and low grass (LG) treatment during periods 1 and 2 analysed by wet chemistry

	Period 1[a]		Period 2[b]	
	HG1	LG1	HG2	LG2
Organic matter digestibility	0.763	0.772	0.799	0.802
Crude protein (g/kg DM)	250	231	216	208
Neutral detergent fibre (g/kg DM)	448	434	428	425
Acid detergent fibre (g/kg DM)	216	213	200	199
Crude ash (g/kg DM)	104	107	96	97

HG1, high grass daily herbage allowance (DHA) with low silage supplementation during period 1; LG1, low grass DHA with high silage supplementation during period 1; HG2, high DHA with no silage supplementation during period 2; LG2, low DHA with silage supplementation during period 2.

[a] Period 1 = 1 February–12 March (weeks 1–6).

[b] Period 2 = 13 March–23 April (weeks 7–12).

Table 5. Mean chemical composition for silage offered to the high grass (HG) treatment during P1 and low grass (LG) treatment during periods 1 and 2 analysed by wet chemistry

	Period 1[a]		Period 2[b]	
	HG1	LG1	HG2	LG2
Organic matter digestibility	0.704	0.704	–	0.744
Crude protein (g/kg DM)	135	134	–	141
Neutral detergent fibre (g/kg DM)	503	507	–	470
Acid detergent fibre (g/kg DM)	317	310	–	291
Crude ash (g/kg DM)	86	82	–	80

HG1, high grass daily herbage allowance (DHA) with low silage supplementation during period 1; LG1, low grass DHA with high silage supplementation during period 1; HG2, high DHA with no silage supplementation during period 2; LG2, low DHA with silage supplementation during period 2.

[a] Period 1 = 1 February–12 March (weeks 1–6).

[b] Period 2 = 13 March–23 April (weeks 7–12).

significant effect ($P < 0.05$) of DMI measurement period on grass, silage and total DMI with total DMI increasing by 1.7 kg DM/cow from measurement 1 to 3.

Animal production

There was no effect of treatment on any of the milk production variables in P1 (Table 7). There was a significant effect ($P < 0.001$) of year for daily milk yield, milk fat yield, milk protein yield and milk solids yield, which were all greater in year 1 (+2.2 kg milk/cow/day, 0.15 kg/cow/day, 0.05 kg/cow/day and 0.20 kg milk solids/cow/day, respectively) compared to year 2. There was a significant interaction ($P < 0.05$) between treatment during P1 and week number for milk fat concentration, as milk

Table 6. The effect of the high grass (HG) and low grass (LG) treatment during periods 1 and 2 on grass dry matter intake (DMI), silage DMI, concentrate DMI and total DMI in years 1 and 2 of the experiment

	Period 1[a]		Period 2[b]			*P*-value					
	HG1	LG1	HG2	LG2	S.E	Treat P1	Treat P2	Measurement period	Treat P1 × treat P2	Treat P1 × measurement period	Treat P2 × measurement period
Grass intake (kg DM/day)	6.9	5.3	13.9	10.5	0.21	<0.001	<0.001	<0.001	0.538	0.006	<0.001
Silage intake (kg DM/day)	3.4	5.4	0.0	3.4	0.12	<0.001	<0.001	<0.001	0.217	0.004	<0.001
Concentrate intake (kg DM/day)	3.5	3.4	2.8	2.9	0.02	0.035	0.408	<0.001	0.857	0.276	0.111
Total intake (kg DM/day)	13.8	14.0	16.6	16.7	0.25	0.524	0.513	<0.001	0.821	0.010	<0.001

HG1, high grass daily herbage allowance (DHA) with low silage supplementation during period 1; LG1, low grass DHA with high silage supplementation during period 1; HG2, high DHA with no silage supplementation during period 2; LG2, low DHA with silage supplementation during period 2; Treat P1, treatment during period 1; Treat P2, treatment during period 2.

[a] Period 1 = 1 February–12 March (weeks 1–6).

[b] Period 2 = 13 March–23 April (weeks 7–12).

fat concentration reduced for the first 4 weeks of the experiment for both treatment groups and increased on week 5. There was no effect of treatment on bodyweight or BCS in P1.

Period 2 (weeks 7–12)

Herbage variables

There was no effect of treatment on any herbage variables during P2 (Table 3). Mean chemical composition for grazed grass and grass silage offered to the HG2 and LG2 treatments is reported in Tables 4 and 5, respectively.

Dry matter intake

Treatment during P2 had a significant effect ($P < 0.01$) on grass and silage DMI (Table 6). The HG2 treatment had a significantly higher ($P < 0.05$) grass DMI (+3.4 kg DM) and the LG2 cows had a higher silage intake (+3.4 kg DM), while total DMI intakes were similar for the HG2 and LG2 treatments (16.7 kg DM/cow/day). There was a significant effect ($P < 0.05$) of measurement period on grass, silage and total DMI with total DMI increasing by 1.9 kg DM/cow from measurement 3 to 6.

Animal production

The effects of the HG2 and LG2 treatment on animal production are reported in Table 7. Treatment in P1 had no carry-over effect on any milk production variables in P2. Treatment in P2 had a significant effect ($P < 0.05$) on daily milk yield (Fig. 2), milk protein concentration, milk protein yield (Fig. 3) and milk solids yield during P2 (Table 7). Cows on the HG2 treatment had a greater milk yield (+0.9 kg milk/cow/day) (Fig. 2) and milk protein concentration (+1.1 g/kg milk) compared to cows on the LG2 treatment. There was a significant interaction between treatment and year for milk fat concentration and milk fat yield in P2. In year 1, the LG2 treatment had a higher milk fat concentration and milk fat yield (+2.6 g/kg milk and +0.03 kg/cow, respectively) while in year 2 the HG2 treatment was higher (+2.3 g/kg milk and +0.09 kg/cow, respectively). There was no effect of treatment on bodyweight or BCS in P2.

Period 3 (weeks 13–16)

Herbage variables

There was a tendency ($P = 0.0584$) for preGHM to be higher for the HG treatment in P3 (+106 kg DM/ha) (Table 8). Treatment and year had a significant interaction for preGSH, postGSH and preGHM. Pre-grazing sward height and postGSH were higher for the HG treatment in year 1 and higher for the LG treatment in year 2. Pre-grazing herbage mass was higher for the HG2 treatment in year 1 (+209 kg DM/ha), with no difference in year 2 (1508 kg DM/ha).

Animal production

There was no effect of treatment applied in P1 on animal performance during P3. The effect of treatment during P2 on milk production in P3 is reported in Table 9. Cows on the HG2 treatment had a greater milk yield (+1.0 kg milk/cow/day) compared to the LG2 treatment in P3. The HG2 cows also had +0.7 g/kg milk protein concentration and +0.04 kg/cow/day milk protein yield compared to the LG2 cows during P3. However, cows on the LG2 treatment had a significantly higher milk fat concentration (+1.3 g/kg milk), which resulted

Table 7. The effect of the high grass (HG) and low grass (LG) treatment on animal production during periods 1 and 2 in years 1 and 2 of the experiment

	Period 1[a]		Period 2[b]			*P*-value				
	HG	LG	HG	LG	S.E.	Treat P1	Treat P2	Week	Treat P1 × treat P2	Treat P2 × week
Daily milk yield (kg/cow/day)	20.5	20.5	24.5	23.6	0.38	0.982	0.048	<0.001	0.813	0.005
Milk fat conc. (g/kg milk)	55.9	56.0	51.2	51.3	0.75	0.703	0.854	<0.001	0.864	0.004
Milk protein conc. (g/kg milk)	36.4	36.7	35.1	34.0	0.03	0.520	0.003	<0.001	0.479	<0.001
Milk fat yield (kg/cow/day)	1.15	1.16	1.23	1.20	0.026	0.825	0.287	<0.001	0.602	<0.001
Milk protein yield (kg/cow/day)	0.75	0.75	0.85	0.79	0.013	0.816	<0.001	<0.001	0.428	<0.001
Milk solids yield (kg/cow/day)	1.91	1.92	2.09	2.01	0.035	0.815	0.027	<0.001	0.610	<0.001
Bodyweight (kg/cow)	495	499	492	485	4.6	0.605	0.121	<0.001	0.717	<0.001

HG, high grass daily herbage allowance (DHA) with low silage supplementation during period 1 and high DHA with no silage supplementation during period 2; LG, low grass DHA with high silage supplementation during period 1 and low DHA with silage supplementation during period 2; Treat P1, treatment during period 1; Treat P2, treatment during period 2.

[a] Period 1 = 1 February–12 March (weeks 1–6).

[b] Period 2 = 13 March–23 April (weeks 7–12).

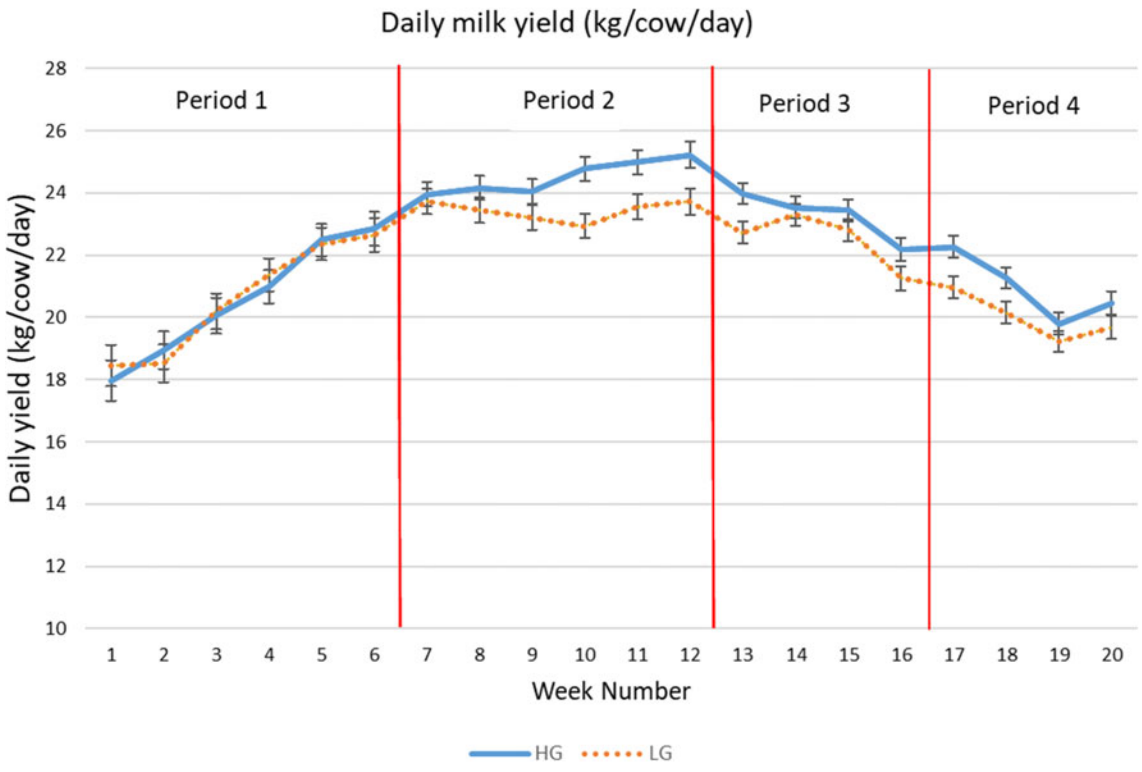


Figure 2. The effect of the high grass (HG = high grass daily herbage allowance (DHA) with low silage supplementation during P1 and high DHA with no silage supplementation during P2) and low grass (LG = low grass DHA with high silage supplementation during P1 and low DHA with silage supplementation during P2) treatments on daily milk yield (kg/cow/day) during period 1 (P1) (weeks 1–6), period 2 (P2) (weeks 7–12), period 3 (P3) (weeks 13–16) and period 4 (P4) (weeks 17–20).

in no difference in milk solids yield during P3. Treatment during P2 had a significant effect ($P < 0.05$) on bodyweight in P3, as the HG2 had greater bodyweights compared to the LG2 treatment (+20 kg), however there was no effect of treatment on BCS.

Period 4 (weeks 17–20)

Herbage variables

There was a treatment by year interaction for preGSH and preGHM. The LG treatment had a higher preGSH and

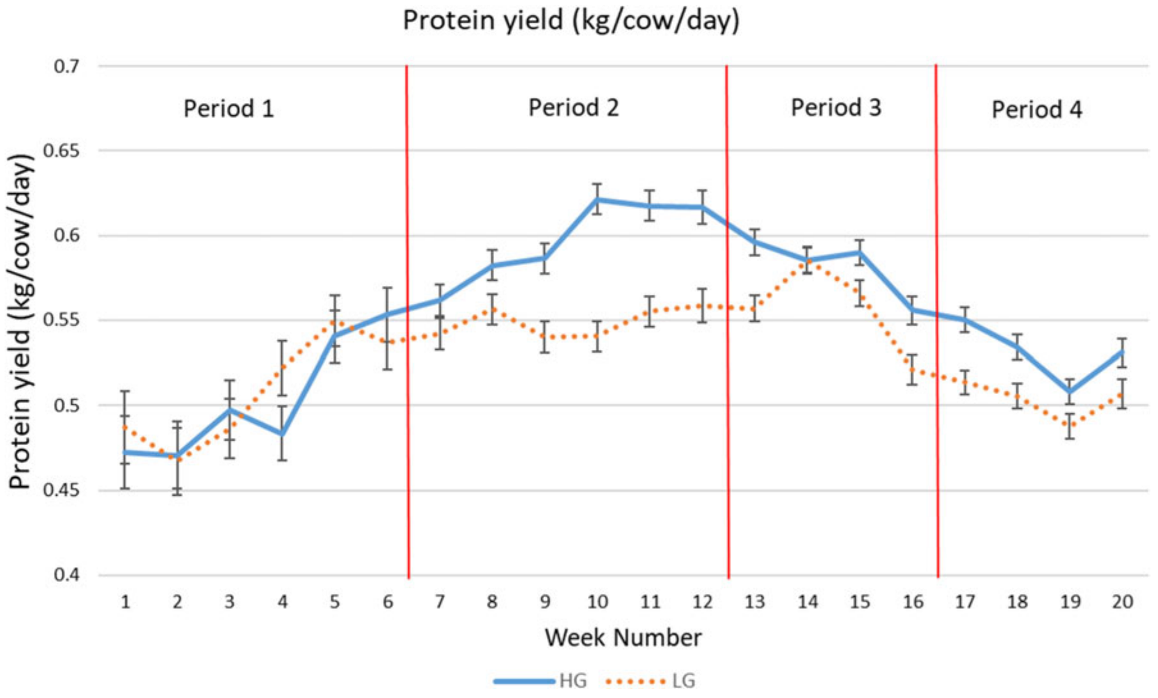


Figure 3. The effect of the high grass (HG = high grass daily herbage allowance (DHA) with low silage supplementation during P1 and high DHA with no silage supplementation during P2) and low grass (LG = low grass DHA with high silage supplementation during P1 and low DHA with silage supplementation during P2) treatments on protein yield (kg/cow/day) during period 1 (P1) (weeks 1–6), period 2 (P2) (weeks 7–12), period 3 (P3) (weeks 13–16) and period 4 (P4) (weeks 17–20).

Table 8. The effect of the high grass (HG) and low grass (LG) treatments on pre- and post-grazing sward height and pre-grazing herbage mass during periods 3 and 4 in years 1 and 2 of the experiment

	Period 3[a]		Period 4[b]			*P*-value		
	HG	LG	HG	LG	S.E.	Year	Treatment	Year × treatment
PreGSH (cm)	11.8	11.3	11.8	11.9	0.31	<0.001	0.453	0.726
PostGSH (cm)	4.05	4.03	4.16	4.04	0.042	<0.001	0.163	0.208
PreGHM (kg DM/ha)	1716	1618	1533	1587	40.3	<0.001	0.431	0.476

HG, high grass daily herbage allowance (DHA) with low silage supplementation during period 1 and high DHA with no silage supplementation during period 2; LG, low grass DHA with high silage supplementation during period 1 and low DHA with silage supplementation during period 2; PreGSH, pre-grazing sward height; PostGSH, post-grazing sward height; PreGHM, pre-grazing herbage mass.

[a] Period 3 = 24 April–21 May (weeks 13–16).

[b] Period 4 = 22 May–18 June (weeks 17–20).

preGHM in year 1 (+1.22 cm and +244 kg DM/ha), while the HG2 treatment was greater in year 2 (+1.15 cm and +135 kg DM/ha).

Animal production

Treatment during P1 had no effect on animal performance during P4. The effect of treatment during P2 on milk production in P4 is reported in Table 10. Cows on the HG2 treatment had a higher daily milk yield (+1.0 kg/cow/day) and milk protein yield (+0.04 kg/cow/day) compared to LG2 cows in P4. In contrast to P3, cows on the HG2 treatment had a higher milk fat yield (+0.05 kg/cow/day) compared to the LG2 treatment in P4. The HG2 treatment also had a higher milk solids yield compared to the LG2 treatment (+0.09 kg/cow/day). Treatment in P2 had no effect on BCS during P4; however, there was a significant effect ($P < 0.05$) on bodyweight in P4. Bodyweight was significantly higher for the HG2 cows during P4 (+26 kg). Bodyweight gain was greater for the HG2 treatment (+22 kg/cow) from P2 to P4 compared to the LG2 treatment (+3 kg/cow).

Discussion

The importance of spring grass in the diet of dairy cows has been shown to improve animal performance during early lactation, however, climatic conditions and low spring grass availability often leads to the requirement of silage supplementation. This experiment investigated the effect of spring grass availability and the use of silage supplementation during early lactation to identify the optimum spring grassland management strategy during periods of grass deficits to ensure adequate DMI and while maximizing milk production. The results of the current study demonstrated that increasing the proportion of spring grass in the diet increases

Table 9. The effect of the high grass (HG) and low grass (LG) treatment during period 2 (week 7–12) on animal production during period 3 (week 13–16) in years 1 and 2 of the experiment

	Period 3[a]			*P*-value		
	HG	LG	S.E.	Treat P2	Week	Treat P2 × week
Daily milk yield (kg/cow/day)	23.4	22.4	0.33	0.025	<0.001	<0.001
Milk fat conc. (g/kg milk)	47.8	49.1	0.05	0.046	<0.001	<0.001
Milk protein conc. (g/kg milk)	35.9	35.2	0.02	0.021	<0.001	<0.001
Milk fat yield (kg/cow/day)	1.10	1.08	0.020	0.881	<0.001	<0.001
Milk protein yield (kg/cow/day)	0.83	0.78	0.010	0.004	<0.001	<0.001
Milk solids yield (kg/cow/day)	1.94	1.88	0.027	0.132	<0.001	<0.001
Bodyweight (kg/cow)	516	489	3.2	<0.001	<0.001	<0.001

HG, high grass daily herbage allowance (DHA) with low silage supplementation during period 1 and high DHA with no silage supplementation during period 2; LG, low grass DHA with high silage supplementation during period 1 and low DHA with silage supplementation during period 2; Treat P2, treatment during period 2.
[a]Period 3 = 24 April–21 May (weeks 13–16).

Table 10. The effect of the high grass (HG) and low grass (LG) treatment during period 2 (weeks 7–12) on animal production during period 4 (weeks 17–20) in years 1 and 2 of the experiment

	Period 4[a]			*P*-value		
	HG	LG	S.E.	Treat P2	Week	Treat P2 × week
Daily milk yield (kg/cow/day)	21.2	20.2	0.32	0.026	<0.001	0.094
Milk fat conc. (g/kg milk)	47.0	46.3	0.05	0.199	<0.001	<0.001
Milk protein conc. (g/kg milk)	36.6	36.1	0.03	0.156	<0.001	0.053
Milk fat yield (kg/cow/day)	0.97	0.92	0.016	0.022	<0.001	<0.001
Milk protein yield (kg/cow/day)	0.76	0.72	0.010	0.002	<0.001	0.198
Milk solids yield (kg/cow/day)	1.75	1.66	0.023	0.002	<0.001	0.002
Bodyweight (kg/cow)	514	488	3.2	<0.001	<0.001	<0.001

HG, high grass daily herbage allowance (DHA) with low silage supplementation during period 1 and high DHA with no silage supplementation during period 2; LG, low grass DHA with high silage supplementation during period 1 and low DHA with silage supplementation during period 2; Treat P2, treatment during period 2.
[a]Period 4 = 22 May–18 June (weeks 17–20).

milk yield and protein content during early lactation and the improved performance persists beyond early lactation.

Spring herbage availability

Implementing an earlier autumn closing date leads to a greater level of herbage available during the subsequent spring, similar to Claffey *et al.* (2019a), due to a longer regrowth period over winter. The build-up of senescent material associated with earlier closing of swards can have a negative impact on grass quality in the subsequent spring as green leaf material declines (Lawrence *et al.*, 2017; Looney *et al.*, 2021). The benefits of high proportions of spring grass in the diet outweigh reductions in sward quality that may occur with early closing due to the high nutritive value of spring grass compared to grass silage (Claffey *et al.*, 2019a). Roche *et al.* (1996) and Claffey *et al.* (2020a) reported that autumn closing date had no effect on late lactation milk production, however, later closing had a negative impact during the subsequent spring with a reduction in spring grass availability, as each day delay in closing reduced pre-grazing herbage mass in spring by 16 kg DM/ha and this leads to a 4.6% reduction in daily milk yield (Claffey *et al.*, 2020a). Claffey *et al.* (2020a) recommended the final grazing rotation should be carried out from late September until mid-November as this allows for greater DHA, increased DMI and improved animal performance during early lactation. In the current study, an increase in OFC (+315 kg DM/ha) leads to an increase in grass DMI during early lactation (average + 2.5 kg DM/cow during P1 and P2) due to higher grass allocation (+3.2 kg DM/cow/day). This is similar to the findings of Claffey *et al.* (2020a) who reported an increase in OFC of 615 kg DM/ha leads to higher DHA (+2.9 kg DM/cow/day) and increased DMI (+1.3 kg DM/cow).

Grass growth in Ireland is highly seasonal with major differences between years depending on climatic conditions (Hurtado-Uria *et al.*, 2013). In the current study, average soil temperature from November to January was 12% higher in year 2 compared to year 1 which resulted in higher spring grass availability in year 2 (HG = + 346 kg DM/ha and LG = + 123 kg DM/ha), similar to Claffey *et al.* (2020a) and Looney *et al.* (2021). Recent trends have shown increased rainfall in spring (Domonkos *et al.*, 2020), as experienced in the current study with 93 mm more rain in February of year 1 compared to year 2 (Table 2), which can create difficult grazing conditions and reduced grass utilization leading to restriction in intake during early lactation if cows are not supplemented. The varying weather conditions between years can be challenging for Irish dairy farmers, however, total DMI and grazing intensity remained similar between years 1 and 2 of the current experiment and was not impacted by differences in rainfall due to the use of on-off grazing strategies (Kennedy *et al.*, 2011) and implementing a target postGSH of 4 cm (Ganche *et al.*, 2013).

Animal production – period 1

There was no difference in animal performance during P1 which may be as a result of the inclusion of silage in the diet of both the HG1 and LG1 treatments. Although there was a difference of 2.5 kg DM silage/cow/day maintained between the HG1 and LG1 treatments, this did not have an impact on milk production (20.5 kg/cow/day) (Table 7). It has previously been reported that the inclusion of grass silage in the diet can reduce individual measured grass DMI due to the larger gut fill and higher fibre content of grass silage (Kennedy *et al.*, 2011). In the current study, total DMI was the same for both treatments during P1 at 13.9 kg DM/cow/day with silage accounting for 25 and 39% of the HG1 and LG1 diets, respectively. This may be as a result of silage only making up a small proportion of the diet and total intakes were lower as this was during the first 6 weeks of lactation. The current study highlights that the level of silage in the diet during the first 6 weeks in spring has no effect on animal performance as milk production was the same for both groups with a 2 kg difference in silage DMI. Similar to Ruiz-Albarrán *et al.* (2012), who reported no difference in milk production when cows were offered 4.5 or 9 kg DM silage supplementation during early lactation, Ruiz-Albarrán *et al.* (2012) also noted that a higher pasture allowance with both levels of silage supplementation did not affect milk production due to a reduction in overall feed quality with lower OMD and CP as a result of including silage in the diet.

Animal production – period 2

The inclusion of silage from weeks 6 to 12 of the study had a negative impact on animal performance. The HG2 treatment had greater milk yields and milk protein content (3.7 and 3.2% greater, respectively) (Table 7) once all silage was removed from the diet from week 6 of the study, regardless of the level of silage offered in P1. Increased spring grass availability and grass DHA for the HG2 treatment increased milk yields by 0.28 kg milk/cow/day for each 1 kg increase in DHA, similar to the findings of Claffey *et al.* (2019a) who reported an increase in daily milk yield of 0.35 kg milk/cow/day for each 1 kg increase in DHA. Despite the increases in milk yield during P2 in the current study, there was no difference in total DMI between groups (16.7 kg DM/cow/day) (Table 6). The difference observed in milk production could be accounted for by the reduced quality of the grass silage compared to grazed grass, reducing the overall quality intake of the animal (O' Brien *et al.*, 2018). This contrasts with the findings of Kennedy *et al.* (2011) who reported no differences in milk production when cows were offered 4 kg DM grass silage compared to cows offered grass-only diets. The study by Kennedy *et al.* (2011) offered grass silage as a method of increasing total DMI when cows weren't restricted, whereas the current study used silage supplementation in a feed deficit situation during which there isn't enough grass available to meet herd demand. Kennedy *et al.* (2011) reported there was no difference in grass DHA (14.4 kg DM/cow/day) throughout the experiment unlike the current study where there was a 3 kg DM difference in DHA offered to the HG and LG treatments during the experimental period. The current study shows a 3.4 kg greater grass DMI for the HG2 cows compared to the LG2 cows, compared to Kennedy *et al.* (2011) who reported a difference of 2.3 kg DM/cow between treatments. Silage quality has a major impact on animal performance when included in the diet (Rego *et al.*, 2008), with defoliation date and pre-cutting yield (kg DM/ha) having a major influence on forage digestibility and therefore, DMI and milk production (Huhtanen *et al.*, 2007). Rinne *et al.* (2002) reported that silage DMI intake was 11% greater with early cut silage (13 June) compared to later cut silage (4 July) and milk yield also reduced by 15% with increased grass maturity at harvest. Digestible organic matter, DM content and fermentation characteristics have the greatest impact on silage DMI (Gordon, 1981; Yan *et al.*, 1996; Huhtanen *et al.*, 2007). The wilting period of silage can influence the extent and type of fermentation and lead to improved silage quality as allowing silage to wilt can reduce water activity and improve fermentation characteristics (Huhtanen *et al.*, 2007). Huhtanen *et al.* (2002) reported that the organic matter content of poorly fermented silage can reduce DMI due to low palatability, reduced passage rate through the rumen and an imbalanced amino acid to energy ratio at tissue level. The negative effects associated with grass silage in the diet can be reduced by offering grass silage of a higher quality (Rinne *et al.*, 2002) by better managing silage defoliation and sward maturity at harvest; however, the benefits of offering grazed grass instead of grass silage in terms of animal production in grazing systems have been reported in the current study and previous studies (Roche *et al.*, 1996; Kennedy *et al.*, 2011; Claffey *et al.*, 2019a).

Rego *et al.* (2008) reported a reduction in milk protein concentration with the inclusion of silage in the diet compared to grazed grass, similar to the current study where the HG2 treatment had a greater milk protein concentration (+1.1 g/kg milk) and protein yield (+0.06 kg) compared to cows on the LG2 treatment. As a result, the inclusion of grass silage in the current study reduced feed quality (−0.068 OMD on average during the study for grazed grass compared to silage) and protein content in the diet (−90.02 g CP/kg DM on average during the study for grazed grass compared to silage) (Tables 4 and 5) which resulted in the reductions in milk and protein yields (Rego *et al.*, 2008). The high CP content in spring grass (McCarthy *et al.*, 2013), similar to the current study can have a negative environmental impact as high protein feeds can lead to an increase in N excretion from dairy cows (Di and Cameron, 2002; Ledgard *et al.*, 2009) and cause greater levels of N leaching (Decau *et al.*, 2004). The inclusion of grass silage with a lower CP content may have a role to play in reducing N excretion, although not measured in the current study and warrants future investigation, particularly during spring grazing as there is increasing pressure to reduce N leaching. It is imperative that the inclusion of silage in the diet of grazing dairy cows does not result in a reduction in animal performance as was reported in the current study.

Animal production – periods 3 and 4

When silage was removed from the LG2 treatment on week 12 of the experiment, the difference observed in animal performance in P2 between the two treatments continued into P3 and P4, with the HG2 cows having 1 kg greater milk yield compared to the

LG2 cows (Tables 9 and 10). Previous studies have reported that cows that have a higher peak milk yield have a greater total milk production (Killen and Keane, 1978). In the current study, the difference in milk yield during the carryover periods (P3 and P4) may have been as a result of a higher peak milk yield achieved by the HG treatment compared to the LG treatment. Both treatment groups reached peak milk yield on week 12 of the experiment; however, the HG2 treatment peaked at 1.5 kg/cow/day greater compared to the LG2 treatment (25.2 and 23.7 kg/cow/day, respectively), at which point silage was still included in the diet of the LG2 treatment. The greater peak yield reached by the HG2 treatment could have led to the higher milk production throughout P3 and P4 (Killen and Keane, 1978). Both groups had a similar rate of decline from week 12 of the study in milk yield across the carryover period (P3 and P4), with the HG and LG treatments declining by 19 and 17%, respectively, from the end of P2 to the end of P4. Dillon *et al.* (2002) also reported that cows that had access to pasture had significantly higher milk yields (+3.2 kg milk/cow/day) until week 19 of lactation compared to cows offered silage during early lactation.

The difference in milk yield during P3 and P4 may also be as a result of the effect of reductions in the quality of the diet on mammary cells. A review by Leduc *et al.* (2021) reported that feed restriction through either reductions in the feed quality or quantity can have negative effects on milk yield, protein and lactose content and mammary metabolism due to changes in gene expression which can lead to cell apoptosis. As cows adapt to changes in feed quality or quantity, they may experience cell apoptosis which is an irreversible process (Boutinaud *et al.*, 2019). In the current study, cows on the LG1 and LG2 treatments may have experienced higher rates of cell apoptosis, which reduced their milk production potential during the carryover period compared to the HG treatment who may have had a greater number of milk-secreting cells during P3 and P4 leading to higher milk production (Boutinaud *et al.*, 2019).

The impact of the silage supplementation for the LG2 treatment on milk protein content remained evident throughout P3. The current study demonstrates the negative impact that silage supplementation has on milk protein concentration with the LG2 treatment increasing milk protein by 1.3 g/kg when silage was removed from the diet on week 13. Kennedy *et al.* (2005) also reported milk protein content to be significantly lower during the carryover period for cows offered grass silage. The differences in milk protein concentration may be as a result of differences in animal production and residual effects of lower quality diet during the previous 6 weeks for the LG2 treatment (Gordon *et al.*, 2000; Dillon *et al.*, 2002). The effect of silage supplementation on milk protein content did not persist after the 4 weeks of P3 as the difference was not evident in P4. This may be as a result of the LG2 treatment taking 4 weeks to adapt to full-time grazing (Kennedy *et al.*, 2005). Kennedy *et al.* (2011) reported no carryover effects for milk protein content once silage was removed from the diet; however, the previous study offered grass silage until 26 March compared to the current study which offered grass silage to cows on the LG2 treatment until 20 April which highlights silage supplementation has more of a negative impact as cows are approaching peak milk production. Silage supplementation should be removed from the diet in mid-March, as after this, reductions in milk yield were observed for cows on the LG2 treatment as they approached peak milk production and for a further 8 weeks (P3 and P4). Milk fat content reduced after silage supplementation was removed from the diet due to a reduction in the fibre content of the diet (Phillips and Leaver, 1985).

The greater bodyweight gain of the HG treatment during P3 and P4 compared to the LG cows in the current study could help in explaining some of the differences observed in the higher milk fat yield on the HG treatment in P3 and P4. A greater bodyweight has previously been shown to allow for higher fat yield as there is more energy available for milk production (Roche *et al.*, 2007). The greater bodyweight gain of the HG treatment compared to the LG treatment during the carryover period (+22 and +3 kg/cow, respectively) was caused by higher grass DMI (+2.5 kg DM/cow/day) by the HG treatment during the first 12 weeks which is similar to Claffey *et al.* (2019a) and McEvoy *et al.* (2008). Greater bodyweight gain with increased proportions of grass in the diet is a direct result of greater proportions of higher quality forage in the diet (McEvoy *et al.*, 2008). High proportions of good quality grass during early lactation allow for greater energy intake compared to offering grass silage as feed quality improves and this allows for bodyweight gain once milk production and maintenance requirements are met (Lewis *et al.*, 2011).

Conclusion

The current study highlights the benefits of increasing the level of grazed grass and reducing the level of grass silage in the diet of early lactation cows and the long-term benefits after silage is removed from the diet on subsequent milk production. Variations in climatic conditions between years has a major impact on grass availability and grazing conditions in spring, however, ensuring a greater level of grass availability on farm in spring can reduce the level of silage supplementation required. The negative effects of silage supplementation on animal performance can be reduced by offering silage during the first 6 weeks of lactation with no immediate or longer term negative impacts on milk production. However, including silage supplementation in the diet of cows nearing peak milk production has negative effects on animal performance for a subsequent 8 weeks after peak yield is reached. The benefits of high grass intakes during early lactation persist beyond the first rotation which highlights the advantages of increasing spring grass availability on farm.

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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. Johnstown Castle, Co Wexford: Teagasc.

AOAC International (1990) *Official Methods of Analysis*, 15th Edn. Arlington, VA, USA: AOAC International.

AOAC (1995) *Official Methods of Analysis*, 14th Edn. Washington, DC: Association of Official Analytical Chemists.

Balaam LN (1968) A two-period design with t^2 experimental units. *Biometrics* **24**, 61–73.

Boutinaud M, Herve L, Quesnel H, Lollivier V, Finot L, Dessauge F, Chanat E, Lacasse P, Charton C and Guinard-Flament J (2019). Review: the cellular mechanisms underlying mammary tissue plasticity during lactation in ruminants. *Animal* **13**, 52–64.

Claffey A, Delaby L, Galvin N, Boland TM and Egan M (2019a) The effect of spring grass availability and grazing rotation length on the production and quality of herbage and milk in early spring. *Journal of Agricultural Science* **157**, 434–448.

Claffey A, Delaby L, Lewis E, Boland TM and Kennedy E (2019b) Pasture allowance, duration and stage of lactation – effects on early and total lactation animal performance. *Journal of Dairy Science* **102**, 8986–8998.

Claffey A, Delaby L, Boland TM and Egan M (2020a) 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.

Claffey A, Delaby L, Lewis E, Boland TM, Galvin N and Kennedy E (2020b) Pasture allowance and duration: the effect of restriction on dry-matter intake, energy balance and indicators of metabolic health in early lactation dairy cows. *Animal Production Science* **61**, 17–25.

Decau ML, Simon JC and Jacquet A (2004) Nitrate leaching under grassland as affected by mineral nitrogen fertilization and cattle urine. *Journal of Environmental Quality* **33**, 637–644.

Di HJ and Cameron KC (2002) Nitrate leaching in temperate agroecosystems: sources, factors and mitigating strategies. *Nutrient Cycling in Agroecosystems* **64**, 237–256.

Dillon P and Stakelum G (1989) Herbage and dosed alkanes as a grass management technique for dairy cows. *Irish Journal of Agricultural Research* **8**, 104.

Dillon P, Crosse S, O' Brien B and Mayes RW (2002) The effect of forage type and level of concentrate supplementation on the performance of spring-calving dairy cows in early lactation. *Grass and Forage Science* **57**, 212–223.

Domonkos P, Coll J, Guijarro J, Curley M, Rustemeier E, Aguilar E, Walsh S and Sweeney J (2020) Precipitation trends in the island of Ireland using a dense, homogenized, observational dataset. *International Journal of Climatology* **40**, 6219–6674.

Doyle P, Tubritt T, O'Donovan M and Crosson P (2022) Economic value of grass and grass-white clover. *Swards for the future Conference proceedings September 2022*, Teasagc, Moorepark, Co. Cork.

Edmondson AJ, Lean IJ, Weaver LD and Farver T (1989) A body condition scoring chart for Holstein dairy cows. *Journal of Dairy Science* **72**, 68–78.

Finneran E, Crosson P, O' Kiely P, Shalloo L, Forristal D 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.

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.

Garry B, O'Donovan M, Beecher M, Delaby L, Fleming C, Baumont R and Lewis E (2018, 17–21 June 2018). Predicting in vivo digestibility of perennial ryegrass using the neutral detergent cellulase method: updating the equation. Sustainable meat and milk production from grasslands. *Proceedings of the 27th General Meeting of the European Grassland Federation*, Cork, Ireland.

Gordon FJ (1981) The effect of wilting of herbage on silage composition and its feeding value for milk production. *Animal Science* **32**, 171–178.

Gordon FJ, Ferris CP, Patterson DC and Mayne CS (2000) A comparison of two grassland-based systems for autumn-calving dairy cows of high genetic merit. *Grass and Forage Science* **55**, 83–96.

Hanrahan L, McHugh N, Hennessy T, Moran B, Kearney R, Wallace M and Shalloo L (2018) Factors associated with profitability in pasture-based systems of milk production. *Journal of Dairy Science* **101**, 5474–5485.

Hughes K, Glass C, Ripchinski M, Gurevich F, Weaver TE, Lehman E and Craig TJ (2003) Efficacy of the topical nasal steroid budesonide on improving sleep and daytime somnolence in patients with perennial allergic rhinitis. *Allergy* **58**, 380–385.

Huhtanen P, Khalili H, Nousiainen JI, Rinne M, Jaakkola S, Heikkilä T and Nousiainen J (2002) Prediction of the relative intake potential of grass silage by dairy cows. *Livestock Production Science* **73**(2-3), 111–130.

Huhtanen P, Rinne M and Nousiainen J (2007) Evaluation of the factors affecting silage intake of dairy cows: a revision of the relative silage dry-matter intake index. *Animal* **1**, 758–770.

Hurtado-Uria C, Hennessy D, Shalloo L, O' Connor D and Delaby L (2013) Relationships between meteorological data and grass growth over time in the south of Ireland. *Irish Geography* **46**, 175–201.

Kennedy E, O'Donovan M, Murphy JP and O' Mara F (2005) Effects of grass pasture and concentrate-based feeding systems for spring-calving dairy cows in early spring on performance during lactation. *Grass and Forage Science* **60**, 310–318.

Kennedy E, O'Donovan M, O'Mara FP, Murphy JP and Delaby L (2007) The effect of early-lactation feeding strategy on the lactation performance of spring-calving dairy cows. *Journal of Dairy Science* **90**, 3060–3070.

Kennedy E, Curran J, Mayes B, McEvoy M, Murphy JP and O'Donovan M (2011) Restricting dairy cow access time to pasture in early lactation: the effects on milk production, grazing behaviour and dry matter intake. *Animal* **5**, 1805–1813.

Killen L and Keane M (1978) The shape of lactation curves in Irish dairy herds. *Irish Journal of Agricultural Research* **17**, 267–282.

Läpple D, Hennessy T and O'Donovan M (2012) Extended grazing: a detailed analysis of Irish dairy farms. *Journal of Dairy Science* **95**, 188–195.

Lawrence DC, O'Donovan M, Boland TM and Kennedy E (2017) Effects of autumn and spring defoliation management on the dry-matter yield and herbage quality of perennial ryegrass swards throughout the year. *Grass and Forage Science* **72**, 38–49.

Ledgard S, Schils R, Eriksen J and Luo J (2009) Environmental impacts of grazed clover/grass pastures. *Irish Journal of Agricultural and Food Research* **48**, 209–226.

Leduc M, Souchet S, Gelé M, Le Provost F and Boutinaud M (2021) Effect of feed restriction on dairy cow milk production: a review. *Journal of Animal Science* **99**, 1–12.

Lewis E, O'Donovan M, Kennedy E, O' Neil B and Shalloo L (2011) Feeding the dairy cow in spring: supplementation requirements and responses. In '*Proceedings of Teagasc national dairy conference. The Irish Dairy Industry: to 2015 and beyond*'. (Ed. Teagasc Moorepark) pp. 71–81. Co. Cork.

Looney C, Hennessy D, Wingler A and Egan M (2021) The effect of autumn closing date on over winter tissue turnover in perennial ryegrass (*Lolium perenne* L.) swards. *Grass and Forage Science* **76**, 533–541.

Mayes RW, Lamb CS and Colgrove P (1986) The use of dosed and herbage n-alkanes as markers for the determination of herbage intake. *Journal of Agriculture Science* **107**, 161–170.

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.

McEvoy M, Kennedy E, Murphy JP, Boland TM, Delaby L and O'Donovan M (2008) The effect of herbage allowance and concentrate supplementation on milk production performance and dry matter intake of spring-calving dairy cows in early lactation. *Journal of Dairy Science* **91**, 1258–1269.

Morgan DJ, Stakelum G and Dwyer J (1989) Modified neutral detergent cellulase digestibility procedure for use with the 'Fibertec' system. *Irish Journal of Agricultural Research* **28**, 91–92.

O' Brien D, Moran B and Shalloo L (2018) A national methodology to quantify the diet of grazing dairy cows. *Journal of Dairy Science* **101**, 8595–8604.

O'Donovan M, Dillon P, Rath M and Stakelum G (2002) A comparison of four methods of herbage mass estimation. *Irish Journal of Agricultural and Food Research* **41**, 17–27.

Phillips CJC and Leaver JD (1985) Supplementary feeding of forage to grazing dairy cows. 2. Offering grass silage in early and late season. *Grass and Forage Science* **40**, 193–199.

Ramsbottom G, Horan B, Pierce KM and Roche JR (2020) Dairy expansion: A case study of spring-calving pasture-based dairy production systems in Ireland. *The Journal of Agricultural Science* **158**, 406–415.

Rego OA, Regalo SMM, Rosa HJD, Alves SP, Borba AES, Bessa RJB, Cabrita ARJ and Fonseca AJM (2008) Effects of grass silage and soybean meal supplementation on milk production and milk fatty acid profiles of grazing dairy cows. *Journal of Dairy Science* **91**, 2736–2743.

Rezaei S (1997) The mathematical analysis of crossover designs (PhD dissertation). The University of Adelaide, November 1997.

Rinne M, Huhtanen P and Jaakkola S (2002) Digestive processes of dairy cows fed silages harvested at four stages of grass maturity. *Journal of Animal Science* **80**, 1986–1998.

Roche JR, Dillon P, Crosse S and Rath M (1996) The effect of closing date of pasture in autumn and turnout date in spring on sward characteristics, dry matter yield and milk production of spring-calving dairy cows. *Irish Journal of Agricultural and Food Research* **35**, 127–140.

Roche JR, Lee JM, Macdonald KA and Berry DP (2007) Relationships among body condition score, body weight, and milk production variables in pasture-based dairy cows. *Journal of Dairy Science* **90**, 3802–3815.

Ruiz-Albarrán M, Balocchi OA, Noro M, Wittwer F and Pulido RG (2012) Effect of increasing pasture allowance and grass silage on animal performance, grazing behaviour and rumen fermentation parameters of dairy cows in early lactation during autumn. *Livestock Science* **150**, 407–413.

Sayers HJ and Mayne CS (2001) Effect of early turnout to grass in spring on dairy cow performance. *Grass and Forage Science* **56**, 259–267.

Teagasc (2016) *Teagasc Dairy Manual. A Best Practice Manual for Ireland's Dairy Farmers*. Carlow: Teagasc.

Teagasc (2017) *Allocating Spring Grass Using the Spring Rotation Planner*. Carlow: Teagasc.

Van Soest PJ, Robertson JB and Lewis BA (1991) Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. *Journal of Dairy Science* **74**, 3583–3597.

Verdon M, Rawnsley R, Raedts P and Freeman M (2018) The behaviour and productivity of mid-lactation dairy cows provided daily pasture allowance over 2 or 7 intensively grazed strips. *Animals* **8**, 115.

Yan T, Patterson DC, Gordon FJ and Porter MG (1996) The effects of wilting of grass prior to ensiling on the response to bacterial inoculation. 1. Silage fermentation and nutrient utilization over three harvests. *Animal Science* **62**, 405–417.