Effect of pre-grazing herbage mass and daily herbage allowance on perennial ryegrass swards structure, pasture dry matter intake and milk performance of Holstein-Friesian dairy cows

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Abstract

To maximize milk output and milk solids per hectare from grazing dairy cows it is necessary to identify the level of grazing swards in order to achieve high pasture dry matter intake (PDMI). The aim of this study was to investigate the effect of pre-grazing herbage mass (HM) and daily herbage allowance (DHA) on perennial ryegrass (*Lolium perenne* L.) swards structure, PDMI and milk performance. Sixty-four spring-calving Holstein-Friesian dairy cows were balanced and randomly assigned to one of four (n = 16) grazing groups (LL, LH, HL and HH) in a 2 × 2 factorial design. The treatments consisted on two pre-grazing HM, low (L- 1,600 kg DM ha^{-1}) or high (H- 2,400 kg DM ha^{-1}) and two DHA, low (L- 15 kg DM cow^{-1}day^{-1}) or high (H- 20 kg DM cow^{-1} day^{-1}). Swards structure, PDMI and milk performance were examined across the grazing season. The low HM groups completed 9.5 rotations of average 22 days length compared to 6.5 rotations of 32 days for the high HM groups. Herbage utilization was greater ($p < 0.001$) when animals offered the low DHA (98.0%) compared to the high DHA (89.9%). Stem and dead DM yield (> 4.0 cm) were lower ($p < 0.001$) for the low HM (221 and 170 kg ha^{-1}, respectively) than for the high HM (388 and 303 kg ha^{-1}, respectively). The high DHA had higher ($p < 0.001$) milk output (19.5 kg day^{-1}) and milk solids (1.46 kg cow^{-1}). The highest milk output per ha and per cow was achieved by LH, with low post-grazing residuals and high sward quality.

Additional key words: grass intake; grazing management; herbage utilization; milk output per hectare; pasture allowance; spring-calving cows; sward quality.

Resumen

Efecto de la oferta y disponibilidad diaria de hierba sobre la estructura morfológica del pasto de raigrás inglés, la ingestión de materia seca y la producción de leche de vacas Holstein-Friesian

Para maximizar la producción de leche en vacuno y el contenido de sólidos en suspensión por hectárea es necesario identificar el nivel de pastoreo para lograr alta ingestión de pasto (PDMI). El objetivo de este estudio fue investigar el efecto de la oferta (HM) y disponibilidad diaria de hierba (DHA) sobre la estructura morfológica del pasto de raigrás inglés (*Lolium perenne* L.), la ingestión y la producción de leche. Sesenta y cuatro vacas Holstein-Friesian de partos de primavera fueron distribuidas y asignadas al azar a cuatro grupos (n = 16) en pastoreo (LL, LH, HL y HH) utilizando un diseño factorial 2 × 2. Los tratamientos consistieron en dos HM pre-pastoreo, baja (L- 1.600 kg MS ha^{-1}) o alta (H- 2.400 kg MS ha^{-1}) y dos DHA, baja (L- 15 kg MS vaca^{-1} día^{-1}) o alta (H- 20 kg MS vaca^{-1} día^{-1}). Se estudió la estructura e ingestión de pasto y la producción de leche durante el pastoreo. Los grupos con baja HM completaron 9,5 rotaciones de 22 días en comparación con 6,5 rotaciones de 32 días en los grupos con alta HM. La utilización del pasto fue superior ($p < 0,001$) con baja DHA (98,0%) que con alta DHA (89,9%). La producción en MS de tallos y material senescente (> 4,0 cm) fue menor ($p < 0,001$) con baja HM (221 y 170 kg ha^{-1}, respectivamente) que con alta HM (388 y 303 kg ha^{-1}, respectivamente). La alta DHA logró mayor ($p < 0,001$) producción de leche (19,5 kg día^{-1}) y sólidos en suspensión (1,46 kg vaca^{-1}). Los valores más altos de producción de leche por ha y por vaca se alcanzaron en LH, con menos rechazos y alta calidad del pasto.

Palabras clave adicionales: calidad del pasto; disponibilidad de hierba; ingestión de hierba; manejo en pastoreo; producción de leche por hectárea; utilización del pasto; vacas de partos de primavera.

Introduction

Irish milk production systems are mainly pasture-based spring-calving dairy cows in order to maximize milk performance per hectare (ha) and per cow by increasing the organic matter digestibility (OMD) of the swards and the pasture dry matter intake (PDMI) of the cows (Stakelum and Dillon, 2007). With the abolition of European milk quotas in 2015 and the feeding costs projected to rise, the major purpose for the Irish dairy industry is to increase the efficiency use of grazed grass in the diet of the lactating dairy cows (McEvoy *et al.*, 2009). Dillon *et al.* (2005) have shown that a 10% increase in the proportion of grazed grass managed for Irish dairy farms may help to reduce the cost of milk produced by €0.025 L^{-1} and to reduce ever-increasing costs of milk production (Keneddy *et al.*, 2007). Using efficiently perennial ryegrass swards grazed rotationally as the primary diet source to feed dairy cows affords Irish farmers the opportunity to increase milk output per cow (Dillon *et al.*, 2002), milk protein content (Kennedy *et al.*, 2005) and herbage utilization (O'Donovan *et al.*, 2004) affecting sward quality for subsequent grazing rotations (Keneddy *et al.*, 2006).

Understanding the important role that pre-grazing herbage mass (HM) and daily herbage allowance (DHA) plays on swards morphological composition, PDMI and milk performance of dairy cows at pasture is a key tool for a better knowledge of the interaction between swards and animals to improve future grassland management practices which can be implemented at farm level with the aim of reducing feeding cost of production and increasing both swards and milk quality and quantity. Maintaining a proper balance between optimizing dairy cows' milk performance and improving swards feeding value is a dual purpose for using more efficiently farm resources and to increase profitability of sustainable dairy systems worldwide (Kennedy *et al.*, 2007; González *et al.*, 2008; McEvoy *et al.*, 2009; Roca *et al.*, 2009).

In rotational grazing systems, rapid changes in swards structure can appear which affect subsequently dairy cows' milk performance (Combellas and Hodgson, 1979). Maintaining high swards quality as the grazing season progresses is the major challenge for appropriate grassland management systems at farm level nowadays. At maximum grass growth, the herbage DM offered

exceeds the demand of animals and quality tends to deteriorate due to a higher proportion of senescent material in the swards. Reducing HM at swards can increase the grass feeding value with higher digestibility, more leaf proportion and, less senescent material across the grazing season, increasing also the PDMI of dairy cows (Holmes *et al.*, 1992; Peyraud *et al.*, 1996; O'Donovan and Delaby, 2008). Hoogendoorn *et al.* (1992) reported an increase in milk yield, milk fat and milk protein content when cows grazed low HM as opposed to medium HM at a similar DHA. Stakelum and Dillon (2007) also found an increased selection of higher digestibility herbage and green leaf content, with higher milk output per cow, on severely grazed swards in comparison to laxly grazed swards. As the quantity of DHA increases, the level of refused pasture normally increases and leading to a decrease in swards quality in subsequent grazing rotations (Lee *et al.*, 2008), but sometimes the levels of milk production can show an increase (Stakelum, 1986). It seems that the combination of low HM and high DHA by using stocking rates (O'Donovan and Delaby, 2008) or just setting the treatments directly as happened in a previous work realized by the same research team, studying the effect of two HM (1,700 or 2,200 kg DM ha^{-1}) and two DHA (16 or 20 kg DM cow^{-1} day^{-1}), obtained the highest milk output per ha and per cow, maintaining low post grazing residuals and high sward quality (McEvoy *et al.*, 2009).

The objective of this new research was to investigate how similar treatments to those established previously, two levels of pre-grazing HM (1,600 or 2,400 kg DM ha^{-1}) and two levels of DHA (15 or 20 kg DM cow^{-1} day^{-1}), affect the sward structure, the PDMI and the milk performance of spring-calving Holstein-Friesian dairy cows across the grazing season.

Material and methods

The study was conducted at Moorepark Research Centre, Fermoy, Co. Cork, Ireland (50° 7' N; 8° 16' W) from April 4 to October 31 in 2008. The soil type was a free draining, acid brown earth with a sandy loam-to-loam texture. The experimental area was a perennial ryegrass sward (*Lolium perenne* L.) from an initial mixture of three late-heading diploid cultivars (Twystar,

Cornwall and Gilford) with no white clover (*Trifolium repens* L.), which after six years old, under a good grazing management, showed a very low proportion of other species.

Weather climatic conditions

Main climatic weather variables (Tª and mean rainfall) during the experimental period were atypical compared to the last 10-years average (1998-2008). Total monthly rainfall was greater during the grazing season in 2008 than the 10-years average for the months June (94 mm, +32%), July (135 mm, +125%) and August (118 mm, +45%). However, in April (38 mm, –45%) and May (51%, –28%), total rainfall was lower than the 10-years average. The total rainfall during the experimental grazing trial in 2008 (639 mm) was 75 mm higher than the 10-years average (564 mm). Mean daily temperatures in 2008 were 0.5-1°C lower than the 10-years average. April and October in 2008 (7.9 and 9.2°C) were colder months compared to the other five months and were 0.8 and 1.4°C colder than the 10-years average, respectively.

Experimental design and treatments

The experiment investigated the effect of offering two target levels of pre-grazing HM (> 4cm), low (L- 1,600 kg DM ha^{-1}) or high (H- 2,400 kg DM ha^{-1}) and two target levels of DHA, low (L- 15 kg DM cow^{-1} day^{-1}) or high (H- 20 kg DM cow^{-1} day^{-1}) on perennial ryegrass swards structure, PDMI and milk performance of spring-calving Holstein-Friesian dairy cows. A randomized block design with a 2 × 2 factorial arrangement of treatments was applied and results in this paper are expressed as means of thirty weeks at grazing pastures. Two levels of pre-grazing HM were created experimentally with a differential dry matter (DM) yield maintained at 800 kg DM ha^{-1} across the grazing season. Two levels of DHA were offered across the two HM treatments, these had a differential of 5 kg DM cow^{-1} day^{-1} maintained in all the rotational grazing paddocks. The following four grazing treatments were imposed during seven months in four separately experimental farmlets: LL (low HM, 1,600 kg DM ha^{-1} and low DHA, 15 kg DM cow^{-1} day^{-1}), LH (low HM, 1,600 kg DM ha^{-1} and high DHA, 20 kg DM cow^{-1} day^{-1}), HL (high HM, 2,400 kg DM ha^{-1} and low DHA,

15 kg DM cow^{-1} day^{-1}) and HH (high HM, 2,400 kg DM ha^{-1} and high DHA, 20 kg DM cow^{-1} day^{-1}).

Animals and grazing groups

Sixty-four spring-calving Holstein-Friesian dairy cows, primiparous ($n = 24$) and multiparous ($n = 40$), were selected from the experimental Moorepark dairy herd. Cows grazed in one large herd from calving to the commencement of the experiment and they were offered 4 kg of concentrate per cow and per day. In the week before the starting week of the study, concentrate supplementation was reduced progressively and animals were removed from the diet on the day prior to the experimental grazing period.

Cows were balanced on calving date (February 11 ± 23.9 days), lactation number (2.6 ± 1.74), pre-experimental milk yield (29.3 ± 4.8 kg cow^{-1}), milk fat content (43.9 ± 0.88 g kg^{-1}), milk protein content (33.4 ± 0.29 g kg^{-1}), body weight (BW) (513 ± 74.4 kg) and body condition score (BCS) (2.96 ± 0.55). Animals were then blocked into the following four grazing groups (LL, LH, HL and HH) and each group was randomly assigned to one of the four different grazing treatments ($n = 16$). Cows were on average 53 days in milk (DIM) when the experiment commenced. No concentrate was offered at all during the experimental period.

Grazing management

The entire experimental area was rotationally grazed once during the pre-experimental period (February 11 to April 3) to a similar post-grazing height of 4.0 ± 0.07 cm and differences in pre-grazing HM were created by varying the time period between initial grazing and applying the experimental grazing treatments. The pastures designated to the high HM treatments were grazed initially followed by the low HM pastures thus creating a longer regrowth interval.

The experimental grazing area comprised of 21.3 ha divided into ten paddocks. Five paddocks were randomly assigned to the low HM treatments and the remaining five paddocks were assigned to the high HM treatments. These paddocks were subsequently divided into 2 sub-paddocks and permanently fenced. Sub-paddocks were randomly assigned to one of the two DHA treatments, with five sub-paddocks per treatment.

A similar grazing area (farmlet) was available for each treatment and each treatment was managed independently of all the other treatments. The first three sub-paddocks grazed per treatment were assigned as grazing only paddocks. The remaining two sub-paddocks per treatment were conserved as silage when the farm cover reached surplus grass supply. The first sub-paddock grazed by each treatment was referred to as the base paddock according to the methodology described by McEvoy *et al.* (2009). If animals were in a grazing only paddock when the base paddock reached target HM, they finished the rotation in that paddock and returned to the base paddock to commence a new rotation. If animals were in a silage paddock when the base paddock reached target HM, they immediately returned to the base paddock. Silage paddocks were cut immediately to ensure that regrowth interval was similar for grazed and ungrazed paddocks. The area for silage was excluded from the calculation of mean stocking rate (SR).

Fresh herbage (> 4.0 cm) was allocated to each individual herd on a daily basis after the morning milking using temporary fencing. No access to the previous days grazing area was allowed and was restricted by back fencing with temporary wire. Paddocks were dusted during April and May with calcined magnesite on a daily basis in order to ensure adequate intake of magnesium in the early lactation period and to prevent hypomagnesaemia. Pastures were not topped at all during the experimental period. In late autumn, pre-grazing HM was allowed to increase in order to ensure that adequate pasture was available to the animals to continue grazing until November, with a mean difference reduced to 500 kg DM ha^{-1} and maintained between the low and high HM swards. Nitrogen fertilizer was applied after each paddock was grazed from April to August, with a total amount of 250 kg nitrogen ha^{-1} applied to each farmlet (60-50-50-50-40 kg nitrogen ha^{-1}).

Sward measurements

HM determination and DM yield

Pasture HM (> 4.0 cm) was determined twice weekly by cutting two strips per paddock (1.2 m wide × 10 m long) per treatment with an Agria machine (Etesia UK Ltd., Warwick, UK). Ten grass height measurements were recorded before and after harvesting on each cut strip using an electronic plate meter (Urban and Caudal, 1990) with a plastic plate (30 × 30 cm and 4.5 kg m^{-1}; Agrosystèmes, Choiselle, France).

DM yield below 4.0 cm was measured to ground level, within two of the four strips cut using the Agria, per treatment area, by harvesting with a scissors the residual herbage within a 0.5 × 0.2 m quadrant. Soil and roots were manually removed and the sample was weighed and dried overnight at 80°C in a drying oven to determine DM content below 4.0 cm.

Grass growth

The grass growth (kg DM ha^{-1} day^{-1}) was calculated by dividing the grass production by the number of days regrowth. The effect of treatment on grazing management (rotation length, stocking rate, milk output and milk solids yield per ha) were calculated by rotation according to the methodology described by Hoden *et al.* (1986).

Pre- and post-grazing sward heights

The pre-grazing sward height was measured daily throughout the experimental period in each plot by recording 30 measurements per treatment across the two diagonals of each paddock by using the electronic plate meter. The DHA for each herd was calculated by multiplying pre-grazing pasture height (> 4.0 cm) by the sward density. Post-grazing sward heights were measured immediately after daily grazing.

Herbage utilization

Herbage mass utilization (> 4.0 cm) was calculated according to the method described by Delaby and Peyraud (1998) and it was further used to evaluate the HM produced in each sward.

Sward structure

Sward structural characteristics describe the proportion and relative vertical distribution of leaf, stem and dead material in the sward profile and it was determined weekly for the duration of the experiment. Approximately twenty sward samples were taken at random by cutting with a scissor at ground level in the

area to be grazed the following day to derive the morphological composition of the sward. The samples were laid in a plastic bag to maintain the vertical structure of the sward. A 150 g sub-sample was cut into two fractions, above and below 4.0 cm. Each individual layer was then manually separated into leaf, stem and dead material (including flower head and seeds if present) and weighed. Each sward constituent was oven dried overnight at 80°C for DM determination.

Criteria for determining when to defoliate pastures have been based on rotation length, sward height and HM following the assumptions of Mayne *et al.* (2000).

Pasture dry matter intake

Individual total PDMI were estimated four times during the experiment in weeks 6, 12, 21 and 28 using the n-alkane technique (Mayes *et al.*, 1986) as modified by Dillon and Stakelum (1989). All cows were dosed twice daily before milking for 12 consecutive days with a paper bung (Carl Roth, GmbH and Co. KG, Karlesruhe, Germany) containing 500 mg of dotriacontane (C32). From day 7 of dosing, fecal grab samples were collected from each cow twice daily for the remaining 6 days and stored at –20°C until analysis. The grab fecal samples of each cow from the total collection were then bulked (10 g of each collected sample) to obtain one sample per cow. This was dried for 48 h at 40°C, milled and analyzed by gas chromatography. In conjunction with the fecal collection, the diet of the animals was also sampled. Herbage representative of that grazed (following close observation of the grazing animals' previous defoliation) was manually collected from each paddock before morning grazing on days 6 to 11 (inclusive) of the intake measurement period. Two samples of approximately 25 individual grass snips were taken from each paddock with a Gardena hand shears. The ratio of herbage C33 (tritriacontane) to dosed C32 was used to estimate PDMI. The n-alkane concentration was determined as described by Dillon (1993).

Animal measurements

Milk yield and composition

Milking took place at 07.00 h and 16.00 h daily. Individual milk yields (kg) were recorded at each

milking (Dairymaster, Causeway, Co. Kerry, Ireland). Milk fat and milk protein content were determined from two successive evening (Tuesday) and morning (Wednesday) weekly milking samples collected and pooled together for later analysis. The concentrations of these two milk constituents were determined using MilkøScan 203 (DK-3400, Foss Electric, Hillerød, Denmark). Solids-corrected milk yield were also calculated using the equation of Tyrrell and Reid (1965).

Body weight and body condition score

Body weight (BW) was recorded weekly electronically using a portable weighing scale and the Winweigh software package (Tru-Test Limited, Auckland, New Zealand). Body condition score (BCS) was scored weekly by one experienced independent observer throughout the experiment on a 1 to 5 scale (1 = emaciated, 5 = extremely fat) with 0.25 increments (Lowman *et al.*, 1976).

Statistical analyses

All statistical analyses were carried out using SAS (SAS Institute, 2005). Sward measurements were analyzed using analysis of variance by the following model:

$$Y_{ijkl} = \mu + H_i + D_j + R_k + W_l(R_k) + H_i \times D_j + e_{ijkl}$$

where: Y_{ijk} represents the response of sward k to HM i and DHA j; μ is the mean; H_i is the HM ($i = 1$ to 2); D_j is the DHA ($j = 1$ to 2); R_k is the rotation ($k = 1$ to 10); $W_l(R_k)$ is the week within rotation ($l = 1$ to 30); $H_i \times D_j$ is the interaction between HM and DHA; and e_{ijkl} is the residual error term.

Animal variables (daily milk yield, milk composition, milk constituent yield, BW and BCS) were analyzed using the model as follows:

$$Y_{ijk} = \mu + H_i + D_j + H_i \times D_j + b_1 X_{ijk} + e_{ijk}$$

where: Y_{ijk} represents the response of animal k offered HM i and DHA j; $b_1 X_{ijk}$ is the respective pre-experimental variable; and e_{ijk} is the residual error term.

Results

Grazing management

The effect of HM and DHA on grazing management and milk output per ha for each of the four grazing

Table 1. Effect of pre-grazing herbage mass (HM; L- 1,600 or H- 2,400 kg DM ha^{-1}) and daily herbage allowance (DHA; L- 15 or H- 20 kg DM cow^{-1} day^{-1}) on grazing management and output per hectare (average 206 days grazing season)

	Treatments[1]				SED	Significance		
	L		H					
	L	H	L	H		HM	DHA	HM*DHA
Number of rotations	9[a]	10[a]	6[b]	7[b]	0.9	***	NS	NS
Rotation length (days)	23[a]	21[a]	34[b]	29[b]	2.96	***	NS	NS
Area offered (m^2 cow^{-1} day^{-1})	98[a]	119[a]	66[b]	83[b]	11.3	***	***	NS
Grass growth (kg DM ha^{-1} day^{-1})	68[a]	77[b]	64[a]	74[b]	2.9	NS	***	NS
Stocking rate (cows ha^{-1})	4.00[a]	3.85[b]	4.01[a]	3.93[b]	0.037	NS	***	NS
Milk output (kg ha^{-1})	15,057[a]	16,983[b]	13,876[c]	15,440[a]	641.1	***	***	***
Milk solids (kg ha^{-1})	1,135[ab]	1,268[c]	1,072[a]	1,157[b]	40.9	***	***	***

[1] LL (low HM, 1,600 kg DM ha^{-1} and low DHA, 15 kg DM cow^{-1} day^{-1}), LH (low HM, 1,600 kg DM ha^{-1} and high DHA, 20 kg DM cow^{-1} day^{-1}), HL (high HM, 2,400 kg DM ha^{-1} and low DHA, 15 kg DM cow^{-1} day^{-1}) and HH (high HM, 2,400 kg DM ha^{-1} and high DHA, 20 kg DM cow^{-1} day^{-1}). [a-c] Means within a row with different superscripts differ ($p < 0.05$). NS: not significant ($p \geq 0.05$). ***: $p < 0.001$. **: $p < 0.01$. *: $p < 0.05$. SEM: standard error of the difference.

treatments is shown in Table 1. On average, the low HM treatments had three more grazing rotations than the high HM treatments with a difference accumulated in rotations length from an extra 10 days per rotation for the high HM (32 days) compared to the low HM treatments. The low HM treatments were allocated a greater ($p < 0.001$, +34 m^2 cow^{-1} day^{-1}) mean grazing area per day compared to the high HM treatments (74 m^2 cow^{-1} day^{-1}). Offering high DHA increased the mean grazing area per day ($p < 0.001$, +19 m^2 cow^{-1} day^{-1}) over the treatments offered low DHA (79 m^2 cow^{-1} day^{-1}). Daily grass growth rate for the low DHA swards (66 kg DM ha^{-1} day^{-1}) was 9.5 kg DM ha^{-1} day^{-1} lower than the high DHA swards. The total area conserved for silage was 5.26 ha (LL), 6.23 ha (LH), 6.78 ha (HL) and 5.77 ha (HH). The effective mean grazing stocking rate (SR) was similar (3.95 cows ha^{-1})

across both HM. The high DHA SR (4.01 cows ha^{-1}) was 0.12 cows ha^{-1} higher than the low DHA system. Total milk output and milk solids per ha were greater ($p < 0.001$) for the low HM treatments (16,020 and 1,202 kg ha^{-1}, respectively) compared to the high HM treatments (14,658 and 1,115 kg ha^{-1}, respectively). The LH had the highest milk output and milk solids per ha compared to the lowest milk output and milk solids per ha obtained from the HL.

Sward structural characteristics

The effect of treatment on sward measurements is shown in Table 2. The mean HM for the low treatments (1,597 kg DM ha^{-1}) was significantly lower ($p < 0.001$, −793 kg DM ha^{-1}) compared to the high HM treatments.

Table 2. Effect of pre-grazing herbage mass (HM; L- 1,600 or H- 2,400 kg DM ha^{-1}) and daily herbage allowance (DHA; L- 15 or H- 20 kg DM cow^{-1} day^{-1}) and their interaction on pre- and post-grazing sward height and herbage utilization during the experimental period

	Treatments[1]				SED	Significance		
	L		H					
	L	H	L	H		HM	DHA	HM*DHA
HM (kg DM ha^{-1})	1,601	1,593	2,376	2,403	168.7	***	NS	NS
DHA (kg DM cow^{-1} day^{-1})	14.8[a]	19.5[b]	14.8[a]	19.6[b]	0.256	NS	***	NS
Pre-grazing height (cm)	11.9[a]	11.5[a]	14.4[b]	14.3[b]	0.595	***	NS	NS
Post-grazing height (cm)	4.2[a]	4.7[b]	4.2[a]	5.2[c]	0.098	***	***	***
Herbage utilization (%)	97.7[a]	91.3[b]	98.3[a]	88.4c	1.66	NS	***	NS

[1] See Table 1. [a-c] Means within a row with different superscripts differ ($p < 0.05$). NS: not significant ($p \geq 0.05$). ***: $p < 0.001$. **: $p < 0.01$. *: $p < 0.05$. SED: standard error of the difference.

The mean DHA for the low treatments (14.8 kg DM cow^{-1} day^{-1}) was significantly lower ($p < 0.001$, –4.8 kg DM ha^{-1}) compared to the high DHA treatments. Pre-grazing sward height was significantly higher ($p < 0.001$, +2.7 cm) for the high HM swards (14.4 cm) compared to the low HM swards. There was an interaction in post-grazing swards heights between HM and DHA, the HH treatment had a higher residual than the LH treatment and the two low DHA treatments. The low HM swards (4.5 cm) had a lower post-grazing height (–0.2 cm) compared to the high HM swards. Treatments offered the low DHA (4.2 cm) showed a significantly lower post-grazing sward height ($p < 0.001$, –0.8 cm) than treatments offered the high DHA. Herbage utilization was significantly greater ($p < 0.001$, +8.1%) for the low DHA treatments (98.0%) compared to the high DHA treatments. The low HM treatments (94.5%) showed higher herbage utilization (+1.1%) than the high HM treatments. The highest herbage utilization was observed in the HL and the lowest was obtained in the HH with the rest of treatments in between.

The effect of HM and DHA on swards morphological composition is shown in Table 3. The mean leaf yield (> 4.0 cm) for the low HM treatments (1,206 kg DM ha^{-1}) was significantly lower ($p < 0.001$, –493 kg

DM ha^{-1}) compared to the high HM treatments. The mean stem and dead DM yield (> 4.0 cm) for the low HM treatments (221 and 170 kg DM ha^{-1}, respectively) were significantly lower ($p < 0.001$, –167 and –134 kg DM ha^{-1}, respectively) compared to the high HM treatments. There were no significant differences in leaf, stem and dead DM yield (< 4.0 cm) sward horizons in either the low or high HM treatments. The mean stem DM yield was lower (–70 kg DM ha^{-1}) in the swards grazed at the low HM (842 kg DM ha^{-1}) in contrast to the high HM with a increased dead DM yield (+111 kg DM ha^{-1}) in the low HM swards (1,047 kg DM ha^{-1}) than in the high HM swards. Leaf and dead proportions did not differ significantly between treatments. Stem proportions were significantly ($p < 0.05$, –0.05) affected by the HM, the low HM treatments (0.35) showed a lower stem proportions than the high HM treatments. The LH had the lowest stem proportion during all the experimental period.

Pasture dry matter intake

There were four weeks PDMI measurements analyzed in two periods, P1 (summer, w-6 and w-12) and

Table 3. Effect of pre-grazing herbage mass (HM; L- 1,600 or H- 2,400 kg DM ha^{-1}) and daily herbage allowance (DHA; L- 15 or H- 20 kg DM cow^{-1} day^{-1}) and their interaction on morphological composition of the swards greater than and less than 4.0 cm during the experimental period

| | Treatments[1] | | | | SED | Significance | | |
| | L | | H | | | | | |
	L	H	L	H		HM	DHA	HM*DHA
> 4.0 cm								
Leaf yield (kg DM ha^{-1})	1,211[a]	1,201[a]	1,690[b]	1,707[b]	122.6	***	NS	NS
Leaf proportion	0.75	0.74	0.71	0.72	0.031	NS	NS	NS
Stem yield (kg DM ha^{-1})	216[a]	226[a]	392[b]	384[b]	61.5	***	NS	NS
Stem proportion	0.14	0.15	0.16	0.15	0.023	NS	NS	NS
Dead yield (kg DM ha^{-1})	174[a]	166[a]	295[b]	312[b]	33.6	***	NS	NS
Dead proportion	0.11	0.11	0.13	0.13	0.018	NS	NS	NS
< 4.0 cm								
Leaf yield (kg DM ha^{-1})	598	539	511	504	116.4	NS	NS	NS
Leaf proportion	0.24	0.22	0.22	0.21	0.043	NS	NS	NS
Stem yield (kg DM h^{-1})	870	813	872	952	86.2	NS	NS	NS
Stem proportion	0.37[ab]	0.33[b]	0.39[ab]	0.41[a]	0.032	*	NS	NS
Dead yield (kg DM ha^{-1})	960	1,134	921	954	170.4	NS	NS	NS
Dead proportion	0.39	0.45	0.39	0.38	0.054	NS	NS	NS

[1] See Table 1. [a-c] Means within a row with different superscripts differ ($p < 0.05$). NS: not significant ($p \geq 0.05$). ***: $p < 0.001$. **: $p < 0.01$. *: $p < 0.05$. SED: standard error of the difference.

Table 4. Effect of pre-grazing herbage mass (HM; L- 1,600 or H- 2,400 kg DM ha^{-1}) and daily herbage allowance (DHA; L- 15 or H- 20 kg DM cow^{-1} day^{-1}) and their interaction on pasture dry matter intake during the experimental period (P1, summer and P2, autumn)

| | Treatments[1] | | | | SED | Significance | | |
| | L | | H | | | | | |
	L	H	L	H		HM	DHA	HM*DHA
P1-PDMI (kg DM cow^{-1} day^{-1})	15.1[a]	16.6[b]	14.2[a]	16.4[b]	0.54	NS	***	NS
P2-PDMI (kg DM cow^{-1} day^{-1})	14.1[a]	15.8[b]	14.0[a]	15.5[b]	0.071	NS	***	NS

[1] See Table 1. [a-c] Means within a row with different superscripts differ ($p < 0.05$). NS: not significant ($p \geq 0.05$). ***: $p < 0.001$. **: $p < 0.01$. *: $p < 0.05$. SED: standard error of the difference.

P2 (autumn, w-21 and w-28) that were presented in a previous paper by Curran *et al.* (2010). Results from the PDMI of sward measurements weeks are shown in Table 4. There was no interaction between HM and DHA for PDMI in both periods. HM no showed any effect on PDMI in P1 and P2. The DHA had a significant effect on PDMI in both periods ($p < 0.001$). The mean PDMI in P1 of cows offered the high DHA swards was significantly ($p < 0.001$, +1.8 kg DM cow^{-1} day^{-1}) higher (16.5 kg DM cow^{-1} day^{-1}) compared to animals offered the low DHA swards. While in P2 these differences were a bit lower ($p < 0.001$, +1.6 kg DM cow^{-1} day^{-1}) between the animals offered the high DHA swards (15.7 kg DM cow^{-1} day^{-1}) compared to the cows offered the low DHA swards.

Animal performance

Milk production and animal performance of all the grazing groups are shown in Table 5. Cows offered the high DHA had a significantly higher ($p < 0.001$, +1.4 kg cow^{-1} day^{-1}) mean milk yield (19.5 kg cow^{-1} day^{-1}) than cows offered the low DHA. The accumulated milk yield per cow and per day during some of the experimental weeks is shown in Figure 1. The highest milk performance was achived by the LH grazing group and the lowest by the HL with the rest of grazing groups (LL and HH) in between. Milk yield of all the groups decreased progresively across the grazing season progressed and according to the lactation stage of all the spring-calving dairy cows. Milk protein and milk fat content did not differ significantly between groups. Cows offered the high DHA swards produced greater ($p < 0.001$, +0.09 kg cow^{-1}) milk solids yield (1.46 kg cow^{-1}) than cows offered the low DHA swards. The highest milk solids yield per cow was obtained by the LH grazing group and the lowest by the HL with the other two groups (LL and HH) in between. There was a significant effect of DHA ($p < 0.001$) on the mean BW and BCS. The high DHA treatments (523 kg) had a higher BW ($p < 0.001$, +12 kg) compared to the low

Table 5. Effect of pre-grazing herbage mass (HM; L- 1,600 or H- 2,400 kg DM ha^{-1}) and daily herbage allowance (DHA; L- 15 or H- 20 kg DM cow^{-1} day^{-1}) and their interaction on milk production and animal performance of dairy cows during the experimental period

| | Treatments[1] | | | | SED | Significance | | |
| | L | | H | | | | | |
	L	H	L	H		HM	DHA	HM*DHA
Milk yield (kg day^{-1})	18.2[a]	20.1[b]	17.9[a]	18.9[b]	0.56	NS	***	NS
Milk protein content (g kg^{-1})	35.0	35.5	34.5	35.2	0.63	NS	NS	NS
Milk fat content (g kg^{-1})	40.8	39.9	42.4	40.6	1.28	NS	NS	NS
Milk solids yield (kg cow^{-1})	1.37[a]	1.50[b]	1.36[a]	1.41[b]	0.046	NS	***	NS
Body weight (kg)	511[a]	521[b]	511[a]	524[b]	5.6	NS	***	NS
Body condition score	2.62[a]	2.74[b]	2.60[a]	2.74[b]	0.071	NS	**	NS

[1] See Table 1. [a-c] Means within a row with different superscripts differ ($p < 0.05$). NS: not significant ($p \geq 0.05$). ***: $p < 0.001$. **: $p < 0.01$. *: $p < 0.05$. SED: standard error of the difference.
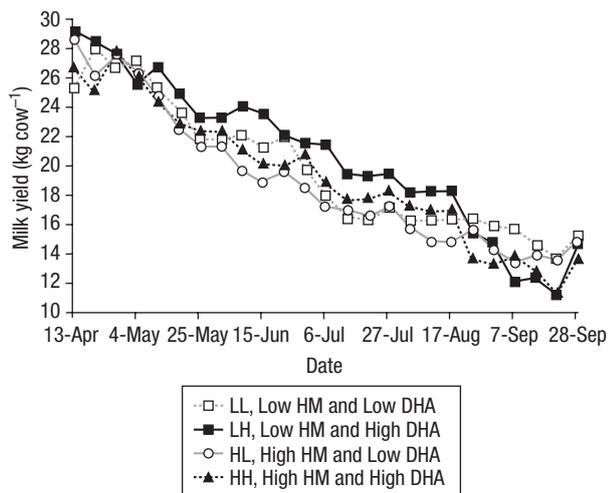
Figure 1. Effect of pre-grazing herbage mass (HM; L- 1,600 or H- 2,400 kg DM ha^{-1}) and daily herbage allowance (DHA; L- 15 or H- 20 kg DM cow^{-1} day^{-1}) on milk yield (kg per cow) at grazing during 24-weeks of the experimental period. Treatments: see Table 1.

DHA treatments. The BCS was also higher ($p < 0.001$, +0.13) for the cows offered the high DHA swards (2.74) in contrast to the low DHA swards.

Discussion

In other previous experiments describing the effects of HM on milk performance of dairy cows compared treatments of early and late grazed swards, with the experiment beginning when the swards were first grazed (O'Donovan *et al.*, 2004; Kennedy *et al.*, 2007). However, in this study as occurred in the work reported by McEvoy *et al.* (2009) all swards were grazed once to a similar post-grazing sward height prior to the experiment commencement in order to ensure similar pre-experimental treatment of all swards and avoid differences arising from grazed and ungrazed swards. The experiment lasted 30 weeks across the grazing season providing an opportunity to assess the cumulative treatment effects of pre-grazing HM and DHA on swards structure, PDMI and dairy cows' milk performance at pasture. In the current research a more approximated situation to the main effects of grazing perennial ryegrass swards with different HM and DHA has been realized with the aim of establishing the sward canopy response and milk output per ha of spring-calving dairy cows throughout the grazing season, which can be really extrapolated in the future to on farm grazing management system.

Grazing management

Within each HM system the grazing SR difference was low (0.07 cows ha^{-1}) between the low HM treatments and the high HM treatments due to different regrowth periods between the low DHA swards and the high DHA swards. In fact, the high DHA swards had a greater (+10 kg DM ha^{-1} day^{-1}) daily growth rate when compared to the low DHA swards. Kennedy *et al.* (2007) reported that high HM swards can support a greater grazing SR of 6.5 cows ha^{-1}. However, grazing at low HM with a mean SR of 4.5 cows ha^{-1} has showed a positive effect on swards quality, PDMI and milk performance. A lower grazing SR difference was found in this experiment (–0.12 cows ha^{-1}) between the two DHA treatments in contrast to the results reported by McEvoy *et al.* (2009) with a grazing SR difference of 0.40 cows ha^{-1} between the low DHA and the high DHA when the mean HM was of 1,700 kg DM ha^{-1} for the low HM treatments and 2,200 kg DM ha^{-1} for the high HM treatments and the mean DHA was of 16 kg DM cow^{-1} day^{-1} for the low DHA treatments and 20 kg DM cow^{-1} day^{-1} for the high DHA treatments. Moreover, the daily growth rate was lower from the experiment of McEvoy *et al.* (2009) compared to the current study with the mean daily growth rate difference (+6.9 kg DM ha^{-1} day^{-1}) between the high DHA swards and the low DHA swards.

Swards structural characteristics

The mean greater proportions of unutilised herbage in the high DHA treatments resulted in the low HM, being higher for the high DHA swards. This suggests that as a sward is more severely grazed total DM yield is reduced, whereas the leaf DM proportion (> 4.0 cm) tends to increase (Stakelum and Dillon, 2007) as occurred in the current grazing experiment and, consequently, the feeding value of the sward tends to increase. The increased regrowth interval and pre-grazing DM yield difference between the two HM treatments suggest that the age (Hoogendoorn *et al.*, 1992) and stage of growth (Dillon *et al.*, 2005) of the plant tissue may be responsible for decreasing the digestibility and quality for the high HM swards compared to the low HM swards. Furthermore, Terry and Tilley (1964) reported that the chemical composition and digestibility of the various plant components (leaf and stem) varies widely both between components and within components as the

plant matures. The proportion of leaf in the swards tends to be greatest in the low HM swards (+0.03), resulting in increased OMD ($p < 0.05$, +8.5 g kg^{-1} of DM) compared to the high HM swards (leaf proportion, 0.72 and OMD, 828.5 g kg^{-1} of DM) which tend to have increased the stem and dead proportions (Hoogendoorn *et al.*, 1992; Stakelum and Dillon, 2007) as occurred in the current experiment (stem, +0.01 and dead, +0.02). Grazing the sward at the three leaf stage is designed to graze the sward when it is at its highest sward quality (Fulkerson and Donaghy, 2001). O'Donovan and Delaby (2008) found greater OMD values with early grazed swards with lower defoliation heights which were directly related to the higher leaf composition of the sward. Similarly, Jacobs *et al.* (1998) associated an increasing HM with a decline in DM digestibility and CP, and increased neutral detergent fibre (NDF). These differences are likely due to differences in proportions of leaf, stem and senescent materials in the sward.

Maintaining the low HM swards throughout the grazing season increased the leaf to stem ratio (5.15) compared to the high HM swards (4.62), this agrees with Kennedy *et al.* (2007) who reported a cumulative effect of grazing severity on leaf to stem ratio. These results have also showed beneficial effects on animal performance. Hoogendoorn *et al.* (1992) reported greater effect of DHA of leaf DM yield on milk production compared to DHA of total DM yield (expressed in kg DM cow^{-1}). Johnson and Parsons (1985) reported that high levels of death and decay accompany poor herbage utilization. This concurs with the findings of this study as the HH swards had greater accumulations of dead material due to a higher post-grazing height and lower levels of utilization than all other treatments. This phenomenon is likely to be the reason for the higher leaf and lower stem production which was apparent with the low HM swards. Carton *et al.* (1989) suggested that a high grazing intensity in the early to mid-summer period controls the reproductive development of the sward and it is responsible of a decreasing in the production and development of reproductive tillers (Hoogendoorn *et al.*, 1992; Hurley *et al.*, 2008). Thereby, avoiding large accumulations of stem in the sward which has a negative impact on pasture quality. This suggestion is consistent with the results found in this experiment in the low DHA swards. Fulkerson and Donaghy (2001) stated that severe defoliation removes much water soluble carbohydrate (WSC) storage capacity and reduces regrowth,

while under lax defoliation, the loss in DM through leaf senescence and reduced rates of tillering are not compensated for the increased growth rate that results. Hunt and Brougham (1967) found that where repeated lax defoliation of perennial ryegrass left enough herbage to intercept 95% of incident light the amount of green leaf and tillers initiated progressively declined, while the proportion of dead material increased. This indicated the need for periodic close defoliation to renew the photosynthetic efficiency of the grass sward. Defoliation intensity determines the absolute amount of stubble and hence remaining WSC. Instead of the fact that the WSC were not measured in the current study, it is important to take into account that changes in tissue partitioning between the low and high HM were due to the severity of defoliation and higher leaf content, which is directly related to WSC content.

Pasture dry matter intake

Animals on the high HM swards achieved lower PDMI than cows grazing low HM swards in both periods because of the low HM cows grazed further into the horizon whereas the high HM cows were possibly at the swards physical restriction of PDMI. This agrees with the results of O'Donovan and Delaby (2008) who suggested that based on chemical composition and nutritive values grass PDMI is likely to be increased by maintaining lower levels of HM. Wade (1991) also reported that sward stem is a barrier to increase PDMI when cows are forced to graze to low post-grazing residuals. The high HM swards in the current study were grazed to low post-grazing heights (4.7 cm) and the PDMI results of the HH grazing group would suggest that this treatment was at its physical limit in terms of sward post-grazing height because these cows could not graze further into the sward horizon. There was no significant effect of HM on PDMI in both periods. Nevertheless, during P1 the low HM and high HM swards were of similar quality and in P2, following the reproductive stage of the plant, the quality of the low HM swards remained relatively constant while the high HM swards quality was deteriorated. Thus, during P1 offering high HM swards resulted in higher levels of PDMI, however during P2 the PDMI of the LL was similar to that of the HL, while PDMI of the LH treatment was significantly greater than all other treatments. The DHA ($p < 0.001$) had a large effect on PDMI. In fact, increasing the DHA it was found a greater PDMI.

The intake response to the DHA was different between periods. For the same post-grazing sward height the PDMI difference between the low DHA grazing groups was higher in P1 than in P2 (0.9 and 0.1 kg DM cow^{-1} day^{-1}, respectively). Stakelum and Dillon (2007) stated that the relationship between DHA and PDMI depends on the levels of DHA being compared, the cutting height of herbage and the levels of production of the experimental animals. Results from this study shows that there is a reduced response level of the low HM. This intake response is in line with that previously reported by Peyraud *et al.* (1996) and Stakelum and Dillon (2007). Combellas and Hodgson (1979) also stated that there is a higher proportion of herbage close to ground level on short, light sward canopies than on tall, heavy swards and this can explain better the results from this experiment with avenues of increasing PDMI remain to be capitalised upon if the base of the sward is focused on.

Animal performance

Holmes *et al.* (1992) reported increased milk production, milk protein and milk fat content by cows grazing low HM compared to high HM swards. This contradicts the short term study of Wales *et al.* (1999), which reported lower milk production for cows on a low HM compared to medium HM swards with early lactation animals. However, in mid-lactation with the same animals there was no effect of HM on animal production, this agrees with the results of the current study because there was no difference in milk production of animals grazing low or high HM swards throughout the grazing season. The milk yield of the LH treatment was 1.9 kg cow^{-1} day^{-1} greater than the other treatments. The higher level of milk production per cow of the LH group is likely due to a cumulative effect of several sward factors. This is similar to the finding of O'Donovan *et al.* (2004) and McEvoy *et al.* (2009) indicating that with high HM swards, offering a high DHA will not result in improved milk yields. In fact, the cumulative effect of grazing low HM swards becomes distinctly apparent in the second half of the grazing season when HM and DHA interact. The results reported by Kennedy *et al.* (2007) showed an increase in milk production, when there was a HM difference of 1,055 kg DM ha^{-1}. Holmes *et al.* (1992) reported an increased milk production from cows grazing low HM (2,860 kg DM ha^{-1}) swards compared

to high HM (4,790 kg DM ha^{-1}, above ground level) swards. Stakelum and Dillon (2007) described large differences in milk yield in extremes of sward quality up to 2.6 and 2.1 kg cow^{-1} day^{-1} in two consecutive experiments, treatment differences in HM were up to 2,300 kg DM ha^{-1}. McEvoy *et al.* (2009) also found a 0.4 kg milk day^{-1} in favor of low HM swards when compared to swards 600 kg DM ha^{-1} higher in DM yield. However, Combellas and Hodgson (1979) and Wales *et al.* (1999) reported no effect of HM on milk composition which is in agreement with the results of the current study. In contrast, Hoogendoorn *et al.* (1992) in two separate grazing experiments, lasting less than 3 weeks, did observe increased protein yield with a low HM (2,900 kg DM ha^{-1}) compared to a high HM (5,100 kg DM ha^{-1}, above ground level).

The effect of DHA was evident in our experiment across the grazing season, milk yield ($p < 0.001$) and milk solids yield ($p < 0.001$) were consistently lower for the low DHA treatments. Wales *et al.* (1999), Delaby *et al.* (2001), Bargo *et al.* (2002), Stakelum and Dillon (2007) and McEvoy *et al.* (2009) all found similar results. The low HM animals were more responsive to the extra pasture allocation as the LL cows had an intake equaling pasture allocation and the LH cows had a greater milk production performance. Peyraud *et al.* (1996) and Maher *et al.* (2003) showed increases in milk protein content when animals were offered a high DHA (31.3 and 33.6 g kg^{-1}, respectively). This is similar to the results obtained in this study with 35.4 g kg^{-1} in the high DHA groups compared to 34.8 g kg^{-1} in the low DHA groups. The milk protein content was higher in the current DHA swards than that achieved by Peyraud *et al.* (1996) and Maher *et al.* (2003). Wales *et al.* (1999) showed lower milk protein content for animals grazing low HM swards but similar protein content for animals allocated high and low DHA. There was no difference in milk fat content between treatments in mid or late lactation which agrees with the results of Bargo *et al.* (2002) and McEvoy *et al.* (2009).

Milk output and milk solids per hectare

Efficient pasture-based dairy production systems are characterized by high milk output per unit of land (per ha) in comparison to confinement systems where efficiency is characterized by high milk output per cow (Clark and Kanneganti, 1998). The current study investigated grazing management practices to increase cow

production from pasture and performance per ha. The results of the current experiment indicate that offering lower HM swards to dairy cows will result in increased milk output per ha in comparison to high HM swards. This difference occurs due to the improved quality of herbage available to the animal because of intense grazing of the sward (Hoogendoorn *et al.*, 1992) throughout the grazing season and the SR which can be maintained on these sward types. Numerous studies have reported high HM swards support higher SR resulting in increased milk production per ha in short term experiments (Holmes *et al.*, 1992; O'Donovan *et al.*, 2004; Kennedy *et al.*, 2006). This study shows that low HM swards managed over the main grazing season (April to October) can support higher SR and also increase milk production and milk solids per ha. The effect of HM on individual factors including SR, milk yield and milk solids per ha is smaller than that reported previously by Kennedy *et al.* (2006) and McEvoy *et al.* (2009). However, the accumulation of the benefits from each factor clearly shows the superiority of grazing low HM swards to optimize the available land to increase output in grazing dairy systems where production per ha is becoming increasingly important. This increase in milk output per ha (+8.5%) on the low HM swards compared to the high HM swards highlights the potential importance to optimize economic performance through efficient grazing management practices as it is on this basis that the dairy processor will make payments in the future (Shalloo *et al.*, 2007).

Conclusions

The effect of pre-grazing herbage mass (HM) and daily herbage allowance (DHA) on swards structure, pasture dry matter intake (PDMI) and dairy cows' milk performance must be considered as a key tool to achieve optimal milk output on a per-cow or a per-ha basis. The high DHA, 20 over 15 kg DM cow^{-1} day^{-1}, using a low HM swards (1,600 kg DM ha^{-1}) improved sward quality presenting lower stem and dead DM yield (> 4.0 cm), higher PDMI and milk yield and more milk solids per cow and per ha, also an increase on body weight and body condition score was found. The results from this study highlight the importance of using low HM swards in the early part of the grazing season by getting a low post-grazing residuals and a high herbage utilization that enabled grazing dairy cows to achieve better performance.

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