



The effect of target postgrazing height on sward clover content, herbage yield, and dairy production from grass-white clover pasture

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ABSTRACT

White clover (*Trifolium repens*) is an important legume for grazed grassland that can increase the profitability and environmental sustainability of milk production. Previous experiments on mown grass-clover plots suggest that low postgrazing heights (PGH) can increase sward clover content and herbage production. However, this has not been tested in actual strip or rotational grazing systems with dairy cows. Furthermore, lowering PGH in grass-only swards (typically perennial ryegrass without white clover) has previously been associated with reduced milk yields per cow. The objective of this experiment was to investigate the effect of PGH by dairy cows on clover content, herbage production, and milk production from strip-grazed grass-white clover swards in Ireland. Three target PGH treatments of 4, 5, and 6 cm were in place for entire grazing seasons (February to November) for 3 consecutive years (2007 to 2009). Each treatment had a mean of 21 Holstein-Friesian dairy cows that strip-grazed a mean annual area of 10.2 ha. Postgrazing height was measured twice a day with a rising plate meter, and cows were moved to the next strip once the target PGH was reached. Annual fertilizer nitrogen input was 90 kg of N/ha for each treatment. The PGH treatment did not significantly affect annual milk yield (6,202 kg/cow), solids-corrected milk yield (6,148 kg/cow), fat, protein, or lactose yields (265, 222, and 289 kg/cow, respectively), cow liveweight (592 kg) or body condition score (3.01). The PGH treatment also had no significant effect on sward white clover content (196 g/kg). However, herbage production of both grass and clover were significantly higher with the 4-cm PGH treatment compared with the 6-cm treatment. Mean annual herbage yields were 11.1, 10.2, and 9.1 t of organic matter (OM)/ha for the 4-, 5-, and 6-cm PGH treatments, respectively. The lower herbage production in the 6-cm PGH treatment resulted in lower annual silage produc-

tion, greater housing requirements, and a substantially higher net silage deficit (−1,917 kg of OM/cow) compared with the 5- or 4-cm treatments (−868 and −192 kg of OM/cow, respectively). Grazing to a PGH of 4 cm is therefore recommended for grass-white clover swards.

Key words: postgrazing height, white clover, perennial ryegrass, milk yield

INTRODUCTION

White clover (*Trifolium repens*) facilitates biological nitrogen fixation (BNF) through its association with *Rhizobium* bacteria and can thereby reduce fertilizer N requirements of grassland for dairy production (Gylfadóttir et al., 2007; Humphreys et al., 2009; Del Prado et al., 2011). White clover is most commonly grown in association with perennial ryegrass (*Lolium perenne*), and increasing its content in herbage can improve sward nutritive value, herbage intake rates, and milk production per cow (Harris et al., 1998; Dewhurst et al., 2009; Kleen et al., 2011). Replacing fertilizer N use with white clover-based BNF can also improve economic performance at the farm level (Doyle and Bevan, 1996; Falconer et al., 2011; Humphreys et al., 2012). This is particularly so in recent years because of the large increase in fertilizer N price relative to milk price (World Bank, 1990–2012). White clover can also have important environmental benefits such as increased biodiversity (Power and Stout, 2011) and reduced greenhouse gas emissions (Li et al., 2011) for dairy production from grazed grassland.

One of the main challenges in achieving the above benefits from white clover is maintaining effective sward clover content (>300 g/kg) within the sward from year to year (Frame and Laidlaw, 1998; Rochon et al., 2004). Previous experiments on mown, small-scale grass-clover plots have shown that lowering defoliation height can increase clover content and clover herbage production (Frame and Boyd, 1987; Acuña and Wilman, 1993; Phelan et al., 2009). The beneficial effect of lowering defoliation height on sward clover content is generally attributed to reduced shading of the clover growing points by grass (Thompson, 1993; Héraut-Bron

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et al., 2001; Christophe et al., 2006). As a result, low postgrazing heights (PGH) are often recommended for grass-clover swards. However, the effect of PGH on clover content in grass-clover swards has not been investigated in actual strip or rotational grazing systems for dairy production over entire grazing seasons. Furthermore, daily herbage allowance (DHA) experiments on grass-only swards have found that lower PGH can be associated with lower milk yields per cow and lower milk fat, protein, or lactose concentrations (Le Du et al., 1979; Maher et al., 2003; Curran et al., 2010).

The objectives of this experiment were to measure the effects of imposing a target PGH of 4, 5, or 6 cm on sward white clover content, herbage production, and milk production from grass-clover swards in a strip-grazing system with dairy cows over several grazing seasons. It was hypothesized that lowering PGH would (1) increase sward clover content, which would increase BNF and herbage production, but (2) also reduce milk yield per cow.

MATERIALS AND METHODS

Experimental Area

This experiment was conducted from January 2007 to December 2009 at Solohead Research Farm in Ireland (52°51'N, 08°21'W, 95 m above sea level). The soils of the farm are 90% poorly drained gleys and 10% gray-brown podzolics with a depth ranging from 5 to 10 m, overlaying Devonian sandstone. Drainage is impeded, which contributes to waterlogged conditions under high rainfall. The soil has a clay-loam texture of 36% sand and 28% clay in the A1 horizon. Soil organic matter content was 13% and soil pH was 6.6 before the experiment. The land has been under permanent grassland for over 50 yr but was reseeded with perennial ryegrass between 1985 and 1995 and oversown with white clover between 2001 and 2006, as described by Humphreys et al. (2009). The botanical composition of the swards (in g/kg of herbage DM, sampled in September 2008) was found to be predominantly perennial ryegrass (approximately 750 g/kg) and white clover (approximately 200 g/kg). Unsown species were primarily *Taraxacum officinale* (dandelion), *Ranunculus repens* (creeping buttercup), *Bellis perennis* (daisy), and *Plantago lanceolata* (ribwort plantain), which accounted for less than 50 g/kg in total.

Soil temperature (°C at depth of 10 cm) and rainfall amounts (mm) were measured every 30 min at an automatic meteorological station on the farm (Campbell Scientific Ltd., Loughborough, UK). The experimental area was 40.8 ha in 2007 and 25.5 ha in both 2008 and 2009.

Experimental Design and Grazing Management

The experiment was a complete randomized block design consisting of 3 treatments that were target PGH of 4, 5, or 6 cm imposed for entire grazing seasons (February to November) over 3 consecutive years (2007 to 2009).

The experimental area was divided into 6 sections according to soil type and drainage status in January 2007. One paddock from each section was randomly assigned to PGH treatment and remained under that treatment until the end of the experiment in December 2009. Paddock size ranged from 1.46 to 3.30 ha² in 2007 (mean = 2.27 ha²) and from 0.94 to 1.97 ha² in both 2008 and 2009 (mean = 1.42 ha²). The total stocking rate in each treatment was 1.99 cows/ha in 2007 and 2.12 cows/ha in 2008 and 2009.

Cows were turned out to graze approximately 3 d after calving in mid-February and remained at pasture until they were dried off and housed full-time at the end of November. Exceptions were made when ground conditions were too wet (soil moisture >60%) or when herbage supply was too low, which generally occurred when herbage growth rates were below demand and pregrazing herbage mass was <500 kg of DM/ha (above PGH). On such occasions, cows were housed at night and fed grass-clover silage ad libitum.

Each treatment was under strip-grazing management, with approximately 0.25 to 0.50 of each paddock allocated each time. The PGH (cm above the soil surface) was measured twice per day from 50 drops with a Filips rising plate meter (www.grasstec.ie). Cows were moved to the next pasture area once the target PGH was achieved, and a back-fence was used to stop animals returning to previously grazed areas.

Slurry produced during housing was stored together and reapplied to each treatment equally during the following grazing season using regulatory protocols (European Communities Good Agricultural Practice for Protection of Water Regulations, 2009, S.I. No. 101) and an umbilical system with downward-facing splash plate. Each treatment received annual mineral fertilizer N input of 90 kg/ha, applied in the form of urea between February and April and as calcium ammonium nitrate (CAN) in May of each year. These were the only forms of synthetic fertilizer N used in this study, and no fertilizer N was applied during the remainder of the growing season.

Excess herbage production was identified throughout the experiment and removed for silage production. These areas were selected when herbage growth rates exceeded demand, resulting in pregrazing herbage mass >2,000 kg of DM herbage (above PGH) per hectare. Such areas were generally closed from grazing between

April 2 and May 28 (first-cut silage) or between May 23 and July 10 (second-cut silage) of each year. The proportion of the grazing area that was removed for silage production is presented in the results.

Animals

Each February, all cows on the farm were divided into 4 main groups on the basis of lactation number (1, 2, 3, and ≥ 4) and then sub-divided into sub-groups of 3 on the basis of calving date. From within each sub-group, 1 cow was randomly assigned to each PGH herd. This procedure was repeated each spring.

The experiment consisted of 81 Holstein-Friesian dairy cows in 2007 (21 primiparous and 60 multiparous) and 54 (12 primiparous and 42 multiparous) in 2008 and 2009. Mean calving date was February 20 (SD = 22 d).

Cows received concentrate feed supplementation (26% barley, 26% corn gluten, 35% beet pulp, and 12% soybean meal) at rates of approximately 3 to 5 kg/cow between February and April and 0 to 4 kg/cow between April and November, depending on herbage availability and quality (see Results). When housed over winter, the groups were fed silage *ad libitum*. The mean composition of fed silage (\pm SD) throughout the experiment was 78 g/kg ash (± 13.3), 784 g/kg OM digestibility (OMD; ± 6.3), and 122 g/kg CP (± 18.9).

Sward Measurements

Herbage Yields and Feeding Quality. Before each grazing event, herbage DM yield was sampled by cutting 2 to 4 random strips, each 5 m long and 0.55 m wide, using a HRH-536 lawnmower (Honda, Alpharetta, GA) set to the target PGH. Before harvesting grass-clover for silage, herbage DM yield was measured from 4 strips (5.0 \times 1.1 m) using an Agria auto-scythe (Etesia UK Ltd., Warwick, UK). On each occasion, the harvested herbage was bulked and weighed to determine herbage mass and a 100-g sub-sample dried for 16 h in a forced-draft oven at 95°C for DM content. Annual herbage yield (kg of DM/ha) was calculated as the sum of herbage removed as pregrazing and presilage cuts. Growth rates for each pregrazing and presilage cut were calculated by dividing the herbage mass by the regrowth interval.

A second 100-g sub-sample of each herbage yield sample was freeze-dried and milled through a 0.2-mm sieve before analyses for ash content (550°C muffle furnace for 12 h), CP (N content \times 6.25; Leco 528 auto-analyzer, Leco Corp., St. Joseph, MI), and *in vitro* OMD as described by Morgan et al. (1989). Herbage yield and CP results are presented as dry OM, as recommended by Elgersma and Schlepers (1996). Daily

herbage allowance (kg of OM above target PGH) was calculated retrospectively by dividing the herbage yield from pregrazing cuts by the number of days at pasture. The net energy (NE) content of pregrazing herbage was calculated from the ash content, OMD, and CP (Jarrige et al., 1986; Jarrige, 1989; O'Mara, 1996).

Silage fed to housed animals was randomly sampled ($n = 88$) throughout the experiment by taking a grab sample of approximately 100 g before feeding. This was analyzed for ash, OMD, and CP using near infrared spectroscopy (model 6500, Foss-NIR System, Hillerød, Denmark).

White Clover Content in Herbage, Stolon Mass, and Biological Nitrogen Fixation. White clover content of herbage in each paddock was measured from 30 randomly distributed herbage snips (each 10 cm \times 30 cm) taken to the target PGH of each treatment with electric hand shears (Accu-shears, Gardena, Ulm, Germany). This was done in April, June, and September of each year. All samples were manually separated to determine the white clover content of herbage DM.

White clover stolon mass was measured in February, May, August, and November of each year by cutting 30 random sods (each measuring 10 \times 10 cm) to a depth of approximately 8 cm from each paddock. White clover stolons with attached roots were manually separated from the sods, washed, and analyzed for DM as described above. Annual grass and clover herbage production was calculated from the mean annual clover content of each paddock and its respective annual herbage yield. The annual BNF was estimated from annual clover herbage yield, sward age, and soil type using the model by Høgh-Jensen et al. (2004).

Animal Production Measurements

Milk Production, Liveweight, and BCS. Milking was conducted at 0730 h each morning and 1530 h each evening. Individual cow milk yield (kg) was recorded at each milking and fat, protein, and lactose concentrations of milk from each cow were measured for a successive morning and evening milking once per week using a Milkoscan 203 analyzer (Foss Electric, Hillerød, Denmark). Yield of SCM was calculated using the equation of Tyrrell and Reid (1965). The liveweight of each cow was recorded once per week using weighing scales and the Winweigh software package (Tru-Test Ltd., Auckland, New Zealand). The BCS of each cow was recorded once every 2 wk using the methodology of Edmonson et al. (1989).

Days at Pasture and Intake Estimates. Days at pasture were recorded for each cow, with a value of 1 ascribed to each 24-h period and a value of 0.5 ascribed

if the animal was at pasture by day only. The amount of concentrate fed per cow was recorded at each milking (Dairymaster, Causeway, Co. Kerry, Ireland), and silage intake was estimated as silage fed to cows when housed.

Intake of grazed pasture OM by each cow was estimated as the difference between NE provided from silage and concentrate and that needed to meet the NE requirements for milk production, maintenance, and pregnancy (Jarrige et al., 1986; Jarrige, 1989; O'Mara, 1996). The NE content of concentrate was calculated from the constituent ingredients, and the NE content of silage was calculated from in vitro DM digestibility (DMD; O'Mara, 1996). The NE content of grazed herbage was calculated from the OMD, CP, and ash content (Jarrige et al., 1986; Jarrige, 1989; O'Mara, 1996). Cow NE requirements were calculated from milk yield, fat, protein, and lactose contents, and liveweight (Jarrige et al., 1986; Jarrige, 1989; O'Mara, 1996). Daily herbage intake (DHI; kg of OM) was estimated for each cow by dividing the annual amount of herbage intake by the number of days at pasture.

Statistical Analyses

All results were subjected to ANOVA using the mixed procedure in SAS (SAS Institute, 2006) with the following model:

$$X_{jkl} = \mu + P_j + Y_l + M_k + PY_{jl} + PM_{jk} + YM_{lk} + PYM_{jkl} + e_{jkl},$$

where X_{jkl} = dependent variable treatment mean, μ = overall mean, P_j = the fixed effect of the j th PGH, Y_l = the fixed effect of the l th year, M_k = the fixed effect of the k th sampling date where applicable, and e_{jkl} = residual error term. Year and sampling date (for sward clover content and clover stolon mass) were entered as repeated measures using the un@cs covariance structure, as recommended by Moser (2004). Paddock was the replicate for sward measurements and cow was the replicate for animal measurements. Year was used as the replicate for sward or animal measurements that were calculated on a herd basis for each treatment: the proportional land area removed for silage, amount of herbage produced as silage, silage surplus, and DHA.

RESULTS

Meteorological Data

Mean daily soil temperature and monthly rainfall amounts for the experimental period and the previous

10-yr means are shown in Figure 1. Mean soil temperature was 10.2, 9.5, and 9.6°C in 2007, 2008, and 2009, respectively, whereas the previous 10-yr mean was 10.9°C (range: 10.0 to 11.8°C). Total rainfall was 990, 1,228, and 1,296 mm in 2007, 2008, and 2009 compared with the previous 10-yr mean of 1,009 mm (range 797 to 1,150 mm). Therefore, 2007 showed values within the range of previous years but 2008 and 2009 were both cooler and wetter (Figure 1).

Measured PGH

The mean monthly PGH measured throughout the experiment are shown in Figure 2. The overall mean PGH over the course of the experiment were 4.1, 5.1, and 5.9 cm for the 4-, 5-, and 6-cm treatments respectively ($P < 0.001$, SEM = 0.02; Figure 2).

Clover Persistence and Annual Grass and Clover Herbage Production

Sward clover content and clover stolon mass per hectare are shown in Table 1. Target PGH treatment had no significant effect on sward clover content or clover stolon mass ($P > 0.05$). However, both were affected ($P < 0.05$) by year: 2009 had higher clover content but lower stolon mass than 2007 (Table 1). Clover content and stolon mass were also affected by interactions ($P < 0.001$) between year and sampling date: both tended to increase throughout the year in 2007 and 2009, but not in 2008.

Annual grass, clover, and total herbage yields are shown in Table 1. The 4-cm PGH treatment increased annual grass ($P < 0.05$), clover ($P < 0.05$), and total herbage OM yields ($P < 0.001$) compared with the 6-cm PGH in all 3 years. Grass and total herbage OM yields were lower in 2008 and 2009 than in 2007 across all treatments ($P < 0.001$). Estimates of BNF were higher with the 4-cm PGH than with the 6-cm PGH ($P < 0.05$; Figure 3) and were not affected by year. The daily herbage growth rates throughout the experiment are shown in Figure 4. The 4-cm treatment had higher growth rates than the 6-cm treatment ($P < 0.05$), and 2007 had higher growth rates than 2009 ($P < 0.001$).

Pregrazing Herbage Quality

The mean ash content, OMD, and CP of pregrazing herbage are shown in Table 2. Mean OMD of pregrazing herbage was not affected by PGH. However, a significant interaction was found between PGH and year ($P < 0.01$), in which the 6-cm PGH had higher OMD than the 4-cm PGH in 2007 only. Moreover, CP was

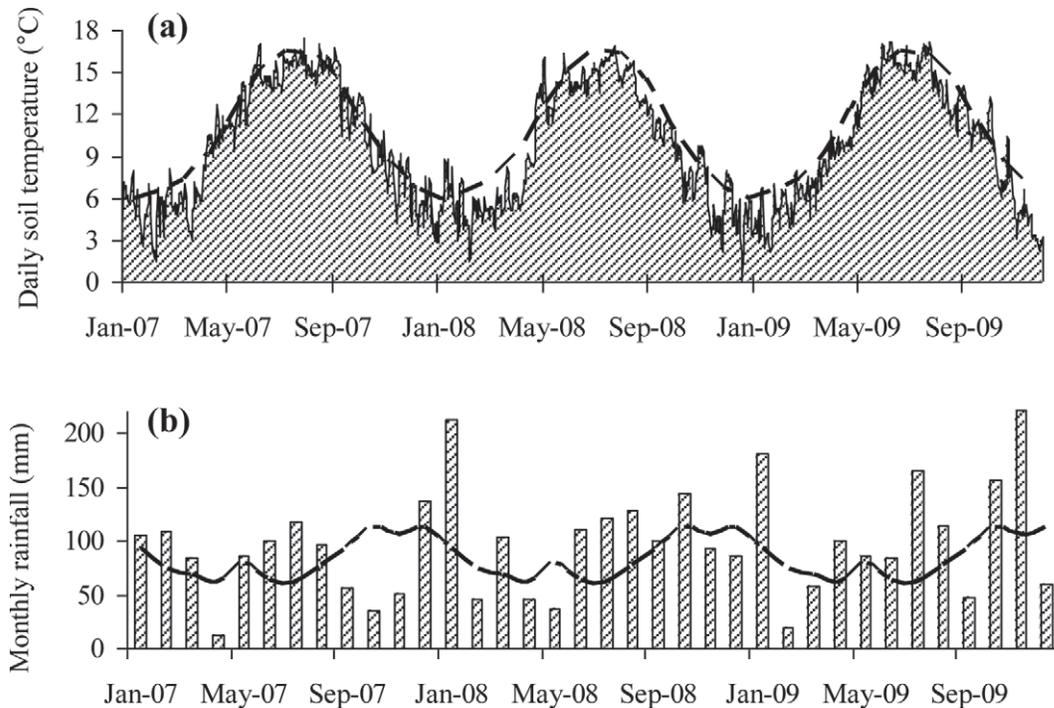


Figure 1. Mean daily soil temperature (a) and monthly rainfall amounts (b) recorded at the meteorological station at Solohead Research Farm between January 2007 and December 2009. The shaded areas show the recorded values during the experimental period, and the dashed lines show the previous 10-yr mean values (1996–2006).

lower ($P < 0.05$) and ash content higher ($P < 0.001$) with the 4-cm PGH (Table 2).

The time interval between successive grazings for each paddock (rotation length) was longer with the 4-cm than the 6-cm PGH ($P < 0.05$; Table 2). However, an interaction with year was found, in which the 5-cm PGH had the longest intervals in 2008 only. Pregrazing herbage mass (above the target PGH) followed a similar trend and was greater with the 4-cm PGH than with the 6-cm PGH. The differences between the 4- and

5-cm PGH were affected by an interaction with year ($P < 0.01$), where the 4-cm PGH had longer intervals and higher herbage masses in 2007 and 2009 but not in 2008, when the 5-cm PGH had the highest pregrazing herbage mass (Table 2).

Days at Pasture and Feed Intake per Cow

Postgrazing height had no effect on estimated intake of grazed pasture or on the amount of concentrate fed

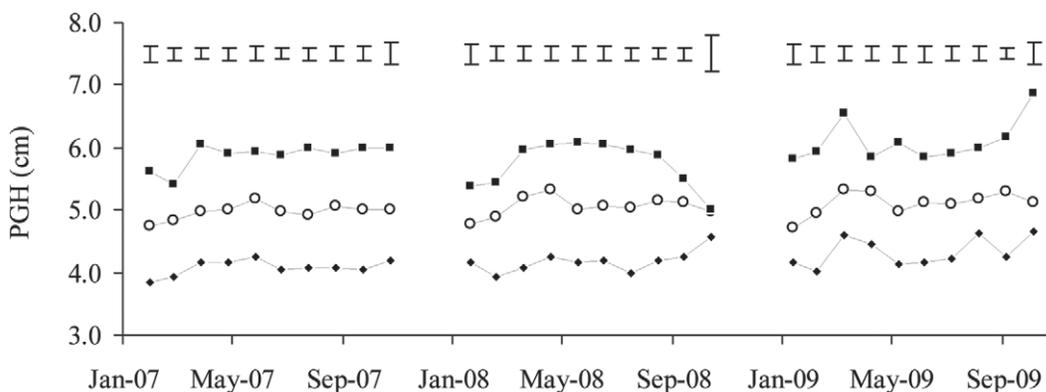


Figure 2. Effect of target postgrazing height (PGH) treatment on actual PGH measured throughout the experiment. Target PGH treatments were 4 cm (◆), 5 cm (○), and 6 cm (■). Error bars show the SEM of the PGH treatment, $P < 0.001$.

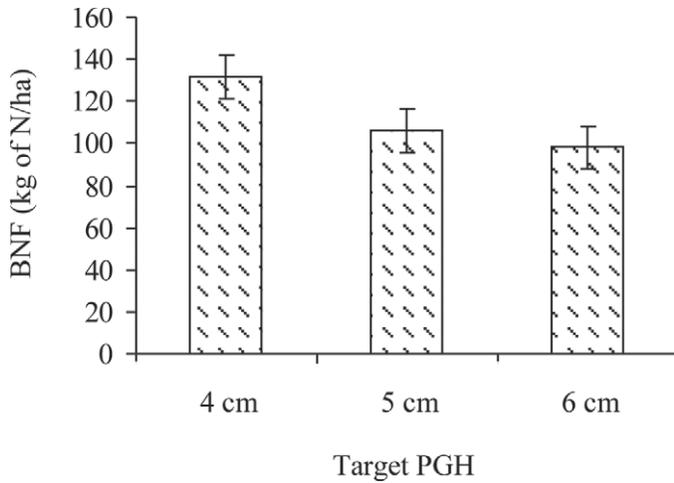


Figure 3. Effect of target postgrazing height (PGH) treatment on annual biological nitrogen fixation (BNF) estimates ($P < 0.05$). Year had no significant effect ($P > 0.05$). Error bars show the SEM of PGH treatment.

(Table 3). Estimates of DHA and DHI were also not affected by PGH (Table 3). The amount of silage fed to cows was also similar across treatments in 2007 and 2008. The weather conditions in 2008 and 2009 resulted in fewer days at pasture, less grazed grass in the cow's diet, and greater demand for silage and concentrate across treatments compared with 2007 ($P < 0.001$). In 2009, the 6-cm PGH had fewer days at pasture and consequently required a greater amount of silage to be fed than the other 2 treatments. This was due to management decisions to house the 6-cm PGH cows at night in April, August, and October because the lower herbage production in that system gave fewer options of dry paddocks to graze than the other treatments.

Milk Production, Liveweight, and BCS

Annual milk, SCM, fat, protein, and lactose yields were not significantly affected by PGH (Table 4). Milk fat, protein, and lactose contents were also not significantly affected (not shown). Liveweight and BCS did not differ during or at the end of each lactation (Table 4).

Differences between years were observed, with lower yields of SCM ($P < 0.01$), fat ($P < 0.01$), protein ($P < 0.05$), and lactose ($P < 0.01$) in 2007 compared with 2008 (Table 4). Liveweight was higher in 2007 and 2008 than in 2009 ($P < 0.001$).

Silage Surplus and Deficit

The higher herbage production with the 4-cm PGH treatment resulted in a greater proportion of the grazing area being taken out for silage making ($P < 0.001$;

Table 1. Effect of target postgrazing height (PGH; 4, 5, or 6 cm) treatment on mean annual sward clover content, clover stolon mass, and annual herbage yield of grass and clover over 3 yr

Item	2007									2008									2009									SEM		
	4 cm	5 cm	6 cm	4 cm	5 cm	6 cm	4 cm	5 cm	6 cm	4 cm	5 cm	6 cm	4 cm	5 cm	6 cm	4 cm	5 cm	6 cm	PGH	Year	PGH × Year									
Sward white clover content (g/kg)	169	143	165	211	219	198	253	196	213	253	196	213	253	196	213	253	196	213	17.7 ^{NS}	15.2 ^{**}	26.4 ^{NS}									
White clover stolon mass (kg of DM/ha)	605	544	555	624	616	582	464	482	404	464	482	404	464	482	404	464	482	404	35.7 ^{NS}	41.4 [*]	71.6 ^{NS}									
Herbage yield (t of OM/ha per year)	10.7	10.2	8.6	8.4	7.6	7.5	7.2	7.2	6.0	7.2	7.2	6.0	7.2	7.2	6.0	7.2	7.2	6.0	0.31 ^{**}	0.31 ^{***}	0.63 ^{NS}									
Grass	2.2	1.7	1.7	2.3	2.0	1.8	2.4	1.8	1.7	2.4	1.8	1.7	2.4	1.8	1.7	2.4	1.8	1.7	0.18 [*]	0.18 ^{NS}	0.94 ^{NS}									
Clover	12.8	11.9	10.3	10.7	9.6	9.3	9.7	9.0	7.6	9.7	9.0	7.6	9.7	9.0	7.6	9.7	9.0	7.6	0.35 ^{***}	0.35 ^{***}	0.60 ^{NS}									
Total herbage	8.3	8.3	7.4	8.2	7.4	8.1	7.4	7.1	6.0	7.4	7.1	6.0	7.4	7.1	6.0	7.4	7.1	6.0	0.29 ^{NS}	0.29 [*]	0.63 ^{NS}									
Harvested as: (t of OM/ha per year)	4.5	3.6	2.9	2.5	2.3	1.2	2.3	1.9	1.6	2.3	1.9	1.6	2.3	1.9	1.6	2.3	1.9	1.6	0.18 [*]	0.18 [*]	0.60 ^{NS}									
Pregrazing cuts																														
Presilage cuts																														

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$; NS = $P > 0.05$.

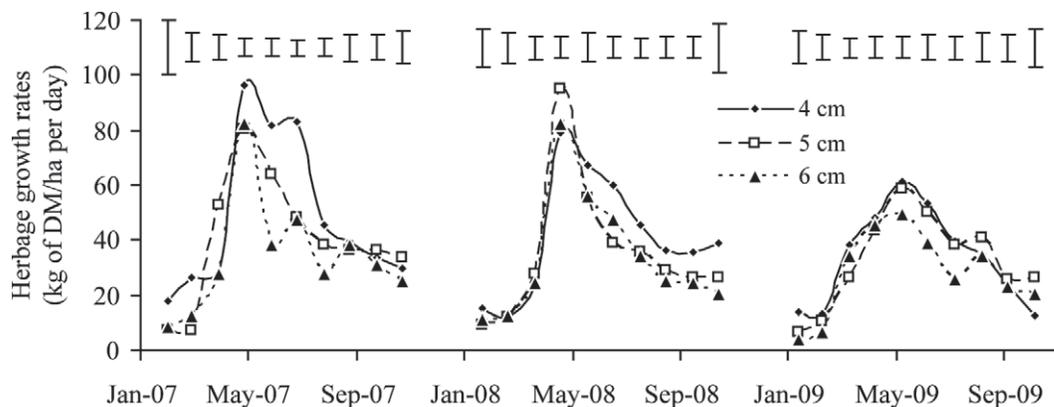


Figure 4. Effect of target postgrazing height (PGH) treatment on daily herbage growth rates throughout the experiment (PGH treatment effect: $P < 0.001$).

Table 5). As a result, the amount of silage harvested differed between all treatments, with the 4-cm PGH producing the most and the 6-cm PGH the least ($P < 0.05$; Table 5). When combined with the greater demand for silage in the 6-cm PGH (Table 4), large differences in silage surplus or deficit were observed between treatments ($P < 0.001$; Table 5). Year also had a large effect ($P < 0.001$), with a surplus of silage for all 3 treatments in 2007, and a deficit in all 3 treatments in 2008 and 2009. Combined over the 3 yr of the experiment, the 4-, 5-, and 6-cm PGH resulted in net silage deficits of -192 , -868 , and $-1,917$ kg of OM/cow, respectively.

DISCUSSION

Grazing Management

Postgrazing height is not an independent management variable in actual grazing systems because either a higher immediate stocking rate (as in DHA experiments) or the same immediate stocking rate grazing for a slightly longer period (as in the current experiment) is required to remove more herbage and achieve a lower PGH (from a given pregrazing herbage mass). Sward herbage mass was similar across treatments at the start of the experiment and after silage was removed. As a result, it took longer to initially graze swards down to 4 cm than to 6 cm at these times. Furthermore, the increased herbage production with the 4-cm PGH resulted in more area being removed for silage in that system (Table 5). Therefore, the results from this experiment should be interpreted as being due to the system-level effects of achieving a target PGH rather than the independent effects of PGH or defoliation height. As this is representative of on-farm conditions where the interrelatedness of grazing management factors is

unavoidable, the results and outcomes are relevant for commercial farms.

Clover Content and Herbage Yields

Previous experiments on mown plots found that sward clover content, clover stolon mass, clover herbage yield, and BNF all increased in response to lowering defoliation height, with little or no effect on grass herbage yield (Frame and Boyd, 1987; Acuña and Wilman, 1993; Schils and Sikkema, 2001). Across these previous experiments, each 1-cm reduction in cutting height increased annual clover yield by 0.17 to 0.53 t of DM/ha and annual total herbage yield by 0.26 to 0.51 t of DM/ha, with generally linear responses to defoliation height. In comparison, each 1-cm reduction in PGH in the current experiment increased annual clover yield by 0.34 t of DM/ha (0.28 t of OM) and annual total herbage yield by 1.23 t of DM/ha (1.01 t of OM). Unlike the previous mown experiments, grass yield also increased, which accounts for the lack of difference in the sward clover content in this experiment.

However, large differences are inherent between grazing and mowing experiments because of the interrelatedness of management variables discussed above, animal treading (Menneer et al., 2005b), selective grazing (Rutter, 2006), and animal excretion (Bao et al., 1998; Yayato et al., 2000). Under grazing conditions, transfer of fixed-N from clover to grass can be higher (Hatch and Murray, 1994; Menneer et al., 2005a; Auerswald et al., 2010) and the competitive ability of clover lower (Edwards et al., 1996; Davies, 2001) than in mown plots, which may have accounted for the lack of differences in clover content in the current experiment. This is supported by results from grass-clover swards under continuous (or set-stocked) grazing with cattle and sheep. For example, continuous grazing ex-

Table 2. Effect of target postgrazing height (PGH, 4, 5, or 6 cm) treatment on herbage ash content, OM digestibility (OMD), and CP, interval length between grazings, and pregrazing herbage mass above PGH over 3 yr

Item	2007			2008			2009			SEM		
	4 cm	5 cm	6 cm	4 cm	5 cm	6 cm	4 cm	5 cm	6 cm	PGH	Year	PGH × Year
Ash content (g/kg of DM)	120	107	100	122	95	98	125	110	102	2.86 ^{***}	2.86 ^{NS}	4.94 ^{NS}
OMD (g/kg of DM)	811	819	829	821	816	817	819	829	816	2.4 ^{NS}	2.4 ^{NS}	4.2 ^{**}
CP (g/kg of OM)	206	221	232	195	195	204	202	206	201	3.3 [*]	3.3 ^{***}	5.8 ^{NS}
Interval between grazings (d)	25.9	21.3	21.6	27.3	33.5	28.2	34.0	31.3	29.9	0.80 [*]	0.80 ^{***}	1.38 ^{**}
Pregrazing herbage mass (kg of OM/ha)	1,169	848	796	1,058	1,211	991	1,045	945	835	32.2 ^{***}	32.1 ^{**}	55.5 ^{**}

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$; NS = $P > 0.05$.

Table 3. Effect of target postgrazing height (PGH, 4, 5, and 6 cm) treatment on grazed pasture, silage, and concentrate intakes per cow over 3 yr

Item	2007			2008			2009			SEM		
	4 cm	5 cm	6 cm	4 cm	5 cm	6 cm	4 cm	5 cm	6 cm	PGH	Year	PGH × Year
Days at pasture	251	249	251	222	221	221	230	225	189	1.76 ^{***}	1.7 ^{***}	3.0 ^{***}
DHA ¹ (kg of OM/cow)	16.7	16.8	14.8	17.4	15.7	17.2	15.1	15.0	15.0	0.53 ^{NS}	0.53 ^{NS}	
Intake per cow												
Grazed pasture (kg of OM)	3,212	3,195	3,244	2,951	2,991	3,025	2,833	2,790	2,639	58.6 ^{NS}	58.4 ^{***}	101.1 ^{NS}
Silage (kg of OM)	1,054	1,068	1,056	1,324	1,333	1,335	1,242	1,288	1,622	16.5 ^{***}	16.4 ^{***}	28.4 ^{***}
Concentrate (kg of OM)	312	307	310	478	477	476	616	615	615	10.8 ^{NS}	10.7 ^{***}	18.5 ^{NS}
DHI ² (kg of OM)	12.8	12.9	13.0	13.3	13.5	13.7	12.3	12.4	13.9	0.27 ^{NS}	0.27 ^{NS}	0.47 ^{NS}

¹Daily herbage allowance above target PGH, estimated from pregrazing cuts.

²Daily herbage intake at pasture, estimated from energy balances.

*** $P < 0.001$; NS = $P > 0.05$.

Table 4. Effect of target postgrazing height (PGH, 4, 5, and 6 cm) treatment on mean annual milk yields, component yields, cow liveweight (LW), and BCS over 3 yr

Item	2007			2008			2009			SEM		
	4 cm	5 cm	6 cm	4 cm	5 cm	6 cm	4 cm	5 cm	6 cm	PGH	Year	PGH × Year
Milk yield (kg/cow)	5,896	6,008	6,183	6,375	6,371	6,452	6,140	6,174	6,218	118.2 ^{NS}	117.7 ^{NS}	203.9 ^{NS}
SCM (kg/cow)	5,746	5,790	6,032	6,313	6,377	6,487	6,196	6,148	6,242	111.3 ^{NS}	110.9 ^{**}	192.0 ^{NS}
Fat (g/kg)	247	247	257	271	274	280	271	266	273	5.2 ^{NS}	5.1 ^{**}	8.9 ^{NS}
Protein (g/kg)	210	216	225	227	230	235	220	218	220	4.2 ^{NS}	4.1 [*]	7.2 ^{NS}
Lactose (g/kg)	270	272	283	300	301	303	288	291	291	5.4 ^{NS}	5.4 ^{**}	9.3 ^{NS}
Mean LW (kg/cow)	595	608	612	599	602	600	555	574	586	8.1 ^{NS}	8.2 ^{**}	14.1 ^{NS}
LW at end of lactation (kg/cow)	627	638	622	652	656	644	584	609	610	8.9 ^{NS}	8.9 ^{**}	15.4 ^{NS}
Mean BCS	2.94	3.00	3.01	3.00	3.00	3.02	2.99	3.08	3.05	0.023 ^{NS}	0.023 ^{NS}	0.040 ^{NS}
BCS at end of lactation	2.89	2.98	2.94	3.00	3.03	3.01	2.93	3.06	3.01	0.032 ^{NS}	0.031 ^{NS}	0.054 ^{NS}
DIM	288	286	287	299	295	297	286	289	288	2.7 ^{NS}	2.7 [*]	4.7 ^{NS}

* $P < 0.05$; ** $P < 0.01$; NS = $P > 0.05$.**Table 5.** Effect of target postgrazing height (PGH, 4, 5, or 6 cm) on the proportion of the grazing area removed for silage production, the amounts of herbage yielded either as pregrazing or presilage cuts, the amounts of silage harvested and ensiled and the end-of year silage surplus/deficit over 3 yr

Item	2007			2008			2009			SEM	
	4 cm	5 cm	6 cm	4 cm	5 cm	6 cm	4 cm	5 cm	6 cm	PGH	Year
Proportional area removed from each grazing system for:											
First-cut silage (May)	0.56	0.43	0.40	0.42	0.51	0.25	0.29	0.37	0.12	0.042 ^{NS}	0.042 ^{NS}
Second-cut silage (July)	0.38	0.22	0.09	0.14	0.00	0.00	0.20	0.11	0.17	0.039 ^{NS}	0.039 ^{NS}
Mean	0.47	0.33	0.25	0.28	0.26	0.13	0.25	0.24	0.15	0.023 [*]	0.023 [*]
Silage (kg of OM/ha):											
Ensiled ¹	3.73	2.94	2.36	2.08	1.89	1.01	1.86	1.50	1.30	0.145 [*]	0.145 ^{**}
Fed	2.09	2.12	2.09	2.80	2.82	2.83	2.63	2.73	3.43	0.146 ^{NS}	0.146 [*]
Surplus or deficit ²	1.32	0.56	0.07	-0.91	-1.10	-1.91	-0.91	-1.34	-2.22	0.090 ^{**}	0.090 ^{**}

¹Proportional loss during ensilage assumed to be 0.25 (McGechan, 1989, 1990).²Silage ensiled minus silage fed.* $P < 0.05$; ** $P < 0.01$; NS = $P > 0.05$.

periments with sheep and cattle have found that lowering grazing height can increase (Laidlaw et al., 1995), reduce (Gibb and Baker, 1989), or have no effect (Del Pozo et al., 1996) on sward clover content. However, the continuous grazing in the above examples allowed animals to have unrestricted access to the entire grazing area. The current experiment expands this work to PGH in strip-grazing systems with dairy cows and shows that lowering the target PGH from 6 to 4 cm can increase both grass and clover herbage yields, although the proportion of white clover in the sward did not change.

The total annual herbage yield response to lowering PGH was large compared with the previous plot-based experiments. The BNF estimates increased by an average of 17 kg/ha per year in response to each 1-cm reduction in PGH. This would indicate an extremely high response rate of 59 kg of extra OM herbage per kg of fixed N, compared with the 10 to 20 kg reported for fertilizer N (Keating and O'Kiely, 2000; O'Donovan et al., 2004; Sun et al., 2008). However, the BNF estimates in this experiment were based solely on clover herbage yield and did not account for any changes in the proportion of fixed-N in clover tissue, N transfer rates, or N accumulation rates that could have occurred under the different treatments (see model description in Høgh-Jensen et al., 2004). Lowering defoliation height can also increase grass herbage production without any source of additional N through increased tillering, photosynthetic efficiency, increased light penetration of the sward, and less respiration and senescence below the defoliation height (Binnie and Harrington, 1972; Parsons et al., 1988; Lee et al., 2008a, 2009). Furthermore, the longer grazing intervals and greater amount of silage harvesting associated with the lower PGH may have further increased herbage production by giving the plants more time in the high growth rate zone of the sigmoidal growth curve (Parsons and Penning, 1988; Binnie et al., 1997).

Pregrazing Herbage Mass, OMD, and CP

Lowering the target PGH in the current experiment reduced herbage OMD in 2007 and CP concentration throughout the experiment. Lowering PGH (by reducing DHA) has previously been associated with increases in herbage OMD and CP in grass-only swards (McEvoy et al., 2009, 2010; Curran et al., 2010). However, in those experiments, pregrazing herbage mass had a larger effect on OMD and CP than did PGH (both were lower at higher pregrazing herbage masses). Lowering PGH in the current experiment increased the time it took for cows to rotate through the paddocks, which consequently increased pregrazing herbage mass

(Table 3). The lower OMD and CP values of pregrazing herbage grazed to 4 cm in the current experiment could therefore be attributed to the higher pregrazing herbage mass associated with that treatment.

Milk Yields

The current experiment found no effect of PGH on milk yield per cow or milk composition. This contrasts with previous experiments on grass-only swards (primarily perennial ryegrass with no clover) where herbage intake, milk yield, protein, fat or lactose concentrations per cow declined with PGH (Le Du et al., 1979; Maher et al., 2003; Curran et al., 2010). However, the current experiment used grass-clover swards. White clover can increase herbage intake compared with grass-only herbage (Bax and Schils, 1993; Harris et al., 1998; Ribeiro Filho et al., 2003). Therefore, its presence in the current experiment may have mitigated the negative effect of lowering PGH on herbage intake or milk yield that was observed in those previous experiments on grass-only swards. Another difference is that the above experiments were all DHA experiments, where pregrazing herbage mass was either measured or controlled and the PGH was a result of adjusting the immediate stocking rate. In such experiments, animal interactions at higher densities and overly restrictive DHA allocations may also be responsible for the lower herbage intakes and milk yields. This was shown by Lee et al. (2008b), who found that reducing PGH from 6 to 4 cm could actually increase milk yield per cow when DHA was kept similar, although the fact that there was no effect on milk solids yield (fat + protein) suggested a transient effect.

In the current experiment, DHA was not measured before grazing and PGH was implemented simply by not moving the cows to new pasture until the target PGH was achieved. This is similar to how target PGH are likely to be achieved on most commercial farms, given the time, labor, skill, and infrastructure that is required to calculate and allocate DHA. When DHA and DHI estimates were calculated retrospectively in the current experiment, no significant difference between treatments was found, which is in accordance with the lack of a difference in milk yields per cow between treatments. However, in DHA experiments, DHA is usually measured to ground level (Peyraud et al., 1996; Lee et al., 2008b) or to a common sward height (Maher et al., 2003; McEvoy et al., 2009), which was not the case in the current experiment.

All of the above experiments also began later in the year (April at the earliest) and were conducted for shorter periods (30 wk at the most). In comparison, the current experiment was conducted from initial turnout

in February to housing in November, which is similar to the grazing season length on most Irish dairy farms (Creighton et al., 2011). The imposition of DHA or PGH treatments for short periods after animals had been housed indoors (Le Du et al., 1979; Mayne et al., 1987) or were already grazing to a common PGH (Maher et al., 2003; McEvoy et al., 2009, 2010; Curran et al., 2010) may have had a greater effect on behavior and herbage intake (and consequently milk yield) than was observed in the current experiment. Measuring the effect of PGH throughout the entire year in the current experiment also resulted in the experimental period including periods when herbage growth rates were lower than demand and supplementary feeds (silage and concentrate) were fed to cows. This could have buffered the effect that PGH would have on milk yield compared with experiments that excluded the use of supplementary feeds (Baudracco et al., 2010). However, all dairy farms in the experimental region use supplementary feeds during the year and the levels of supplementation were low compared with the national average for dairy farms (636, 880, and 765 kg of OM cow for 2007, 2008, and 2009, respectively; National Farm Survey, 2007–2009).

Implications for Grazing Management

Achieving a target PGH of 4 cm increased BNF estimates and herbage production which, as stocking rate was constant across treatments, resulted in a greater proportion of the land being used for silage production compared with achieving a target PGH of 6 cm. The weather conditions of the years in the current experiment highlight the implications of silage surplus/deficit on farms with impeded drainage. Extremely wet soil conditions can reduce herbage growth through anoxia (McFarlane et al., 2003) and treading damage by grazing animals (Greenwood and McKenzie, 2001; Nie et al., 2001; Drewry et al., 2008). This not only results in lower silage production but also increases silage demand as animals are more likely to be housed. All treatments required more housing at night during the wetter years of 2008 and 2009. However, cows on the 6-cm PGH treatment were housed for a total of 41 and 36 d more than those on the 4- and 5-cm treatments, respectively. This occurred when the 6-cm PGH herd was housed at night during April, August, and October. Figure 4 shows the growth rates for the PGH treatments throughout the experiment. The difference between treatments in 2009 was not much greater at these times of the year than in previous years. However, overall growth rates were lower across all treatments in 2009, which exacerbated the problems of grazing on wet soil because it further limited the options of drier

paddocks that could be grazed. Wet soils in this region require a flexible management approach, in which the drier paddocks are grazed when conditions are wettest. When herbage supply is lower than demand (approximately 36 kg of OM/ha per day) for long periods, as it was with the 6-cm PGH in 2009, the ability to do this is curtailed.

Financial net margins have previously been shown to be negatively correlated with annual rainfall at Solohead Research Farm (Humphreys et al., 2012). In 2007, all treatments had a net silage surplus but the weather conditions in 2008 and 2009 cancelled this surplus and resulted in net silage deficits in all treatments by the end of the experiment. However, the cost of producing and feeding on-farm silage is approximately 2.8 to 3.2 times higher than grazed pasture on the basis of euros per energy unit provided (O'Donovan et al., 2011). Therefore, the increased herbage production with the 4-cm PGH might be more profitably exploited by increasing the stocking rate. Recent meta-analysis shows that increasing stocking rate by 1 cow/ha (minimum = 1.3, maximum = 4.5) generally reduces milk yield per cow by 8.7% but increases milk yield per hectare by 19.6% (McCarthy et al., 2011). As stocking rate might be better defined by changes in feed availability and requirements (Holmes et al., 2002; McCarthy et al., 2011), increasing stocking rate in response to the greater herbage production that was achieved with the 4-cm PGH treatment would be logical. However, increasing stocking rate would essentially reduce DHA, with the reductions in DHI and milk production per cow, as discussed previously, more likely to occur. Furthermore, it is not necessarily just lowering the PGH that resulted in increased herbage yield, as longer regrowth intervals and a greater amount of silage cutting were also associated with that treatment. Increasing stocking rate could also increase the risk of treading damage, which could negate any increase in herbage production on soils with impeded drainage. Management strategies such as on-off grazing (Kennedy et al., 2011) and extending the grazing interval (Phelan et al., 2011) need to be used and further developed in such a scenario.

CONCLUSIONS

The hypothesis that lowering PGH from 6 to 4 cm would increase sward clover content and herbage production but reduce milk yield per cow in the grazing systems of this experiment was partially accepted. An increase in herbage production (as measured in pre-grazing and presilage herbage yields) was observed but no increase in sward clover content or reduction in milk yield per cow. Lowering the target PGH from 6 to 4 cm

was associated with longer herbage regrowth intervals, higher herbage yields of both grass and clover, and higher silage production. Milk production, liveweight, and BCS in Holstein-Friesian dairy cows were not affected by PGH in this experiment. A target PGH of 4 cm is therefore recommended for grass-clover swards under grazing systems similar to the ones described because it increased herbage production without negatively affecting animal performance. The effect of increasing stocking rate while lowering PGH on herbage and animal production from grass-clover swards needs to be investigated.

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