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Effect of stocking rate on milk and pasture productivity and supplementary feed use for spring calving pasture fed dairy systems

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ABSTRACT

The productivity of grazing systems is primarily limited by the scale and efficiency of systems applied to the grazable land platform adjacent to the milking parlor. The objective of this study was to compare forage production, utilization and quality, milk production, and requirement for supplementary feeds for 2 different grazing platform stocking rate (GPSR) treatments over 4 yr. Animals were randomly allocated to 1 of 2 GPSR treatments: high-closed (HC; 3.1 cows/ha) and high-open (HO; 4.5 cows/ha), which were designed to represent alternative GPSR in a post-European Union milk quota, spring calving, pasture-based milk production system. Animal production data were analyzed using Proc MIXED of SAS with GPSR, year, and parity included as fixed effects in the final model. Within a seasonal spring calving grazing system, at high GPSR and offering moderate amounts of additional supplements based on pasture supply deficits, both systems produced more milk and fat plus protein per hectare in comparison with Irish commercial dairy farms. Although requiring additional supplementation, increased GPSR resulted in increased milk production per hectare but also in an increased requirement for concentrate and forage supplementation during lactation. No significant influence of GPSR was found on body weight and body condition score or reproductive performance during the 4-yr study period. In addition, GPSR also had no effect on pasture production, utilization, or quality during the study period. The strategic use of additional supplements with restricted pasture availability at higher GPSR maintained milk production per cow and significantly increased milk production per hectare.

Key words: grazing platform stocking rate, milk production, pasture-based system

INTRODUCTION

Temperate grazing systems of production are characterized by a prolonged grazing season (>275 d) and a predominantly grazed pasture diet (Dillon et al., 2005; Läpple et al., 2012). Such systems, based on a comparably cheap grazed feed source, provide pasture-based milk producers worldwide with a competitive economic advantage over other production systems based on high milk output per hectare with reduced fixed and variable costs (Finneran et al., 2010). Indeed, it is widely acknowledged that the quantity of grazed pasture utilized per hectare is the most important factor influencing operating profit and, therefore, return on capital, on grazing farms (Shalloo et al., 2004; Dillon et al., 2008).

Stocking rate (**SR**) has been acknowledged as the key factor influencing productivity per hectare on pasture-based dairy farms for many years (Hoden et al., 1991; Macdonald et al., 2008; McCarthy et al., 2011). The aforementioned studies have demonstrated that higher SR result in a reduction in milk production per cow, but an increase in pasture utilization and milk production per hectare (Macdonald et al., 2008; McCarthy et al., 2011). Milk productivity per hectare is the product of SR, expressed as cows per hectare and milk production per cow, and increasing either or both will increase milk production per hectare provided that sufficient feed per hectare is provided (Macdonald et al., 2008).

Many pastureland farms consist of multiple discrete land parcels that are frequently removed from the milking parlor and consequently, cannot be grazed by the dairy herd. In such situations, the productivity of the grazing dairy farm is primarily limited by the scale, and efficiency of systems applied to the grazable land platform adjacent to the milking parlor, whereas the other land parcels are used as young stock rearing and conserved forage production support blocks (O'Donnell et al., 2008; del Corral et al., 2011). Recent studies have acknowledged that, in comparison with grazable area accessible to the milking herd (known as the grazing platform), external land parcels are associated with increased foraging costs, increased management complexity, and reduced farm productivity (del Corral et

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al., 2011). Given such limitations, many studies have highlighted the necessity for pasture-based farmers to develop improved agronomic management practices to increase pasture productivity on each existing hectare of grazing platform (Macdonald et al., 2008; McCarthy et al., 2013). Furthermore, the use of imported supplementary feeds to sustain high animal productivity at high grazing platform SR (**GPSR**) has recently received more attention (Bargo et al., 2003; Coleman et al., 2010; Fariña et al., 2011). Both Coleman et al. (2010) and Baudracco et al. (2010) suggested that increased supplementation coupled with increased overall SR, can efficiently support high fat plus protein production per cow and per hectare at higher SR while also achieving high levels of pasture utilization compared with lowly supplemented lower SR systems. Equally, however, previous studies have also indicated that the efficiency of pasture utilization and milk production by grazing animals is diminished within systems based on increased supplementation and such systems need careful management to control substitution rates and minimize the decline in pasture utilization (Bargo et al., 2003; Ramsbottom et al., 2015). When supplements are consumed by grazing cows, pasture DM intake is usually reduced due to the partial displacement (substitution) of grazed forage from the diet of supplemented animals (Kellaway and Porta, 1993; Bargo et al., 2003). However, few studies have investigated the effects of increased supplementation of grazing animals on cumulative pasture production, quality, and utilization efficiency within complete farm systems.

Knowledge of the relationship between SR, feed system (**FS**), and sward productivity is fundamental to the sustainable management of intensified grazing systems. Despite its critical importance, few studies have quantified the biological effectiveness of systems combining increased GPSR with increased supplementation on both milk productivity and pasture utilization efficiency. Consequently, the objective of this study was to compare pasture production, utilization, and quality, milk production per cow and per hectare, and requirement for supplementary feeds for 2 different GPSR treatments within integrated grazing systems over 4 consecutive years.

MATERIALS AND METHODS

This study was carried out at Ballyhaise College (54°051′N, 07°031′W) in the Republic of Ireland over a 4-yr period from 2008 to 2011. The experimental site comprises a variety of soil types including alluvial, brown earth, brown podzolic, and gley on a lower Silurian sandstone bedrock. The topography ranges from alluvial flatlands (along the Annalee River, which transects the site) to various shaped, recurrent drumlins with steep slopes (9–18°) and intervening U-shaped valleys.

Animals

The data presented were collected from 97, 110, 115, and 120 animals in 2008, 2009, 2010, and 2011, respectively. During the 4 yr of the study, the experimental herd consisted of Holstein-Friesian (58%), Holstein-Friesian Jersey crossbred (32%), and Holstein-Friesian Norwegian Red crossbred animals (10%), and all animals had received genetic evaluation values using the Irish genetic evaluation system (economic breeding index; **EBI**). The average overall EBI, milk sub-index, and fertility sub-index of the animals over the period was €103, €35, and €59, respectively, during the study period (ICBF, 2009). In yr 1, the experimental animals were assigned to 1 of the 2 GPSR groups before calving based on breed, parity, calving date, previous lactation milk yield, BCS, BW, and EBI. All multiparous animals were subsequently retained on the same GPSR system for the duration of the study. Primiparous animals entering the study were randomly assigned to GPSR treatment based on EBI, breed, calving date, and precalving BW and BCS.

Feed Systems

All multiparous animals were randomly allocated to 1 of 2 possible grazing platform pasture-based feed systems (**GPFS**), namely a high closed feed system (**HCFS**), which had an overall GPSR of 3.1 cows per hectare, or a high open feed system (**HOFS**), which had an overall GPSR of 4.5 cows per hectare. The HCFS was designed as a predominantly self-sufficient GPFS based on high levels of pasture utilization and whereby purchased forage and concentrates would not exceed 30% of total feed requirements. In contrast, the HOFS was created as a high-productivity pasture system to increase milk output per hectare by increasing GPSR and supplementing animals with additional forage and concentrates to meet the additional feed requirements particularly in spring and autumn, corresponding to early and late lactation when pasture growth was reduced. The HOFS was designed to increase productivity on fragmented land holdings where winter feed can be imported from external land parcels. Additional grass silage required for both GPFS was conserved from similar pastures adjacent to the experimental area. The ingredient composition of the concentrate feed (kg/t as fed) used was as follows: barley 250, corn gluten 260, beet pulp 350, soya-bean meal 110, and minerals plus vitamins 30.

Grazing Management

The experimental area was a permanent grassland site containing greater than 80% perennial ryegrass (*Lolium perenne* L.). At the beginning of the farmlet study, a total of 37 paddocks (of on average 0.87 ha) were grouped into 18 sets of 2 (balanced on location, pasture species, topography, and soil type) and randomly assigned to each GPFS. In the first year of the study (2008), 20 paddocks were assigned to the HCFS (15.53 ha) and 13 paddocks were assigned to the HOFS (9.54 ha). During that year, these areas were stocked with 49 and 48 cows on the HCFS and the HOFS, respectively. In the following 3 yr (2009–2011), 3 paddocks were added to the HCFS and 2 to HOFS to allow for herd expansion. During this 3-yr period, the HCFS consisted of 63 cows grazing 20.05 ha and the HOFS consisted of 57 cows grazing 12.63 ha. All paddocks assigned to an individual GPFS at the beginning of the study remained on the same GPFS for the duration of the study. As the herd expanded by 24% over the period of the study, the average lactation number of the animals used in the study was 2.2 lactations.

Cows were turned out to pasture immediately postpartum (mid-February) and grazed whenever weather conditions allowed, only returning indoors under severe weather conditions. On-off grazing (Kennedy et al., 2009) was used as a management tool to facilitate grazing during periods of inclement weather while reducing pasture damage due to poaching. Weekly grazing management during the first rotation (February 1 to April 1) was based on allocating an equal and increasing proportion of each farmlet to each treatment up to the start of the second rotation. During the main grazing season when actual pregrazing herbage mass in the next grazing paddock exceeded the target level, the paddock was skipped and herbage was harvested as silage (Coleman et al., 2010). Concentrates fed in the milking parlor were used to fill deficits in the feed budget of up to 4 kg of DM per cow per day during periods when inadequate supplies of pasture were available. Where deficits in excess of 4 kg of supplement were identified, grass silage was fed in addition to 4 kg of concentrates to reduce the risks of rumen acidosis arising from high levels of concentrate supplementation on highly digestible pastures (Plaizier et al., 2008). During periods when more than 4 kg of DM of silage were required, cows were housed at night and fed pasture only by day. Over the 4-yr period, average grazing season length (defined as the number of days when grazed pasture was included in the animal diet) was 275 d extending from early February to mid-November. To reduce feed demand during the autumn when growth rates declined rapidly, cows which failed to conceive during the breeding season were culled from the experimental treatments to extend the grazing season. Once the target closing average farm pasture supply was reached (550 kg of DM/ha), all cows were housed full-time and fed grass silage and concentrates. Cows were subsequently dried off in weekly batches based on parity, milk yield, BCS, and expected calving date from early November with all animals dried off by mid-December. The minimum dry period length for all animals was 56 d and up to 84 d for thin and primiparous cows. During the dry period, all cows were fed grass silage and a standard dry cow mineral mix from 8 wk prepartum.

Artificial fertilizer application rate was constant for both treatments at 250 kg of N per ha per yr (and was applied in 8 equal applications from late-February to mid-September). A rotational grazing system was practiced with the entire area of each farmlet available for grazing in the spring and autumn and growth rates for each week of the year were derived by calculating the net weekly herbage accumulation on ungrazed paddocks. During the main grazing season, both GPFS were managed similarly, on a similar rotation length and grazing similar pregrazing herbage masses. Residency times within paddocks were determined by the achievement of a target postgrazing residual sward height of 4 cm. Silage conservation strategy was adjusted to best suit each GPFS. In the HCFS, the entire area was available for grazing in the spring and autumn. As growth rates increased above demand, a proportion (circa 25%) of the available area was closed for silage, fertilized and allowed to grow for 8 wk before harvesting. Any further surpluses which arose were removed as bale silage after a 4-wk regrowth period. Because the GPSR was markedly higher in the HOFS, the demand per hectare was always high (in excess of 72 kg of DM/ha per d), so opportunities to remove silage from the grazing platform area were greatly reduced. Consequently, no fixed area was closed for silage and all surpluses were removed after a 4-wk regrowth period.

Herbage Measurements

Grazing details were collected on all paddocks during each grazing rotation for 3 of the 4 yr of the study (2009 to 2011 inclusive) and from August 1 onward in 2008. Pregrazing and postgrazing herbage mass (>3.5 cm horizon) was determined before and after grazing on each paddock for each of the GPSR treatments by harvesting 5 quadrants (0.5 m × 0.5 m) of pasture using a Gardena hand shears (Accu 60, Gardena International GmbH, Ulm, Germany). The 5 quadrants were spaced equally along the diagonal of each paddock. All mown herbage from each quadrant was collected and weighed, and a subsample was taken and dried for 16 h at 90°C for DM determination. The average paddock pregrazing and postgrazing herbage mass above a cutting height of 3.5 cm was then calculated. Pregrazing and postgrazing sward heights were also determined on each paddock before and after grazing by taking between 30 and 50 measurements across the diagonal of the paddock using a folding pasture plate meter with a steel plate (Jenquip, Feilding, New Zealand).

Herbage disappearance was also calculated based on the following formula:

$$\text{herbage disappeared} = (\text{pregrazing herbage mass} - \text{postgrazing herbage mass}); \text{kg of DM/ha}.$$

Grazing efficiency was subsequently calculated for each paddock based on the formula:

$$\text{grazing efficiency} = (\text{herbage disappeared}/\text{pregrazing herbage mass}) \times 100, \%.$$

Daily herbage allowance and daily herbage disappeared were also calculated based on the residency time within each paddock. Grazing data were analyzed for 3 periods of the grazing season: spring (turnout to April 15), midseason (April 15 to July 31), and autumn (August 1 to November 15) corresponding to early and late lactation where the demand for pasture exceeds supply and mid-lactation where pasture supply exceeds demand. Total annual pasture production for each farmlet was calculated using the methodology outlined previously by McCarthy et al. (2013). Silage intakes were measured on a weekly feed budget basis where daily silage allocated to dry cows and milking cows were weighed separately and recorded for each group.

Chemical Analyses

Herbage samples were collected from each paddock for each GPSR and were dried at 40°C for 48 h and milled through a 1-mm sieve. Samples were bulked by FS by week and analyzed for DM, ash, ADF, NDF (Van Soest, 1963), CP (Leco FP-428; Leco Australia Pty Ltd., Baulkham Hills, New South Wales, Australia), and OM digestibility (Morgan et al., 1989). Samples collected for chemical analysis were bulked for each experimental week and analyzed for DM content, ash, ADF, and NDF (Ankom Technology, Macedon, NY), OM digestibility (Fibered Systems, Foss, Ball mount, Dublin, Ireland), and CP (Leco FP-428, Leco Australia Pty Ltd.). Concentrate samples were collected on a weekly basis. These samples were then bulked for each month and were analyzed for DM, ash, CP, NDF, and crude fiber. Silage samples were collected twice weekly and bulked for each experimental week. Silage samples were analyzed for DM, ash, CP, NDF, and ADF.

Animal Measurements

Cows were milked at 0700 and 1530 h daily throughout lactation in all 4 yr of the study. Weekly milk production was derived from individual milk yields (kg) recorded at each milking. Milk fat, protein, and lactose concentrations were determined weekly from one successive evening and morning milking sample from each cow using a Milkoscan 203 (DK-3400, Foss Electric, Hillerød, Denmark). Weekly fat plus protein and SCM (Tyrrell and Reid, 1965) yields were also calculated. Milk, fat, protein, lactose, and fat plus protein yield per hectare (from the grazing area) were calculated by multiplying total milk and fat plus protein production per cow by the GPSR of each treatment to give the yield per hectare.

Individual animal BW was recorded weekly upon exit from the milking parlor using an electronic scale (Tru-Test Ltd., Auckland, New Zealand). In addition, BCS was assessed every 3 wk by the same individual throughout the study on a scale of 1 to 5 in increments of 0.25 as outlined by Edmonson et al. (1989). Body weight and BCS variables analyzed were BW and BCS at calving, nadir, and at the end of lactation. Body weight and BCS change from calving to nadir and from nadir to the end of lactation were also analyzed. Reproductive measurements calculated and analyzed were 24-d submission rate (calculated based on an animal being served within the first 24 d of the breeding season irrespective of calving date), calving to first service interval (interval in days from calving to first service), calving to conception interval (interval in days from calving to conception), conception rate to first service (pregnant to first service and pregnant at the end of the breeding season), pregnancy rate after the first 42 d of the breeding season (pregnant at d 42 of breeding season and pregnant at the end of the 13-wk breeding season), and overall pregnancy rate (confirmed by ultrasound scanning 150 d after the start of the breeding season). All incidences of lameness, mastitis, and calving difficulty were recorded in a database as they occurred. Somatic cell count was determined from consecutive morning and evening milkings once weekly from individual cows. The SCC was recorded using a flow cytometer (Bentley 3000, Bentley Instruments Inc., Chaska, MN).

All cows were examined before breeding start date using transrectal ultrasound imaging (Aloka SDD 500 V scanner with a 5-MHz transducer, Aloka Ltd., Tokyo, Japan) to assess the degree of uterine involution and to detect ovarian or uterine disorders. The incidence of reproductive disorders (such as endometritis, pyometra, ovarian cysts, or exhibiting no resumption of ovarian activity) was recorded. Anovulatory anestrous cows were treated with the following protocol: injection (i.m.) of GnRH [0.01 mg of Buserelin (Receptal), Intervet, Dublin] and insertion of an intravaginal progesterone releasing device (Eazi-breed CIDR containing 1.38 g of P4, Pfizer Animal Health, Dublin, Ireland). Seven days later, each cow received an injection (i.m.) of $PGF_{2\alpha}$ (Lutylase, Pfizer Animal Health), and the following day the CIDR was removed. Ovulation was induced by administering GnRH 36 h after CIDR withdrawal. Breeding commenced on May 5 for both FS. Cows were visually observed for estrus at least 4 times daily for the duration of the breeding season. Tail paint was used as a heat detection aid and was reapplied when necessary. Artificial insemination was used for the first 8 wk of the breeding season, and bulls were introduced for the remaining 5 wk. Cows displaying estrus were inseminated by the same technician during each year of the study. Cows detected in estrus at morning milking were inseminated that morning, whereas cows detected later that day were inseminated the following morning. All cows were inseminated with thawed-frozen semen, the quality of which had been verified before the start of the breeding season. Pregnancy diagnosis was performed by transrectal ultrasound imaging 150 d after the beginning of the breeding season to determine overall pregnancy rates.

Statistical Analysis

The effects of GPFS on total lactation yields for milk and fat plus protein, milk composition, calving to first service interval, and calving to conception interval were determined using mixed models (Proc Mixed; SAS Institute Inc., 2006) with cow included as a repeated effect to account for the repeated lactations per cow; a compound symmetry covariance structure with heterogeneous variances provided the best fit to the data. Initial models included the effects for GPFS, parity, year, breed, calving date, and interactions. Nonsignificant effects ($P > 0.05$) were removed from the models by backward elimination. Number of services per cow was analyzed using the Kruskal-Wallis nonparametric test (PROC NPAR1WAY, SAS Institute Inc., 2006). Binary data (pregnancy rate to first and second service, 42-d pregnancy rate, submission rate, and overall pregnancy rates) were analyzed using chi-squared analysis (PROC FREQ, SAS Institute Inc., 2006) over the 4 yr of the project.

The effects of GPFS and year on daily herbage allowance, total feed allowance, and postgrazing height was determined using mixed models (Proc Mixed, SAS Institute Inc., 2006) with rotation included as a repeated effect. A compound symmetry covariance structure provided the best fit to the data. The effects of FS on BW, BCS, calving to first service interval, and calving to conception interval were analyzed using general linear models (Proc GLM, SAS Institute Inc., 2006), and the effects of FS, year, parity, breed, and their interactions were included in the model.

RESULTS

Climate and Pasture Production

Monthly rainfall and temperature data for the 4-yr study period and for the 10-yr average (2001 −2011) are presented in Table 1. Average annual rainfall and mean temperature at the site over the 4 yr from 2008 to 2011 (1,046 mm and 9°C, respectively) were very similar to the 10-yr average (1,019 mm and 9.1°C, respectively). On average over the 4 yr, November had the greatest rainfall (128 mm), whereas June had the lowest rainfall (55 mm). Additionally, December was the coldest month (average mean temperature of 2.5°C), whereas July was warmest (average mean temperature of 14.8°C).

Average annual net herbage production was 13,225 (SEM = 542) kg of DM per ha during the 4-yr study period (Figure 1) and was unaffected by GPFS (P = 0.394). Year had a significant effect on annual herbage production ($P = 0.001$), and was least in 2008 and greatest in 2011 (11,647 and 15,472 kg of DM per ha, respectively). On average over the study period, average daily growth rate (kg of DM per ha per day) exceeded daily herd demand for 192 d for HCFS compared with 130 d for HOFS.

Grazing Characteristics and Feed Inputs

The effect of GPFS on grazing characteristics and sward quality is presented in Table 2. As the grazing management decision rules were the same for both GPFS during the main grazing season (April to August), the grazing year has been broken into 3 distinct periods for analysis: spring (turnout to pasture in early February until the end of the first rotation in April), midseason (from the beginning of the second rotation in mid-April until late July), and autumn (from the start of August until the end of the grazing season in mid-November). Over the entire grazing season, pregrazing herbage mass ($P < 0.05$) was higher for HCFS

Table 1. Temperature (°C) and rainfall (mm) data for each month during 2008 to 2011 compared with the previous 10-yr period

Month	Rainfall		Mean temperature	
	2008–2011	10 yr average	2008–2011	10 yr average
January	97	85	3.4	4.4
February	55	68	4.8	5.1
March	73	67	5.8	5.9
April	70	69	8.9	8.4
May	62	75	11.1	11.2
June	54	63	13.5	13.5
July	92	77	14.8	14.6
August	118	112	14.0	14.2
September	106	102	12.7	12.8
October	116	120	9.9	9.4
November	128	119	6.7	6.9
December	71	56	2.5	3.4
Annual	1,046	1,019	9	8.3

compared with HOFS (1,390 and 1,246 kg of DM/ha, respectively), whereas postgrazing residual sward height and grazing efficiency were similar for both FS (38.2 mm and 97.2%, respectively). Similarly, herbage disappearance tended to be higher ($P < 0.07$) for HCFS compared with HOFS (1,324 and 1,254 kg of DM/ha, respectively). A significant GPFS by season interaction was found for herbage disappearance ($P < 0.04$) due to the comparably increased herbage disappearance for HCFS compared with HOFS during autumn (1,586 vs. 1,417 kg of DM/ha). No significant differences were found in sward CP or OM digestibility between FS. Season had a significant effect on grazing parameters with the exception of sward CP content. Pregrazing herbage mass, postgrazing residual sward height, and herbage disappearance were least in spring (941 kg of DM/ha, 35.7 mm, and 1,069 kg of DM/ha), greatest in autumn (1,581 kg of DM/ha, 39.1 mm, and 1,501 kg of DM/ha), and intermediate during mid-season (1,433 kg of DM/ha, 38.8 mm, and 1,297 kg of DM/ha), whereas grazing efficiency was greater in spring (102.2%) compared with mid-season and autumn (94.5%) due to the increased grazing severity achieved during spring. Sward OM digestibility content was greatest in spring (827.4 g/kg), intermediate in mid-season (817.3 g/kg), and least during autumn (800.3 g/kg). No GPSR or seasonal differences were observed in silage or concentrate quality. The chemical composition of grass silage (71, 144, 548, and 329 g/kg for ash, CP, NDF, and ADF, respectively) and concentrate (97, 152, 319, and 174 g/kg for ash, CP, NDF, and crude fiber, respectively) was similar to previous studies (Coleman et al., 2010; McCarthy et al., 2013).

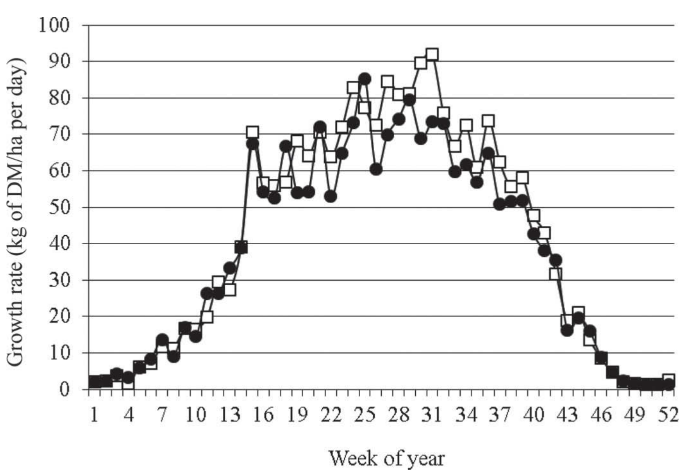

Figure 1. Effect of grazing platform feed system [high closed (HCFS) = 3.1 cows/ha, ●; and high open (HOFS) = 4.5 cows/ha, □] on pasture growth during the 4-yr study.

The effect of GPFS on herbage utilization and concentrate and silage supplementation requirements during the 4-yr study period are presented in Table 3 and Figure 2. No significant difference was found in total herbage utilization (9,972 kg of DM/ha) or in the grazed herbage utilization between GPFS (8,792 kg of DM/ha); however, more herbage was harvested as silage within the HCFS farmlet (1,704 vs. 644 kg of DM/ha per yr for HOFS). Consequently, and although the HCFS was designed as a predominantly enclosed GPFS wherein, the majority of the feed required would be harvested within the farmlet area, lower than anticipated average pasture growth during the 4 yr of the study necessitated that 1,704 kg of DM/ha (or 550 kg of DM/cow) of forage were imported as winter feed from outside the HCFS farmlet to meet the feed requirements of this treatment. In comparison, 3,924 kg of DM/ha (or 1,288 kg of DM/cow) of winter forage was imported from outside the HOFS treatment area.

Table 2. The effect of grazing platform feed system[1] (GPFS) and season[2] (S) on grazing characteristics and sward quality during the 4-yr study (2008–2011)

Item	GPFS		SEM	*P*-value		
	HCFS	HOFS		GPFS	S	GPFS*S
Pregrazing herbage mass, kg of DM/ha	1,390	1,246	33.4	0.003	0.001	0.26
Spring	950	932				
Mid-season	1,539	1,324				
Autumn	1,683	1,480				
Postgrazing residual herbage height, mm	38.7	37.7	0.34	0.46	0.001	0.11
Spring	35.8	35.7				
Mid-season	38.8	38.9				
Autumn	39.7	38.5				
Herbage disappeared,[3] kg of DM/ha	1,324	1,254	41.5	0.07	0.001	0.04
Spring	1,080	1,058				
Mid-season	1,307	1,287				
Autumn	1,586	1,417				
CP content, g/kg	236.6	226.9	9.87	0.28	0.66	0.97
Spring	243.7	232.0				
Mid-season	233.8	226.4				
Autumn	232.3	222.2				
OM digestibility, g/kg	814.8	815.1	10.97	0.98	0.04	0.89
Spring	829.7	825.1				
Mid-season	814.4	820.1				
Autumn	800.5	800.2				

[1]Grazing platform stocking rate: high closed (HCFS) = 3.1 cows/ha, high open (HOFS) = 4.5 cows/ha.

[2]Season: spring (January–March), mid-season (April–July), autumn (August–November).

[3]Herbage disappeared (kg of DM/ha) = (pregrazing herbage mass – postgrazing herbage mass).

Concentrate and silage supplementation also varied significantly between GPFS during lactation. The HOFS received more concentrate and silage (872 and 634 kg of DM/cow, respectively) during lactation compared with HCFS (551 and 360 kg of DM/cow, respectively). Based on the feed requirements, each GPFS was also defined in terms of comparative stocking rate (CSR; Macdonald et al., 2008) incorporating both animal size, level of supplementation and herbage productivity as an alternative measure of GPSR. The CSR was 90 kg of BW/tonne of DM available for both the HCFS and HOFS treatments.

Table 3. Effect of grazing platform feed system[1] on animal diet and supplementary feed requirements

Feed system	HCFS	HOFS
Lactating cow diet, kg of DM/cow		
Grazed pasture	2,724	2,031
Concentrate	551	872
Grass silage	360	634
Nonlactating cow diet, kg of DM/cow		
Grass silage	808	797
Feed utilized, kg of DM/ha per yr		
Grazed pasture	8,445	9,139
Grass silage produced	1,704	644
Grass silage imported	1,917	5,796
Concentrates imported	1,708	3,924

[1]Grazing platform feed system: high closed (HCFS) = 3.1 cows/ha, high open (HOFS) = 4.5 cows/ha.

Milk Production, BW, BCS, and Reproductive Performance

The effect of FS on total lactation milk production and composition over the 4-yr study period is shown in Table 4 and Figures 3 and 4. Average lactation length was similar for both GPFS (270 d). The HOFS produced more milk (4,865 kg), SCM (4,948 kg), and milk solids (390 kg) per cow compared with HCFS (4,648, 4,756, and 377 kg, respectively), whereas the persistency of lactation was similar for both FS (Figure 3). Milk fat and lactose content were unaffected by GPFS (45.7 and 47.4 g/kg, respectively); however, milk protein content was significantly higher ($P < 0.001$) for HCFS (35.7 g/kg) compared with HOFS (35.0 g/kg). At the system level, milk and milk solids yield per hectare of milking platform were significantly higher ($P < 0.001$) for HOFS (22,229 and 1,786 kg, respectively) compared with HCFS (14,190 and 1,153 kg, respectively; Figure 4).

Feed system had no significant effect on BW and BCS during lactation (Table 5, Figure 5). No significant effect of GPFS, interaction between breed group and GPFS, or interaction between GPFS and parity was observed for any of the reproductive variables measured over the 4-yr study period, and therefore only the main effects of GPFS are shown (Table 5). The average intervals from calving to first service and from calving to conception were 75 and 100 d, respectively.

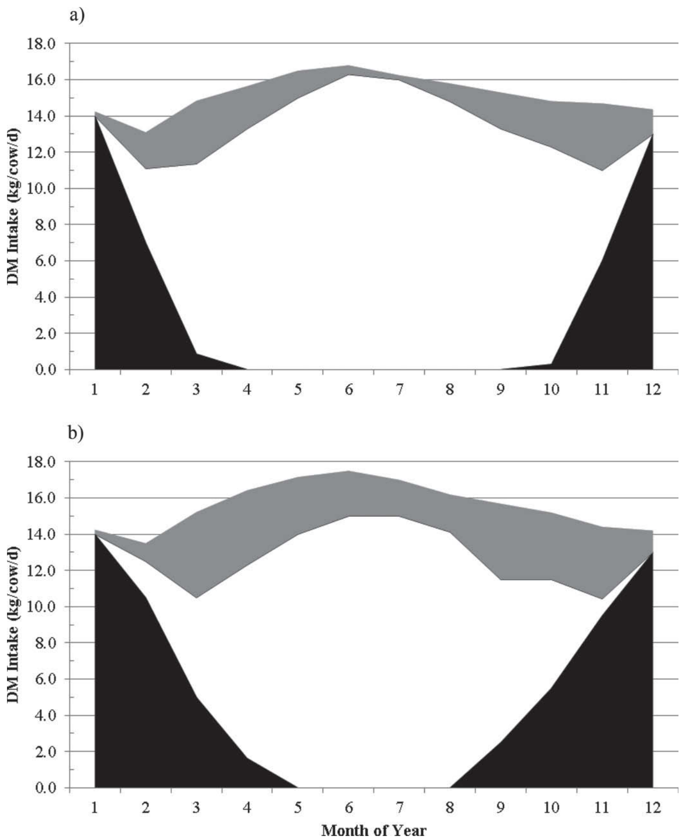

Figure 2. Effect of grazing platform feed system [a = high closed (HCFS) = 3.1 cows/ha; and b = high open (HOFS) = 4.5 cows/ha] on dietary intake (kg of DM/cow per d) during lactation (silage, black shading; concentrate, gray shading; and pasture, white area).

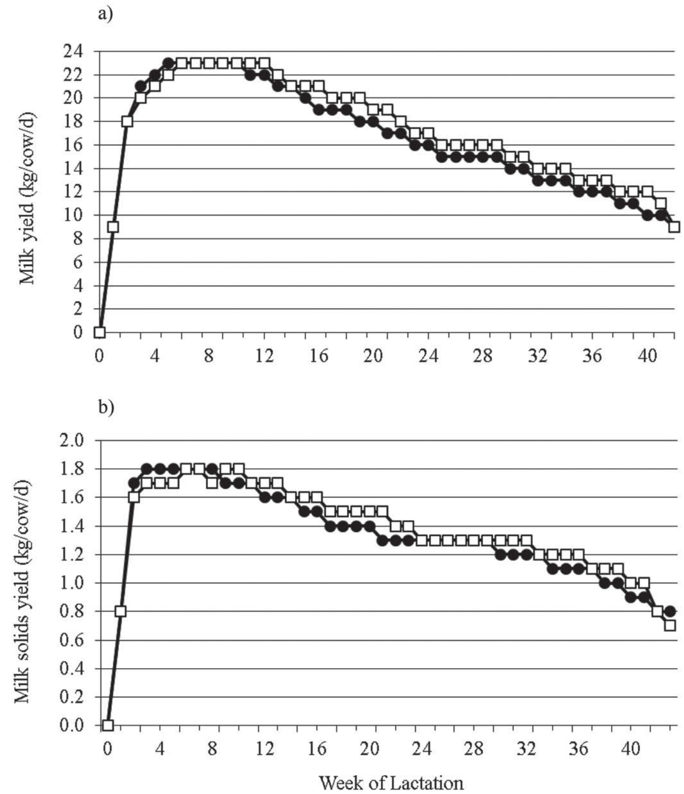

Figure 3. The effect of grazing platform feed system [high closed (HCFS) = 3.1 cows/ha, ●; and high open (HOFS) = 4.5 cows/ha, □] on a) daily milk yield (kg/cow per d) and b) daily milk solids (milk fat plus protein) yield (kg of milk solids/cow/d) for each week of lactation.

Similarly, no significant differences were found between FS in the number of services received per cow (1.8), the submission rate during the first 24 d of the breeding period (83%), the conception rate to first service (41%), the 6-wk pregnancy rate (57%), or the overall 13-wk pregnancy rate (80%).

DISCUSSION

Traditional pasture-based milk production systems are based on a medium overall farm SR (2 to 3 livestock units/ha) and based on high mid-season pasture growth, which exceeds animal requirements (Dillon et al., 2005). In such systems, both the lactation and total winter

Table 4. Effect of grazing platform feed system[1] on total lactation milk production and composition

Item	HCFS	HOFS	SEM	*P*-value
Individual animal performance				
Lactation length, d	269	271	6.3	0.54
Milk yield, kg/cow	4,648	4,865	53.4	0.002
SCM yield, kg/cow	4,756	4,948	53.3	0.007
Fat plus protein yield, kg	377	390	4.3	0.02
Milk constituent, g/kg				
Fat	45.6	45.8	0.4	0.65
Protein	35.7	35.0	0.15	0.001
Lactose	47.3	47.5	0.09	0.07
System performance				
Milk yield, kg/ha	14,190	22,229	208.4	0.001
Fat plus protein, kg/ha	1,153	1,786	17.2	0.001

[1]Grazing platform feed system: high closed (HCFS) = 3.1 cows/ha, high open (HOFS) = 4.5 cows/ha.

Table 5. Effect of grazing platform feed system[1] on reproductive performance, BW, and BCS

Reproductive performance	HCFS	HOFS	SEM	*P*-value
Calving to service interval, d	75	75	1.0	0.84
Calving to conception interval, d	100	99	2.3	0.72
Services per cow, no.	1.8	1.8	0.07	0.80
24-d submission rate, %	81	85		0.19
Conception rate to first service, %	38	43		0.26
6-wk pregnancy rate, %	56	58		0.81
Overall pregnancy rate, %	79	81		0.50
BW at calving, kg	501	497	6.2	0.62
Nadir BW, kg	448	458	5.6	0.19
BW at the end of lactation, kg	519	512	5.3	0.27
BCS at calving	3.12	3.14	0.024	0.54
Nadir BCS	2.81	2.81	0.033	0.90
BCS at the end of lactation	2.89	2.94	0.020	0.12

[1]Grazing platform feed system: high closed (HCFS) = 3.1 cows/ha, high open (HOFS) = 4.5 cows/ha.

feed requirements of the herd are produced from the grazable farm area (Dillon et al., 1995; McCarthy et al., 2011). The dominant effect of increasing SR on grazed pasture utilization and milk production per hectare has been widely reported, albeit with lowered levels of milk production per cow (Macdonald et al., 2008; McCarthy et al., 2011). The HCFS treatment represents the control GPSR and was chosen as a normal but intensive GPSR recommended to commercial pasture-based milk producers and used within research trials (Horan et al., 2004; Macdonald et al., 2008; McCarthy et al., 2013). The HOFS was designed to quantify the biological effect of significantly increasing GPSR to maximize milk production and pasture utilization on the grazable area and to acquire the additional spring, autumn, and winter feed requirements for the herd from outside the grazable area. The intensity of both FS within the cur-

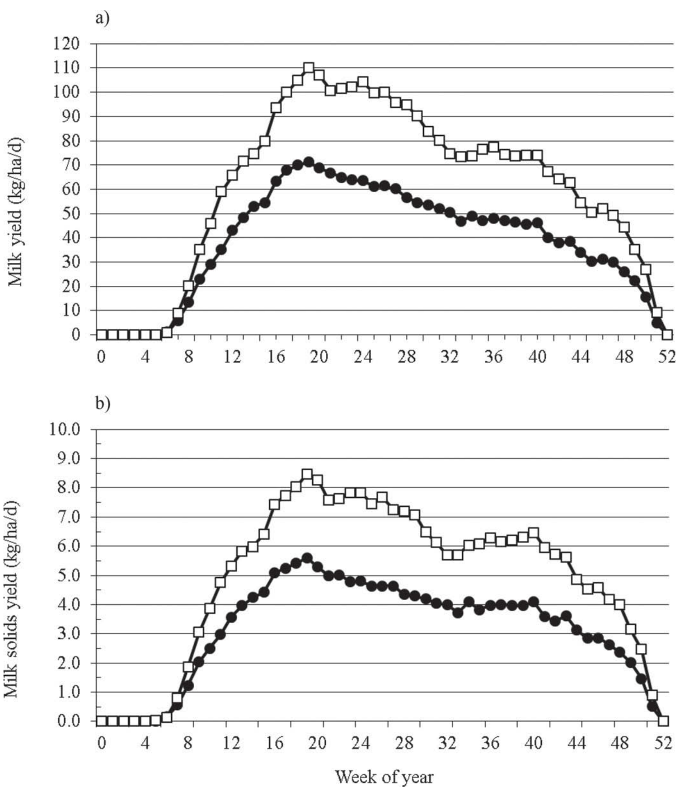

Figure 4. The effect of grazing platform feed system [high closed (HCFS) = 3.1 cows/ha, ●; and high open (HOFS) = 4.5 cows/ha, □] on (a) daily milk yield (kg/ha per d) and (b) daily milk solids (milk fat plus protein) yield (kg/ha/d) for each week of year.

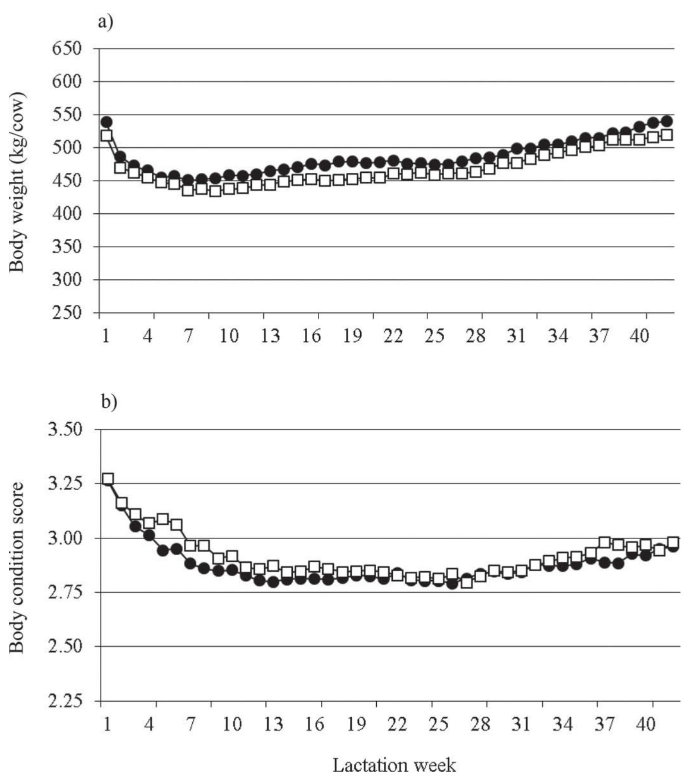

Figure 5. The effect of grazing platform feed system [high closed (HCFS) = 3.1 cows/ha, ●; and high open (HOFS) = 4.5 cows/ha, □] on (a) BW and (b) BCS per week of lactation.

rent experiment is exemplified by the high CSR of both FS, which is indicative of optimally designed systems in terms of feed inputs vis a vis animal requirements (Macdonald et al., 2008). The average amount of herbage used (10.0 t of DM/ha) and milk production per hectare (14,190 and 22,229 kg of milk/ha for HG and HOFS, respectively) in this study is well above that normally achieved on commercial dairy farms (7.1 t of DM/ha and 9,120 kg milk/ha at a mean GPSR of 1.8 to 1.9 livestock units/ha; Dillon et al., 2005; Creighton et al., 2011; NFS, 2014) and is indicative of the potential productivity of intensified grazing systems.

Experiments using SR as the main variable are difficult to interpret because of the important effect of experimental decision rules. Previous studies have reported inconsistent effects of SR on pasture accumulation and utilization. The lack of an effect of SR on net herbage accumulation and total utilization has been reported in several recent experiments using similar measurement methodologies (Valentine et al., 2009; Fariña et al., 2011; both of these studies were undertaken in Australia with a range of SR from 2.5 to 7.4 cows/ha with varying levels of supplementary feed). Although beneficial effects of increasing SR on net herbage production, grazed pasture utilization, and feed quality have also been reported in the literature (Hoden et al., 1991; Macdonald et al., 2008; McCarthy et al., 2013), increasing SR is frequently associated with changes in rotation lengths, grazing severities, and feed allocation rates, which independently influence forage growth, utilization, and quality (Bargo et al., 2003; Lee et al., 2007; Sollenberger and Vanzant, 2011). In contrast, this experiment was designed to impose similar grazing management in both GPSR treatments, and accordingly no significant differences in pasture production, quality, and utilization were observed. Similarly, several other recent SR experiments using similar measurement methodologies have also observed no effect of SR on pasture productivity, herbage utilization, or sward quality (Valentine et al., 2009; Fariña et al., 2011).

The higher total lactation milk, SCM, and fat plus protein yield achieved with the HOFS group is expected given the large increase in energy supply with this FS. This is consistent with previous studies, which showed that total DMI increased with increasing proportion of concentrate in the diet (Bargo et al., 2003). The decline in milk protein content observed with the HOFS also agrees with previous findings (Horan et al., 2004) and can be attributed to the increased conserved grass silage content and reduced grazed grass content of the HOFS lactation diet. Stocking rate treatment had no effect on BW and BCS characteristics or on the reproductive parameters measured in this study, which is indicative of both the similarity and adequacy of feed supply to animals in both systems examined. The overall similarity in BW, BCS, and reproductive performance between GPSR treatments in this study is also consistent with previous studies (Horan et al., 2004; Macdonald et al., 2008; Patton et al., 2012).

The provision of adequate amounts of winter feed is a key requirement of Irish pasture-based production systems. Although the quantity of silage produced was higher for HCFS compared with HOFS (1,704 and 644 kg of DM/ha, respectively), the lower than anticipated annual growth during the study resulted in reduced conserved forage production and an increased lactation requirement for silage supplements. Consequently, both GPFS required significant additional silage imports (1,917 and 5,796 kg of DM/ha) to meet the winter feed requirements. When similar pasture productivity (13,225 kg of DM/ha) and average silage conservation efficiency is considered (0.75; Bastiman and Altman, 1985), the additional feed required for dairy cows correspond to an additional external support land area requirement of 3.9 and 7.4 ha for HCFS and HOFS, respectively (and equivalent to an overall land area SR of 2.63 and 2.85 cows/ha, respectively).

Increasing SR traditionally results in reduced pasture DM intake and milk production but increased milk production per hectare (Macdonald et al., 2008; McCarthy et al., 2011). The use of supplementary feeds to maintain individual animal performance at higher GPSR is generally considered to reflect the commercial effect of SR increase on dairy farms where SR and supplementation usually increase simultaneously (Jensen et al., 2005). Previous studies have also observed a strong positive effect of higher levels of concentrate and forage supplementation during lactation on milk production characteristics when compared with pasture-only diets (McCarthy et al., 2007; Valentine et al., 2009; Fariña et al., 2011). Increased SR combined with increased concentrate supplementation (HOFS) within the current study created a similar CSR and level of pasture utilization and resulted in increased milk and milk fat plus protein production per cow and per hectare. Equally, the similarity of postgrazing residuals and grazing efficiency between HCFS and HOFS is also indicative of the efficient supplementation of the HOFS based on consistently matching supplementation rates to herd requirements.

Where pasture supply is sufficient to meet animal requirements, it is generally considered uneconomical to use supplements due to high pasture substitution rates and low milk production responses to supplementary feeding on grazing dairy farms (Bargo et al., 2003; Ramsbottom et al., 2015). In the current study, however, supplements were only offered to HOFS to alleviate shortfalls in herbage DMI by reducing pasture allowance and maintaining similar postgrazing residuals to HCFS. Similar to previous studies combining increased SR and increased supplementation (Coleman et al., 2010), a substantial increase in milk and milk fat plus protein production per hectare (+56 and +55%, respectively) was realized in HOFS. The overall increase in milk production corresponds to a systemic response of 1.40 kg of additional milk and 0.11 kg of additional fat plus protein per kg of additional feed used within the higher GPSR system. High systemic responses to supplementation have also previously been attributed to a reduced substitution rate of concentrate for herbage within restricted higher SR systems (Bargo et al., 2003).

The success of pasture-based dairy farms is dependent on maximizing productivity from pasture and output per hectare on the milking platform (Dillon et al., 2008; Macdonald et al., 2008). In comparison with milk productivity within typical grazing systems (763 kg of milk and fat plus protein/ha; Dillon et al., 2005), the results of this analysis demonstrate the capacity for increased milk fat plus protein productivity (+151 and +234% for HCFS and HOFS, respectively) within both pasture-based systems. Moreover, the superior performance of the HOFS treatment indicates that, based on increased feed supplementation complemented with an increased SR to maintain a moderate pasture allowance, high levels of pasture utilization and efficient utilization of available feed resources can be achieved within pasture systems incorporating increased supplementary feed levels. Notwithstanding these benefits, further whole-farm research should be conducted to explore both the economic and environmental implications of such systems before recommendations can be made to pasture-based milk producers. These results also suggest that, in order for pasture-based dairy farmers to harness the benefit of the increased SR reported here, improved grazing management skills at farm level will be required with such intensified systems to further increase herbage utilization on commercial farms and minimize the requirement for imported feed supplementation to the levels reported in this study.

CONCLUSIONS

Access to adequate grazable area is a critical limitation to the productivity of grazing systems. To our knowledge, this is the first farmlet experiment to explore the effects of increased grazing area SR on both the productivity of pastures and animals and requirements for additional supplements within intensified grazing systems. The strategic use of additional supplements with restricted pasture availability combined to maintain production per cow at higher GPSR and significantly increase milk production per hectare. The results of the present study indicated that increasing GPSR had no effects on pasture production, utilization, and feed quality.

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