Production parameters of autumn-calving cows offered either a total mixed ration or grazed grass plus concentrate during early lactation

E. Kennedy,¹ E. Lewis, J. P. Murphy, N. Galvin, and M. O'Donovan

Teagasc, Animal and Grassland Research and Innovation Centre, Moorepark, Fermoy, Co. Cork, Ireland

ABSTRACT

The objective of this experiment was to measure the milk yield and composition from cows offered a total mixed ration (TMR) compared with those grazing grass and offered different quantities of concentrates during the first 6 wk of lactation when the experimental diets were offered, and for the remainder of lactation when all animals were offered a similar diet. Forty-eight (18 primiparous and 30 multiparous) Holstein-Friesian dairy cows (mean calving date, September 12 ± 15 d) were randomly assigned to a 4-treatment (n = 12) randomized block design experiment. The 4 treatments were (1) housed indoors and offered *ad libitum* TMR (ITMR; control); (2) grazed grass and 1 kg (dry matter; DM) of concentrate/cow per day (G1); (3) grazed grass and 4 kg (DM) of concentrate/cow per day (G4); (4) grazed grass and 8 kg (DM) concentrate/cow per day (G8). Experimental treatments were imposed starting on September 29, 2008, and lasted for 6 wk. Following the 6-wk experimental period, all cows were managed similarly. They were offered a TMR until turnout to pasture the following spring (February 10, 2009) and grazed grass from then until drying off. The deferred effect of the 6-wk experimental period on production parameters was monitored during a 13-wk period, and total lactation production was also investigated. During the 6-wk experimental period, total dry matter intake (DMI) was greater for ITMR and G8 cows compared with G4 and G1 cows. Differences in total DMI, measured during the 6-wk period when treatments were imposed, were reflected in milk yield. During the 6-wk period, ITMR cows had the greatest milk yield (27.3 kg/cow per day) and G1 cows had the lowest (21.1 kg/cow per day). Milk yields of the G4 and G8 cows were similar (24.8 kg/cow per day). We detected no effect of treatment on milk fat (3.77%) or milk protein (3.25%)

concentration. Treatment did affect milk solids yield (MSY): ITMR cows yielded 1.90 kg/cow per day, which did not differ from that of the G8 cows (1.75 kg/cow per day), G1 cows had the lowest MSY (1.53 kg/cow per day) and that of G4 (1.69 kg/cow per day) cows was lower than ITMR but not different from G8. At the end of the 6-wk experimental period, the ITMR and G8 cows had greater body weight (525 kg/cow) than the G4 and G1 cows (502 kg/cow). Treatment had no effect on milk yield or composition during the remainder of the lactation and no effect on cumulative lactation milk yield or composition. The data from this experiment indicate that herbage can be incorporated into the diet of early-lactation, autumn-calving dairy cows without any negative consequences on total lactation milk yield or composition.

Key words: autumn calving, grass, milk yield, milk composition

INTRODUCTION

As a result of recent trade liberalization policies within the European Union, Irish dairy farmers are now exposed to world market prices for their product (Dillon et al., 2008). The challenge they face is to improve the competitiveness of their dairy farms by increasing productivity while minimizing the associated costs of production. Dillon et al. (2005) reported that pasture-based dairy systems have lower costs of production due to the utilization of pasture, which is a cheap feed compared with supplements such as grass silage and concentrate (Finneran et al., 2012). Unfavorable climatic conditions during autumn result in reduced herbage availability (Creighton et al., 2011) and poor quality herbage (McCarthy et al., 2013; Tuñón et al., 2014). Irish dairy producers tend to utilize less herbage in autumn than during the rest of the year. This is especially true for farmers involved in winter milk production systems, which are higher input systems [D. C. Lawrence (Teagasc Moorepark), L. Shalloo (Teagasc, Dairy Production Research Department, Cork, Ireland), E. M. Kennedy, M. O'Donovan, T. M. Boland (University College Dublin, Ireland), A. Lawless

Received October 7, 2014.

Accepted July 16, 2015.

¹Corresponding author: Emer.Kennedy@teagasc.ie

(Teagasc, Animal & Grassland Research and Innovation Centre, Johnstown Castle, Ireland), and J. Patton (Teagasc, Dairy Production Research Centre, Cork, Ireland), unpublished data].

Typically, greater production levels are achieved from a TMR compared with pasture (Kolver and Muller, 1998). Kennedy et al. (2005) reported no difference in the milk production or DMI of spring-calving dairy cows in early lactation offered high quality pasture compared with cows offered a high concentrate and grass silage diet. There is a substantial cost savings when grazed grass is included in the diet (O'Donovan and Kennedy, 2009). For pasture-based dairy farmers, particularly those farming in temperate climates, the grazing interval needs to be increased to allow high (>2,000 kg of DM/ha) herbage mass (**HM**) to accumulate so that sufficient herbage is available during the autumn (O'Donovan, 2000), at a time when grass growth is slow. As herbage quality is lower in autumn than at other times during the year (McCarthy et al., 2013), maintaining a lower pregrazing HM during this period may help improve herbage quality and animal production.

Recent experiments have reported that supplementing early-lactation spring-calving dairy cows with concentrate increased DMI, resulting in greater immediate milk yields (McEvoy et al., 2008) and greater total lactation milk production (Kennedy et al., 2007). Early-lactation supplementation regimens have previously been shown to induce deferred effects on subsequent milk production, when a reduction in total feed or concentrate allowance was imposed; however, the data are inconsistent (Broster and Broster, 1984; Friggens et al., 1998; Ganche et al., 2013; Roche et al., 2013). Factors that influence deferred effects include the supplemental diet (Friggens et al., 1998), timing of supplementation, and duration and magnitude of the supplementation (Broster and Broster, 1984; Delaby et al., 2009; Ganche et al., 2013). Utilizing lower cost feeds, such as grazed grass and a low level of supplementary concentrate, for a short period during early lactation may result in little differences in total lactation milk production compared with high-input diets such as a TMR, yet a cost savings may be achieved.

The objective of this experiment was to examine the effect of offering 3 quantities of concentrate at pasture to autumn-calving dairy cows in early lactation and to compare the milk production of these cows to those offered a TMR diet indoors. The experiment also aimed to evaluate the deferred effects of an early-lactation feeding regimen on milk production performance during the deferred effect period and on total lactation milk yield.

MATERIALS AND METHODS

The experiment was conducted at the Teagasc, Animal and Grassland Research and Innovation Centre, Moorepark, Fermoy, Co. Cork, Ireland (52°16'N, 8°25'W) from September 29, 2008, to June 28, 2009. The soil type was a free-draining, acid brown earth with a sandy loam-to-loam texture. The experimental area was a permanent grassland site containing a high level of perennial ryegrass, with no clover present in the sward.

Animals and Experimental Design

The experiment had a randomized block design with 4 treatments. Forty-eight Holstein-Friesian dairy cows were selected from the Moorepark autumn-calving herd. Eighteen cows were primiparous and the remaining 30 were multiparous (10 cows in their second lactation and 20 cows in their third or greater lactation). Cows were blocked based on calving date (mean $\pm$ SD; September 12 $\pm$ 15 d), first 7-d milk yield of the present lactation (22.2 $\pm$ 3.52 kg/cow per day), parity (2.3 $\pm$ 1.23), previous-lactation milk yield (35 wk; 5,088 $\pm$ 974.7 kg) [dam's first-lactation milk yield (first 35 wk) in the case of primiparous cows], milk fat (4.10 $\pm$ 0.303%), protein (3.29 $\pm$ 0.158%), and lactose concentrations (4.61 $\pm$ 0.130%), BW (530 $\pm$ 66.1 kg), and BCS (3.08 $\pm$ 0.487).

Cows were blocked into groups of 4 and then randomly assigned to 1 of the following treatments at 10 DIM: (1) indoors offered ad libitum TMR on a full-time basis (**ITMR**; control); (2) grazed grass and 1 kg (DM) of concentrate/cow per day (**G1**); (3) grazed grass and 4 kg (DM) of concentrate/cow per day (**G4**); (4) grazed grass and 8 kg (DM) of concentrate/cow per day (**G8**). Before assignment to treatment, all cows were offered ad libitum pasture and 4 kg (DM) of concentrate/cow per day.

Management of Experimental Treatments

Each animal was assigned to her respective treatment for a 6-wk experimental period. At the end of the 6-wk period, all cows were housed indoors as a single group for a 13-wk period and were offered ad libitum TMR until turnout the following spring (February 10, 2009) to monitor the deferred effect of each treatment (Figure 1). From turnout, all cows grazed as a single group and were offered fresh herbage and 3 kg (DM) of concentrate/cow per day until May 1 (an additional 11 wk). Cows were offered a grass-only diet for the remainder of the lactation (7 wk).

Grazing Treatments. During the 6-wk experimental period, fresh herbage was allocated daily after morning milking to cows assigned to each of the 3 grazing treatments (G1, G4, and G8). The experimental area was blocked into 6 paddocks. Within each paddock, the 3 grazing treatments simultaneously grazed adjacent to one another as separate herds. A common compressed postgrazing sward height of 6 cm was targeted, and daily herbage allowances (**HA**) were adjusted to achieve this target. Cows were individually offered their concentrate allocation in 2 equal feeds at the a.m. and p.m. milkings in the milking parlor.

ITMR Treatment. The cows assigned to the ITMR treatment were group-housed and offered a TMR. The ingredients were mixed and dispensed using a Keenan diet feeder (Keenan Holdings Ltd., Borris, Co. Carlow, Ireland). The concentrate inclusion in the ITMR was increased incrementally over the first 2 wk to avoid metabolic disorders associated with a rapid diet change. The concentrate inclusion rate then remained static for the remainder of the experiment. The composition of the TMR was (mean $\pm$ SD; DM basis) 4.1 ± 0.55 kg/cow per day of grass silage, 8.2 ± 0.98 kg/cow per day of maize silage, 0.7 ± 0.07 kg/cow per day of straw, 10.4 ± 0.99 kg/cow per day of concentrate and 1.5 ± 0.133 kg/cow per day of molasses. Concentrate composition on a fresh weight basis was 14.5% barley, 19% citrus

pulp, 25% maize gluten, 36% soya, 2.5% fat, and 3% vitamins and minerals.

The TMR was offered daily. Before feeding, the previous day's refusals were removed and weighed to estimate group DMI. The TMR ingredients were sampled individually twice weekly. These were dried for 48 h at 40°C, and then milled through a 1-mm sieve in preparation for chemical analysis. The TMR was offered in excess to encourage high voluntary intakes. No concentrate was offered to these cows in the milking parlor.

Sward Measurements

Herbage Mass Determination and Grass Sampling. Paddock pregrazing HM (>4 cm) was determined twice weekly by harvesting 2 strips (1.2×10 m) per treatment with an Agria machine (Etesia UK Ltd., Warwick, UK.). Ten grass height measurements were recorded before and after cutting 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; Agrosystèmes, Choiseille, France). This allowed the calculation of mass of herbage/cm (kg of DM/cm per ha) = herbage mass (DM/ha)/(precutting height – postcutting height). All mown herbage from each strip was collected, weighed, and sampled (approximately 0.3 kg of fresh weight). A subsample of approximately

Figure 1. Effect of feeding regimen during the first 6 wk of lactation on daily milk yield profile of autumn-calving dairy cows during the 37 wk of the experiment. G1 = grass + 1 kg (DM) of concentrate/cow per day; G4 = grass + 4 kg (DM) of concentrate/cow per day; G8 = grass + 8 kg (DM) of concentrate/cow per day; ITMR = indoor TMR. The end of the experimental period (wk 6) and the end of the 13-wk deferred effect period (wk 19) are indicated, as are the 2 periods when DMI was estimated.

0.1 kg was dried for 48 h at 40°C in a drying oven for determination of DM content.

Herbage representative of that selected by the G1, G4, and G8 treatment cows was sampled weekly with a Gardena (Accu 60, Gardena International GmbH, Ulm, Germany) hand shears, with awareness of the previous defoliation height recorded from each treatment. A subsample was stored at -20°C before being freeze-dried and milled through a 1-mm sieve before chemical analysis.

Pre- and Postgrazing Sward Heights. The pregrazing sward heights were determined daily in each plot by recording 30 measurements across the 2 diagonals of the paddock, using the electronic plate meter described above. Pregrazing measurements were recorded for each of the 3 treatments. Postgrazing sward height was measured immediately after grazing for each of the 3 individual treatments using the same methodology.

Animal Measurements

Milk Production. Individual cow milk yields (kg) were recorded at each milking. Weekly milk fat, protein, and lactose concentrations were determined from one successive a.m. and p.m. milking sample. The concentrations of these constituents were determined using a Milkoscan 203 (Foss Electric, Hillerød, Denmark). Milk solids yield (**MSY**) was calculated as the sum of milk fat yield and milk protein yield. Energy-corrected milk yield was calculated using the following equation: $\text{ECM yield} \times [1 + 0.0055 \times (\text{fat content} - 40) + 0.0033 \times (\text{protein content} - 31)]$; Faverdin et al. (2010).

Body weight was measured weekly using an electronic portable weighing scale and the Winweigh software package (Tru-Test Limited, Auckland, New Zealand). Body condition score was recorded weekly on a 1 to 5 scale (1 = emaciated, 5 = extremely fat) with 0.25-unit increments (Edmonson et al., 1989) by one experienced independent observer throughout the experiment. Cows were assessed by palpating key areas of their body. Although this system is similar to the New Zealand 10-point scoring system, it differs from the 5-point system used in the United States, where cows are visually assessed (Roche et al., 2004). Changes in BW and BCS during the 6-wk experimental period were calculated using values of BW and BCS from the first 2 and last 2 wk of the period when experimental treatments were applied (i.e., average of wk 5 and 6 minus average of weeks 1 and 2); BW and BCS change during the deferred effect period were also calculated using values from the first 2 and last 2 wk of that period (i.e., average of wk 7 and 8 minus average of wk 18 and 19).

Intake Estimation

Individual grass DMI (**GDMI**) for the G1, G4, and G8 treatment cows were estimated twice during the 6-wk experimental period (wk 2 and 5) using the *n*-alkane technique (Mayes et al., 1986) as modified by Dillon and Stakeelum (1989). All concentrate offered to the cows was eaten in the parlor, thus the quantity of concentrate offered was summed with each cow's individual GDMI to give total DMI (**TDMI**). All cows were dosed twice daily, before milking, for 12 consecutive days with a paper bolus (Carl Roth GmbH and Co. KG, Karlsruhe, Germany) containing 500 mg of dotriacontane (C_{32}). From d 7 of dosing, fecal grab samples were collected from each cow twice daily, before morning and afternoon milkings, for the remaining 6 d. The fecal grab samples were bulked per cow (12 g of each collected sample to give a 72-g bulk sample) and dried for 48 h in a 40°C oven in preparation for chemical analysis of alkanes.

The diet of the cows was also sampled. Herbage representative of that grazed (with awareness of the previous defoliation height recorded from each treatment) was manually collected from each paddock before the a.m. grazing on d 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 *n*-alkane concentrations (C_{25} - C_{36}) of the pellets, feces, herbage, and concentrate were analyzed using a modification of the method of Mayes et al. (1986), which used direct saponification (Dillon, 1993). The recovery correction factors used to adjust the actual *n*-alkane concentrations in the DM of feces were those reported by Dillon (1993), which were 0.618, 0.686, 0.722, 0.769, 0.777, 0.844, and 0.891 for heptacosane (C_{27} -alkane), octacosane (C_{28} -alkane), nonacosane (C_{29} -alkane), triacontane (C_{30} -alkane), hentriacontane (C_{31} -alkane), tritriacontane (C_{33} -alkane), and pentatriacontane (C_{35} -alkane), respectively. The recovery factor for C_{32} -alkane was assumed to be the same as that of C_{33} -alkane.

The GDMI of the ITMR cows was measured during the same weeks that individual DMI of the grazing cows was measured. A known quantity of fresh TMR was offered daily. Before feeding, the previous day's refusals were removed, weighed, and sampled (for DM analysis) and a mean cow DMI was calculated.

Chemical Analyses

Herbage samples were analyzed for DM, ash (AOAC International, 1995; method 942.05), CP (Leco FP-428; Leco Australia Pty Ltd., Castle Hill, Australia), ADF

and NDF (AOAC International, 1995; method 973.18), using sodium sulfate for the NDF (Ankom Technology, Macedon, NY), and organic matter digestibility (OMD; using the method described by Morgan et al., 1989; Fibertec Systems, Foss, Dublin, Ireland). Maize silage, grass silage, and straw samples were analyzed for DM, ash, CP, NDF, and ADF using the methods described above. The concentrate offered was analyzed for DM, ash, CP, and NDF concentrations.

Statistical Analyses

All herbage data were analyzed by ANOVA using the following model:

$$Y_{ijk} = \mu + T_i + W_j + e_{ijk},$$

where Y_{ijk} = dependent variable, μ = mean, T_i = treatment ($i = 1$ to 4), W_j = week ($j = 1$ to 6), and e_{ijk} = residual error term.

Milk yield, milk protein, fat, and lactose concentrations and yields, MSY, ECM, BW, and BCS were analyzed by using a repeated-measures model in PROC MIXED (SAS Institute, 2006), with experimental week included as a repeated effect. Cow was included as a random effect, and parity, treatment, and week were included as fixed effects. All interactions between parity, treatment, and week were also included. Days in milk and pre-experimental production data were included in the model. Because of differences in parity, pre-experimental values were centered within parity before inclusion. That is, the deviations from the parity mean were used as covariates. The incorporation of individual animal covariates within the model aimed to reduce the residual error term, therefore explaining more variation within parity. Orthogonal contrasts of the milk production, milk constituent yield, milk composition, and DMI of the 3 grazing treatments versus the ITMR

treatment were made using the contrast statement of SAS (SAS Institute, 2006).

RESULTS

Chemical Analyses

The DM of the herbage offered to the grazing cows was 153 ± 23.7 g/kg (Table 1). The CP of the herbage was 212 ± 8.8 g/kg of DM, and NDF and ADF were 492 ± 18.0 and 290 ± 14.7 g/kg of DM, respectively. The OMD of the herbage was 736 ± 30.4 g/kg of DM. Concentrations of ash, CP, NDF, and ADF of the maize silage were 44 ± 4.4 , 98 ± 4.6 , 461 ± 42.6 , and 280 ± 23.0 g/kg of DM, respectively. The chemical composition of the straw was ash, 38 ± 1.8 , CP, 64 ± 5.9 , NDF, 823 ± 5.6 , and ADF, 554 ± 9.7 g/kg of DM. The DM of the grass silage was 227 ± 29.7 g/kg, and CP and NDF were 212 ± 8.8 and 492 ± 17.9 g/kg of DM, respectively. The CP of the concentrate offered to the grazing cows was 164 ± 16.4 g/kg of DM, whereas ash and NDF were 92.3 ± 15.4 and 214 ± 15.2 g/kg of DM, respectively. The CP of the TMR concentrate was greater than that of the grazing cows' concentrate (260 ± 16.4 g/kg of DM) but the ash and NDF contents were similar (91 ± 11.2 and 224 ± 25.6 g/kg of DM).

Sward Measurements

Pregrazing HM and compressed pregrazing sward height did not differ between the 3 grazing treatments (1,708 kg of DM/ha and 12.5 cm, respectively; Table 2). Compressed postgrazing sward height was also similar between the 3 grazing treatments (6.0 cm).

Daily herbage allowance was different between all treatments and ranged from 18.7 kg of DM/cow for the G1 cows to 12.1 kg of DM/cow for the G8 cows. The G4 cows were offered an intermediate quantity (14.1

Table 1. Chemical analyses (g/kg) of grass, maize silage, grass silage, straw, and concentrate offered to early-lactation, autumn-calving dairy cows¹

Item	Grass	Maize silage	Grass silage	Straw	Grazing cow concentrate	TMR concentrate	TMR mix ²
DM	153 (23.7)	300 ³	227 (29.7)	880 ³	898 (2.1)	902 (2.3)	572
Ash	111 (15.4)	44 (4.4)	19 (4.67)	38 (1.8)	92 (15.4)	91 (11.2)	60
CP	212 (8.8)	98 (4.6)	212 (8.8)	64 (5.9)	164 (16.4)	260 (16.4)	189
NDF	492 (18.0)	461 (42.6)	492 (17.9)	823 (5.6)	214 (15.2)	224 (25.6)	372
ADF	290 (14.7)	280 (23.0)		554 (9.7)			
OM digestibility	736 (30.4)						
DM digestibility			696 (55.8)				

¹Values in parentheses are the standard deviations of the mean of repeated sampling during the study.

²Calculated value.

³Values not available; those used were taken from O'Mara (1994).

Table 2. Effect of feeding regimen during the first 6 wk of lactation on sward measurements

Item ¹	Regimen ²			SE	P-value
	G1	G4	G8		
Daily HA >4 cm, kg of DM/cow per day	18.7	14.1	12.1	1.41	0.001
Pregrazing HM >4 cm, kg of DM/ha	1,746	1,726	1,653	217.5	0.722
Pregrazing sward height, cm	12.6	12.6	12.4	0.94	0.843
Postgrazing sward height, cm	6.1	6.1	5.7	0.44	0.282
Area, m ² /cow per day	137.4	93.9	79.8	33.22	0.007

¹HA = herbage allowance; HM = herbage mass.

²G1 = grass + 1 kg (DM) of concentrate/cow per day; G4 = grass + 4 kg (DM) of concentrate/cow per day; G8 = grass + 8 kg (DM) of concentrate/cow per day.

kg of DM/cow). Consequently, area allocation per cow per day was greatest for the G1 cows (137 m²/cow), whereas it did not differ significantly between the G4 and G8 cows (94 and 80 m²/cow, respectively).

Animal Production

Experimental Period Production. Dry matter intake, using the *n*-alkane technique, was measured on 2 occasions for the cows offered a pasture-based diet during the 6-wk experimental period. During the first intake estimation period, when treatments were on average 35 DIM (wk 2 of experiment), the GDMI of the G1 cows was similar to that of the G4 cows (13.3 kg of DM/cow per day) but it was greater than that of the G8 cows (12.1 kg of DM/cow per day). The G4 and G8 cows were similar (12.8 and 12.1 kg of DM/cow per day,

respectively). The G1 cows had the lowest TDMI (14.6 kg of DM/cow per day; $P < 0.001$) followed by the G4 cows (16.7 kg of DM/cow per day), whereas the G8 cows had the greatest TDMI of the grazing cows (20.1 kg of DM/cow per day; Table 3). During the second intake estimation period, when the treatments were on average 51 DIM, GDMI was significantly different between all 3 treatments. Total DMI was also different between the G1, G4, and G8 cows (14.6, 16.8, and 19.8 kg of DM/cow per day). The TDMI of the ITMR cows during wk 2 of the experiment was 19.7 kg of DM/cow. During wk 5 of the experiment, TDMI of the ITMR cows was 21.6 kg of DM/cow per day. During the 6-wk experimental period, mean TDMI of the ITMR cows was 20.9 kg of DM/cow per day, similar to that of the G8 cows.

Mean milk yield of the ITMR cows (27.3 kg/cow per day) was greater (+3.7 kg/cow) than mean milk yields

Table 3. Effect of feeding regimen during the first 6 wk of lactation on total dry matter intake (TDMI), (immediate) milk yield, and milk composition of autumn-calving dairy cows

Item ¹	Regimen ²				SE	P-value
	G1	G4	G8	ITMR		
TDMI (35 DIM)	14.6 ^a	16.7 ^b	20.1 ^c	19.7 ²	0.51	0.001
TDMI (51 DIM)	14.6 ^a	16.8 ^b	19.8 ^c	21.6 ²	0.32	0.001
Milk yield, kg/d	21.1 ^b	24.1 ^c	25.4 ^c	27.3 ^a	0.72	0.001
ECM yield, kg/d	21.2 ^b	24.0 ^c	25.0 ^c	26.9 ^a	0.69	0.001
Milk fat concentration, %	3.99	3.76	3.60	3.73	0.109	0.083
Milk protein concentration, %	3.21	3.23	3.32	3.24	0.055	0.508
Milk lactose concentration, %	4.73 ^b	4.71 ^b	4.75 ^b	4.84 ^a	0.026	0.006
Milk fat yield, g/d	847 ^b	910 ^{ab}	911 ^{ab}	1,015 ^a	36.5	0.023
Milk protein yield, g/d	679 ^b	782 ^c	844 ^{ac}	884 ^a	27.0	0.001
Milk lactose yield, g/d	999 ^b	1,136 ^c	1,206 ^c	1,318 ^a	32.6	0.001
Milk solids (MS) yield, kg/d	1.53 ^b	1.69 ^c	1.75 ^{ac}	1.90 ^a	0.058	0.001
Total 6-wk MS yield, kg	64 ^b	71 ^c	74 ^{ac}	80 ^a	8.2	0.001
Percentage of total-lactation MS produced in 6-wk period	2.14	2.60	2.48	2.62	1.546	0.378
End BW, kg	498 ^b	505 ^b	524 ^a	525 ^a	21.8	0.01
BW changeover 6-wk period, kg/d	-0.75 ^b	-0.50 ^b	-0.14 ^a	-0.11 ^a	0.520	0.01
End BCS	2.52	2.66	2.56	2.68	0.292	0.529
BCS change over 6-wk period	-0.56	-0.43	-0.52	-0.40	0.292	0.529

^{a-c}Means within a row with different superscripts differ ($P < 0.05$).

¹G1 = grass + 1 kg (DM) of concentrate/cow per day; G4 = grass + 4 kg (DM) of concentrate/cow per day; G8 = grass + 8 kg (DM) of concentrate/cow per day; ITMR = indoor TMR.

²Individual TDMI of the grazing cows (G1, G4, and G8) was measured using the *n*-alkane technique; group TDMI of the ITMR cows was measured by subtracting measured refusals from the previous day's known quantity of fresh TMR offered.

Figure 2. Effect of feeding regimen during the first 6 wk of lactation on BCS profile of autumn-calving dairy cows during the 37 wk of the experiment. G1 = grass + 1 kg (DM) of concentrate/cow per day; G4 = grass + 4 kg (DM) of concentrate/cow per day; G8 = grass + 8 kg (DM) of concentrate/cow per day; ITMR = indoor TMR. The end of the experimental period (wk 6) and the end of the 13-wk deferred effect period (wk 19) are indicated.

from cows in all other treatments, whereas milk yield of the G1 cows (21.1 kg/cow per day) was lower (−4.6 kg/cow per day) than that of cows from all other treatments. The milk yields of the G4 and G8 cows did not differ and were intermediate to those of the ITMR and G1 cows (24.8 kg/cow per day; Table 3).

We detected no effect of treatment on milk fat (3.77%) or protein (3.25%) concentration. Milk lactose concentration was increased (+0.12%/cow per day) by offering a TMR (4.84%) compared with cows from all other treatments. Milk fat yield of the ITMR cows was greater (+168 g/cow per day) than that of the G1 cows (847 g/cow per day) but did not differ from the G4 and G8 cows (911 g/cow per day). The milk fat yield of the G1 cows was not different from that of the G4 and G8 cows. The ITMR cows (884 g/cow per day) had greater milk protein yield than G1 and G4 (−205 and −102 g/cow per day, respectively). Milk protein yield from the G8 cows (844 g/cow per day) was similar to that of cows from the G4 and ITMR treatments but greater than that of cows in the G1 treatment. When the milk protein yield of the ITMR cows was compared with all grazing herds, it was 11.6 g/cow per day greater. Milk lactose yield was greatest for the ITMR cows (1,318 g/cow per day) and lowest for the G1 treatment (999 g/cow per day); the G4 and G8 cows, which did not differ from each other, were intermediate (1,171 g/cow per day). The milk lactose yield of the ITMR cows was 20.7 g/cow per day greater than that of all grazing treatments.

Treatment affected MSY; ITMR yielded 1.90 kg/cow per day, similar to the G8 cows (1.75 kg/cow per day), G1 had the lowest MSY 1.53 kg/cow per day, whereas

that of G4 (1.69 kg/cow per day) was lower than that of ITMR but not different from that of G8. However, the ITMR treatment had a 0.24 kg/cow per day greater MSY compared with all 3 grazing treatments. The ECM yield of the ITMR cows was greater (+3.5 kg/cow per day) than all grazing treatments; the ECM of the G1 cows was lower (21.2 kg/cow per day) than all other treatments. The G4 and G8 treatments were similar to each other (24.0 kg/cow per day).

At the end of the 6-wk experimental period, the ITMR and G8 cows had greater BW (525 kg) than the G4 and G1 cows (502 kg). Change in BW over the experiment was least for the ITMR and G8 cows (−0.13 kg/d) and greatest for the G4 and G1 cows (−0.67 kg/d). We detected no effect of treatment on BCS at the end of the experiment (2.61) or on BCS change over the 6-wk experimental period (−0.48 over the 6-wk period; Figure 2).

Deferred Effect Period

Previous experimental treatment did not affect milk yield (24.3 kg/cow per day; Table 4), ECM (25.4 kg/cow per day) or milk fat (3.76%), protein (3.24%), and lactose (4.76%) concentrations. We observed no difference between treatments in milk fat (912 g/cow per day), protein (787 g/cow per day), or lactose (1,158 g/cow per day) yield. There was no treatment effect on daily MSY (1.70 kg/cow per day) or total MSY produced during the deferred effect period (155 kg/cow). We observed no difference in BW at the end of the deferred effect period between the 4 treatments (551 kg). However, BW change during this period was

Table 4. Effect of feeding regimen during the first 6 wk of lactation on milk yield and composition during the deferred lactation effect period (13 wk from housing to turnout the following spring, February 10) of autumn-calving dairy cows

Item	Regimen				SE	P-value
	G1	G4	G8	ITMR		
Milk yield, kg/d	23.9	24.2	23.7	25.5	0.86	0.478
ECM yield, kg/d	25.1	25.3	24.6	26.4	0.87	0.512
Milk fat concentration, %	3.87	3.68	3.71	3.78	0.088	0.458
Milk protein concentration, %	3.25	3.14	3.30	3.26	0.051	0.169
Milk lactose concentration, %	4.81	4.73	4.74	4.77	0.028	0.145
Milk fat yield, g/d	912	893	877	966	36.1	0.341
Milk protein yield, g/d	778	761	785	823	26.9	0.439
Milk lactose yield, g/d	1,147	1,144	1,125	1,215	39.8	0.418
Milk solids (MS) yield, kg/d	1.69	1.65	1.66	1.79	0.063	0.424
Total MS yield, kg (13-wk period)	155	151	151	162	22.1	0.666
End BW, kg	552	540	569	542	32.8	0.222
BW change, kg/d (13-wk period)	0.35 ^{bc}	0.28 ^b	0.42 ^c	0.15 ^a	0.146	0.002
End BCS	2.57	2.62	2.70	2.75	0.279	0.488

^{a-c}Means within a row with different superscripts differ ($P < 0.05$).

¹G1 = grass + 1 kg (DM) of concentrate/cow per day; G4 = grass + 4 kg (DM) of concentrate/cow per day; G8 = grass + 8 kg (DM) of concentrate/cow per day; ITMR = indoor TMR.

lower (0.15 kg/d) for the ITMR cows than for cows in all other treatments. The BW change of the G1 cows (0.35 kg/day) was similar to that of the G4 and G8 cows (0.28 and 0.42 kg/d, respectively) but the G4 and G8 cows were different from each other. Body condition score did not differ between cows from the 4 treatments at the end of the deferred effect period (2.66).

Total Milk Production

Treatment did not affect cumulative lactation milk yield (5,445 kg/cow per lactation; Table 5). No difference was detected in milk fat, protein, and lactose concentrations (3.86, 3.37, and 4.70%, respectively) or yields (208, 182, and 367 kg, respectively) between the 4 treatments. Body weight and BCS recorded at the end of the lactation were similar between treatments (533 kg and 2.97, respectively).

DISCUSSION

Although offering herbage with a moderate to low concentrate input compared with a TMR reduced milk production in the first 6 wk of lactation, cumulative lactation milk production did not differ between treatments. This indicates that grazed grass can be incorporated into the diet of autumn-calving cows with potential economic benefits.

Effect of Early-Lactation Diet on Immediate Production

In the present experiment, G1 cows yielded 23% less milk than the ITMR cows (27.3 kg/d) during the 6-wk experimental period. Offering 4 kg (DM) of concentrate/cow per day (G4 cows) resulted in a 12% lower milk yield than the ITMR cows, and offering 8 kg (DM) of concentrate (G8 cows) reduced milk yield by 7%

Table 5. Effect of feeding regimen during the first 6 wk of lactation on cumulative milk production of autumn-calving dairy cows (37 wk)

Item	Regimen ¹				SE	P-value
	G1	G4	G8	ITMR		
Milk yield, kg	5,403	5,328	5,376	5,672	284.7	0.677
Milk fat concentration, %	4.01	3.82	3.87	3.75	0.155	0.468
Milk protein concentration, %	3.37	3.31	3.45	3.34	0.065	0.224
Milk lactose concentration, %	4.73	4.69	4.67	4.70	0.040	0.465
Milk fat yield, kg	214	200	204	212	13.1	0.736
Milk protein yield, kg	180	175	183	187	10.0	0.735
Milk lactose yield, kg	366	357	360	383	18.9	0.579
Milk solids yield, kg	395	375	389	400	21.9	0.762
End BW, kg	530	537	540	525	10.8	0.581
End BCS	2.93	2.91	3.02	3.02	0.076	0.472

¹G1 = grass + 1 kg (DM) of concentrate/cow per day; G4 = grass + 4 kg (DM) of concentrate/cow per day; G8 = grass + 8 kg (DM) of concentrate/cow per day; ITMR = indoor TMR.

compared with the ITMR cows. Although differences in milk yield were observed, it could be argued based on previous literature that larger differences should have been expected, particularly if higher yielding cows (i.e., cows with a higher genetic potential for milk production) were enrolled in the experiment. Kolver and Muller (1998) and Mayne (1995) reported a milk production potential of 29.6 and 27 kg/cow per day, respectively, for high-yielding Holstein Friesian cows from pasture alone. Even with 8 kg (DM) of concentrate, the G8 cows achieved a milk yield of only 25.4 kg/cow per day. This indicates that the genetic potential for milk production of the cows used in the present study may have been lower than that of cows used in other studies in which a TMR diet was offered. The lower milk yields in this experiment are due to the high percentage (38%) of primiparous cows and perhaps to the high proportion of New Zealand Holstein Friesian (NZHF) genetics within the herd (Horan et al., 2005b). O'Neill et al. (2011) evaluated the production of early-lactation, spring-calving dairy cows offered a TMR or pasture-only diet over a 10-wk period and reported that cows offered a TMR had greater milk yields (+8.4 kg/d; +28%) than the pasture-fed cows (21.1 kg/d). Similarly, Kolver and Muller (1998) reported a 33% greater milk yield for TMR fed cows than for pasture-fed cows (29.6 kg/d). In both of these experiments, however, the pasture-based cows were offered no concentrate. Horan et al. (2005b) and Kolver et al. (2002) previously reported that North American Holstein Friesian (NAHF) cows are more responsive in terms of milk yield to high-concentrate systems, whereas NZHF cows are more suitable for pasture-based systems. As the cows used in the current experiment had a high proportion of NZHF genetics and lower milk production than those reported in the experiment of Kolver and Muller (1998), the lesser milk response to the TMR was not surprising. Furthermore, diverging DMI were recorded during the experiment and these differences were reflected in milk yield, as DMI is a main determinant of milk production. The mean TDMI over the 6-wk experimental period for the G1, G4, and G8 cows were 14.6, 16.8, and 20.0 kg/cow per day, respectively.

Although we observed a difference in milk yield between the G8 and ITMR cows during the experimental period, there was no difference in MSY. The lack of difference in MSY could be attributed to the fact that milk protein concentration was numerically higher in the G8 treatment than in the ITMR treatment. Previous research has indicated a beneficial effect on milk protein concentration of including grazed grass in the diet of early-lactation dairy cows (Dillon et al., 2002; Kennedy et al., 2005).

Grazing management practices and climatic conditions dictate that pregrazing HM is greater in autumn than in spring (Ganche et al., 2013) to facilitate the extension of the grazing season into late autumn. Consequently, pregrazing HM in autumn is frequently greater than 2,000 kg of DM/ha (>4 cm; Roche et al., 1996). In the current experiment, pregrazing HM was maintained at 1,700 kg of DM/ha. Hennessy et al. (2006) reported that autumn swards with a pregrazing HM of 1,500 kg of DM/ha had a greater proportion of leaf (+0.22) compared with swards with a pregrazing HM of 2,100 kg of DM/ha. This resulted in a +10 and +48 g/kg difference in CP (249 g/kg of DM) and DM digestibility (807 g/kg), respectively. In the current experiment, despite a seasonally low pregrazing HM of approximately 1,700 kg of DM/ha, sward quality was poor (736 g/kg of OMD). Although the G1 cows were only offered 1 kg of concentrate, their GDMI and post-grazing height were similar to those of the other grazing treatments. This resulted in the G1 cows losing more BW during early lactation than the G8 and ITMR cows (as well as having lower milk production performance). McEvoy et al. (2008) reported a GDMI of almost 14 kg/cow per day in early-lactation, spring-calving cows offered no concentrate when grazing to 3.5 cm. However, when cows grazing a pasture-only diet grazed to 4.4 cm, GDMI increased to almost 16 kg/cow per day. Perhaps the lower quality of autumn pasture in the current study contributed to the lower intakes. Even though the pregrazing yield was less than that typically observed in autumn pastures, autumn pasture nevertheless contains a high proportion of senescent material and a lower proportion of green leaf compared with spring grass (Hennessy et al., 2006). Hoogendoorn et al. (1992) previously showed that DMI and milk production were positively related to the proportion of green leaf in the sward. In autumn, there is an accumulation of dung deposits in the sward, thus the palatability of the grass is not homogeneous and may result in highly selective grazing and reduced intake. The area around the dung deposit that is rejected is estimated to be 5 (Bastiman and Van Dijk, 1975) to 12 (Greenhalgh and Reid, 1969) times that of the dung deposit itself, which may have contributed to the low grass intake in the present experiment.

Milk Production Response to Concentrate Feeding and Substitution Rate During the Experimental Period

Milk production response to concentrate offered was defined as the increase in kilograms of milk per kilogram of concentrate offered during the experimental period.

In this experiment, when daily concentrate input for the cows at pasture increased from 1 to 4 kg of DM/cow per day, there was an (immediate) response (1.03 kg of milk/kg of concentrate DM). This is similar to that reported by Kennedy et al. (2007; 1.1 kg of milk/kg of concentrate DM offered) and Horan et al. (2005b; 1.00 kg of milk/kg of concentrate DM) and is due to the fact that total energy intake was increased when more concentrate was included in the diet. The response to increasing concentrate from 1 to 8 kg was 0.61 kg of milk/kg of concentrate was similarly due to a greater total energy intake on the higher concentrate rate feeding treatment. The current experiment was completed in very early lactation, and stage of lactation can affect the magnitude of milk response to supplements (Stockdale, 1999) because energy is partitioned more toward milk production than to body condition in early lactation (Broster and Broster, 1984). We expected that as concentrate feeding level increased, the milk production response to concentrate would decrease, in agreement with the literature (Dillon et al., 2002).

McEvoy et al. (2008) reported a linear increase in milk production when 3 different quantities of concentrate (0, 3, and 6 kg of DM/cow per day) were offered for an 11-wk period to dairy cows producing approximately 30 kg/cow per day in early lactation. Bargo et al. (2003) also reported a linear increase in milk production as the quantity of concentrate in the diet increased. In the present experiment, we found a significant increase in milk yield when concentrate supplementation was increased from 1 to 4 kg of DM/cow per day but unlike McEvoy et al. (2008) and Bargo et al. (2003), the increases was not linear, as no increase in milk yield occurred when supplementation was increased from 4 to 8 kg of DM/cow. Bargo et al. (2003) concluded that milk production of high-producing cows (>28 kg milk/cow per day) in early lactation increases linearly as the quantity of concentrate increases from 1.8 to 10 kg of DM/cow per day, with an overall milk response of 1 kg of milk/kg of concentrate. Dillon (2006) reported a lower response to concentrate with low- to moderate-yielding cows. We detected a quadratic response to concentrate in the current experiment. The lack of a linear response to the greater level of concentrate in this experiment is not surprising given the genetic background of the herd. Horan et al. (2005b) reported that the milk production response to concentrate supplementation was greater for cows with a greater proportion of NAHF genetics (1.05 kg of milk/kg of concentrate) compared with cows with a greater proportion of NZHF genetics (0.55 kg of milk/kg of concentrate).

Forage intake can be negatively affected by concentrate supplementation (Bargo et al., 2003), which can result in a substitution effect (Grainger and Matthews,

1989). The GDMI recorded for each individual treatment in both the first and second measurement periods in the current study were similar. There was no significant difference in GDMI between the G1 and G4 treatments on either occasion so no substitution was observed. When an additional 7 kg of concentrate DM/cow per day was offered to the G8 cows, compared with the G1 cows, they substituted on average 0.23 kg of grass DM/kg of additional concentrate. Although lower than previous studies (Stockdale, 1999, 2004; Kennedy et al., 2007), which reported a substitution rate of 0.27 to 0.46 kg of herbage/kg of concentrate and 0.33 to 0.43 kg of herbage/kg of concentrate, the values were similar to those reported by McEvoy et al. (2008; 0.19 kg of herbage/kg of concentrate). Substitution rate can be affected by many pasture, animal, and supplement factors (Stockdale, 2000). However, no substitution was observed between the G4 and G8 treatments or between the G1 and G4 treatments, which may indicate that there was insufficient power in this experiment to detect significant differences; only numerical differences between the grazing treatments were observed.

Effect of Early-Lactation Diet on Production During the Deferred Period

We detected no difference between treatments in any milk production parameters during the 13-wk period when deferred effects were being measured. Between the first and last weeks when the experimental treatments were imposed (i.e., wk 1 and 6 of the 6-wk period), the milk yield of the G1 and G4 cows decreased by a proportion of 0.16 and 0.07, respectively, whereas the milk yields of the G8 and ITMR cows increased by a proportion of 0.04 and 0.15, respectively; Figure 1). Previous studies have shown that, during this early stage of lactation, milk yield should be increasing toward peak production rather than decreasing (Horan et al., 2005b). Interestingly, when changes in milk yield during the first 2 wk of the deferred effect period (i.e., wk 7 and 8 of the experiment) were observed, there were proportional increases in milk yield of 0.21 and 0.09 for the G1 and G4 cows, respectively. In contrast, milk yields during the first 2 wk of the deferred effect period were decreased by a proportion of 0.02 and 0.03 for the G8 and TMR cows, respectively; this decline is more typical of cows offered an unrestricted diet during early lactation (Horan et al., 2005a). This ability of the G1 and G4 animals to decrease milk energy output when assigned to a low energy diet and to increase milk production again when a higher plane of nutrition is offered may be an acquired genotypic feature of cows selected for seasonal pasture-based dairy systems (Burke and Roche, 2007). The results of this experi-

ment are in contrast, however, to the experiment of Roche (2007), in which it was reported that offering an inadequate quantity of feed during the first 5 wk of lactation reduced milk yield for the following 10 wk due to the negative effect of energy restriction. In the present experiment, it was clear that the lower concentrate input of the G1 and G4 cows, offered in conjunction with a low energy grass feed in early lactation, had no lasting consequences because we observed no difference in cumulative milk production at the end of lactation, again highlighting the ability of the dairy cow to adjust milk production in response to the level of nutrients offered (Friggens et al., 1998).

Following the end of the 6-wk experimental period, the BW of the G1 and G4 cows was significantly lower than that of the G8 and ITMR cows; however, there were no differences in BW at the end of the deferred effect period. It is possible that these differences in BW arose from differences due to gut fill during the 6-wk experimental period (Allen, 1996). This hypothesis is further substantiated when the BCS profile (Figure 2) of all 4 treatments is considered, because at the end of the 6-wk experimental period, there was no difference in BCS between the 4 treatments and this lack of difference remained until the end of lactation. Statistical differences in BCS can be hard to achieve if group size is small; however, in this experiment, the numerical difference in BCS between the G1 and ITMR treatments was only 0.16, which is not biologically significant. This lack of difference between treatments in BW and BCS is not surprising and previous experiments (Ganche et al., 2013) offering differing quantities of feed to early-lactation, pasture-based dairy cows also reported no differences in BW or BCS.

Cumulative Milk Production

Interestingly, we detected no difference between the 4 treatments in terms of milk yield or MSY when the full lactation (37 wk) was considered. This is probably due to a dilution effect as treatments were only imposed for a 6-wk period in early lactation, after which cows were fed an *ad libitum* TMR followed by a grazed grass diet for the remaining 31 wk of the study. This gave the cows in the G1 and G4 treatments, which initially had a lower milk production, ample time to recover from any imposed dietary restrictions and to respond to the higher plane of nutrition offered from wk 7 onward. This phenomenon was observed in previous studies where the diet of early-lactation cows at pasture was restricted for a 5-wk period—there were immediate reductions in milk production but no effect on cumulative milk production (Crosse et al., 2015). Those authors also attributed the lack of difference to

a dilution effect. Furthermore, the data from the current experiment and previous studies (Delaby et al., 2009; Ganche et al., 2013) indicate that, if the period of restriction is not imposed for too long and the diet of cows is not overly restrictive, total lactation milk production is unaffected. In this experiment, cows were not restricted as they grazed to 6 cm, which is a lax postgrazing height in intensive pasture-based systems during the autumn period (McCarthy et al., 2013). The lack of effect of treatment on cumulative lactation milk production in this experiment indicates that grazed grass can be incorporated into the diet of the early-lactation, autumn-calving cows, with favorable economic implications due to reduced feed costs.

Economics

White et al. (2002) reported that although milk production was lower for pasture-based systems, costs associated with feed, culling, and other economic factors were lower, which indicated that pasture-based systems can be competitive when compared with confinement systems. In their study, daily feed costs were lower for cows on pasture than for confinement cows. Generally, feed costs are considerably greater in autumn-calving systems than in spring-calving systems, where greater proportions of grazed grass can be utilized. Incorporating grass, a relatively cheap feed (Finneran et al., 2012), into the diet, even if for a limited time, can help reduce feed costs over the entire lactation. The data from this study indicate that grazed pasture can be incorporated into the diet of early-lactation cows, thereby capitalizing on lower feed costs. Based on the data of Finneran et al. (2012), the feeding costs for the forage-based component of the diet in this experiment were, on average, 56% more expensive for the TMR diet than the average of the pasture-based diets during the 6-wk experimental period. Feed costs would have been similar for the remainder of lactation as all cows were offered similar diets after the 6-wk period. Furthermore, in the present study, there were no significant differences between the G8 and ITMR treatment in terms of MSY, even though the ITMR cows were receiving an additional 2 kg (DM) of concentrate/cow per day; this would have large repercussions on the cost of production. For example, if the concentrate was priced at €220/t of DM and the ITMR cows received 84 kg of extra concentrate over the course of the 6-wk experimental period, the difference would be more than €18/cow. This indicates that the inclusion of pasture in the early-lactation, autumn-calving cow diet, even for a short period such as 6 wk in this study, could have a positive effect on farm profitability.

CONCLUSIONS

Milk yield in the first 6 wk of lactation was reduced by offering herbage with a moderate to low concentrate input compared with a TMR. A similar milk solids yield was achieved with a TMR diet compared with herbage supplemented with 8 kg of concentrate/cow per day. Cumulative lactation milk yield did not differ between the treatments. This indicates that herbage can be incorporated into the diet of early-lactation, autumn-calving dairy cows without any negative consequences on total lactation milk production. Using this strategy will reduce associated feed costs and help improve overall farm profitability.

ACKNOWLEDGMENTS

The authors acknowledge the financial support of the Irish Dairy Levy and sincerely thank all the farm staff at Moorepark for their care of the experimental cows and assistance during the experiment. The input of E. Ganche and G. Duboc (AGRIC, Teagasc Moorepark, Ireland) is also acknowledged. We also thank F. Flynn, J. Nash, and the late M. Feeney for their technical assistance over the course of the experiment (AGRIC, Teagasc Moorepark, Ireland). The input of P. Moate (ECODEV, Ellinbank, Australia) into manuscript preparation is also acknowledged.

REFERENCES

- Allen, M. S. 1996. Physical constraints on voluntary intake of forages by ruminants. *J. Anim. Sci.* 74:3063–3075.
- AOAC International. 1995. *Official Methods of Analysis*. Vol. 1, 16th ed. AOAC Int., Arlington, VA.
- Bargo, F., L. D. Muller, E. S. Kolver, and J. E. Delahoy. 2003. Invited review: Production and digestion of supplemented dairy cows on pasture. *J. Dairy Sci.* 86:1–42.
- Bastiman, B., and J. P. F. Van Dijk. 1975. Muck breakdown and pasture rejection in an intensive paddock system for cows. *Experimental Husbandry* 28:7–17.
- Broster, W. H., and V. J. Broster. 1984. Reviews of the progress of dairy science: Long-term effects of plane of nutrition on the production of the dairy cows. *J. Dairy Res.* 51:149–196.
- Burke, C. R., and J. R. Roche. 2007. Effects of pasture feeding during the periparturient period on postpartum anovulation in grazed dairy cows. *J. Dairy Sci.* 90:4304–4312.
- Creighton, P., E. Kennedy, L. Shalloo, T. M. Boland, and M. O'Donovan. 2011. A survey analysis of grassland dairy farming in Ireland, investigating grassland management, technology adoption and sward renewal. *Grass Forage Sci.* 66:251–264.
- Crosse, M., M. O'Donovan, T. M. Boland, L. Delaby, E. Ganche, and E. Kennedy. 2015. Using post-grazing sward height to impose dietary restrictions of varying duration in early lactation: Its effects on spring-calving dairy cow production. *Animal* 9:592–603.
- Delaby, L., P. Faverdin, G. Michel, C. Disenhaus, and J. L. Peyraud. 2009. Effect of different feeding strategies on lactation performance of Holstein and Normande dairy cows. *Animal* 3:891–905.
- Dillon, P. 1993. The use of n-alkanes as markers to determine intake, botanical composition of available or consumed herbage in studies of digesta kinetics with dairy cows. PhD Thesis. National University of Ireland, Dublin, Ireland.
- Dillon, P. 2006. Achieving high dry-matter intake from pasture with grazing dairy cows. Pages 1–26 in *Fresh Herbage for Dairy Cattle: The Key to a Sustainable Food Chain*. Vol. 18. A. Elgersma, J. Dijkstra, and S. Tamminga, ed. Springer, Dordrecht, the Netherlands.
- Dillon, P., S. Crosse, B. O'Brien, and R. W. Mayes. 2002. The effect of forage type and level of concentrate supplementation on the performance of spring-calving dairy cows in early lactation. *Grass Forage Sci.* 57:212–224.
- Dillon, P., T. Hennessy, L. Shalloo, F. Thorne, and B. Horan. 2008. Future outlook for the Irish dairy industry: A study of international competitiveness, influence of international trade reform and requirement for change. *Int. J. Dairy Technol.* 61:16–29.
- Dillon, P., J. R. Roche, L. Shalloo, and B. Horan. 2005. Optimising financial return from grazing in temperate pastures. Pages 131–147 in *Utilisation of grazed grass in temperate animal systems. Proceedings of a Satellite Workshop of the XXth International Grassland Congress*. J. J. Murphy, ed. Cork, Ireland. Wageningen Academic Publishers, Wageningen, the Netherlands.
- Dillon, P., and G. Stakelum. 1989. Herbage and dosed alkanes as a grass management technique for dairy cows. *Irish J. Agric. Food Res.* 8:104. (Abstr.)
- Edmonson, A., I. Lean, L. Weaver, T. Farver, and G. Webster. 1989. A body condition scoring chart for Holstein dairy cows. *J. Dairy Sci.* 72:68–78.
- Faverdin, P., R. Delagarde, L. Delaby, and F. Meschy. 2010. Alimentation des vaches laitières. Pages 23–58 in *Alimentation des Bovins, Ovins et Caprins*. INRA, Paris, France.
- Finneran, E., P. Crosson, P. O'Kiely, L. Shalloo, D. Forristal, and M. Wallace. 2012. Stochastic simulation of the cost of home produced feeds for ruminant livestock systems. *J. Agric. Sci. (Camb.)* 150:123–139.
- Friggans, N. C., G. C. Emmans, I. Kyriazakis, J. D. Oldham, and M. Lewis. 1998. Feed intake relative to stage of lactation for dairy cows consuming total mixed diets with a high or low ratio of concentrate to forage. *J. Dairy Sci.* 81:2228–2239.
- Ganche, E., L. Delaby, M. O'Donovan, T. Boland, and E. Kennedy. 2013. Direct and carryover effect of post-grazing sward height on total lactation dairy cow performance. *Animal* 7:1390–1400.
- Grainger, C., and G. L. Matthews. 1989. Positive relation between substitution rate and pasture allowance for cows receiving concentrates. *Aust. J. Exp. Agric.* 29:355–360.
- Greenhalgh, J. F. D., and G. W. Reid. 1969. The effect of grazing intensity on herbage consumption and animal production. III. Dairy cows grazed at two intensities on clean or contaminated pasture. *J. Agric. Sci. (Camb.)* 72:223–228.
- Hennessy, D., M. O'Donovan, P. French, and A. S. Laidlaw. 2006. Effects of date of autumn closing and timing of winter grazing on herbage production in winter and spring. *Grass Forage Sci.* 61:363–374.
- Hoogendoorn, C. J., C. W. Holmes, and A. C. P. Chu. 1992. Some effects of herbage composition, as influenced by previous grazing management, on milk production by cows grazing on ryegrass/white clover pastures. 2. Milk production in late spring/summer: Effects of grazing intensity during the preceding spring period. *Grass Forage Sci.* 47:316–325.
- Horan, B., P. Dillon, D. P. Berry, P. O'Connor, and M. Rath. 2005a. The effect of strain of Holstein-Friesian, feeding system and parity on lactation curves characteristics of spring-calving dairy cows. *Livest. Prod. Sci.* 95:231–241.
- Horan, B., P. Dillon, P. Faverdin, L. Delaby, F. Buckley, and M. Rath. 2005b. The interaction of strain of Holstein-Friesian cows and pasture-based feed systems on milk yield, body weight, and body condition score. *J. Dairy Sci.* 88:1231–1243.
- Kennedy, E., M. O'Donovan, J. P. Murphy, L. Delaby, and F. P. O'Mara. 2005. Effects of grass pasture and concentrate-based feeding systems for spring-calving dairy cows in early spring on performance during lactation. *Grass Forage Sci.* 60:310–318.

- Kennedy, E., M. O'Donovan, F. P. O'Mara, J. P. Murphy, and L. Delaby. 2007. The effect of early-lactation feeding strategy on the lactation performance of spring-calving dairy cows. *J. Dairy Sci.* 90:3060–3070.
- Kolver, E. S., and L. D. Muller. 1998. Performance and nutrient intake of high producing Holstein cows consuming pasture or a total mixed ration. *J. Dairy Sci.* 81:1403–1411.
- Kolver, E. S., J. R. Roche, M. J. de Veth, P. Thorne, and A. R. Napper. 2002. Total mixed ration versus pasture diets: Evidence of a genotype $\times$ diet interaction. *Proc. N.Z. Soc. Anim. Prod.* 62:246–251.
- Mayes, R. W., C. S. Lamb, and P. A. Colgrove. 1986. The use of dosed herbage n-alkanes as markers for the determination of herbage intake. *J. Agric. Sci. (Camb.)* 107:161–170.
- Mayne, S. 1995. Implications of genotype $\times$ nutrition interactions for efficiency of milk production systems. Pages 67–73 in *Breeding and Feeding the High Genetic Merit Dairy Cow*. T. L. Lawrence, F. J. Gordon, and A. Carson, ed. Occ. Publ. No. 19. British Society of Animal Science, Berkshire, UK.
- McCarthy, B., K. M. Pierce, L. Delaby, A. Brennan, C. Fleming, and B. Horan. 2013. The effect of stocking rate and calving date on grass production, utilization and nutritive value of the sward during the grazing season. *Grass Forage Sci.* 68:364–377.
- McEvoy, M., E. Kennedy, J. P. Murphy, T. M. Boland, L. Delaby, and M. O'Donovan. 2008. The effect of herbage allowance and concentrate supplementation on milk production performance and dry matter intake of spring-calving dairy cows in early lactation. *J. Dairy Sci.* 91:1258–1269.
- Morgan, D. J., G. Stakelum, and J. Dwyer. 1989. Modified neutral detergent cellulase digestibility procedure for use with the “fibretec” system. *Isr. J. Agric. Res.* 28:91–92.
- O'Donovan, M. 2000. The relationship between the performance of dairy cows and grassland management on intensive dairy farms in Ireland. Dublin. PhD Thesis. University College Dublin, Ireland.
- O'Donovan, M., and E. Kennedy. 2009. Pasture to profit—Using key technologies. In: *Moorepark '09: Irish dairying—New thinking for challenging times*. F. Buckley, ed. Teagasc, Moorepark, Ireland.
- O'Mara, F. 1994. A Net Energy System for Cattle and Sheep. University College Dublin, Dublin, Ireland.
- O'Neill, B. F., M. H. Deighton, B. M. O'Loughlin, F. J. Mulligan, T. M. Boland, M. O'Donovan, and E. Lewis. 2011. Effects of a perennial ryegrass diet or total mixed ration diet offered to spring-calving Holstein-Friesian dairy cows on methane emissions, dry matter intake, and milk production. *J. Dairy Sci.* 94:1941–1951.
- Roche, J. R. 2007. Milk production responses to pre- and postcalving dry matter intake in grazing dairy cows. *Livest. Sci.* 110:12–24.
- Roche, J. R., P. G. Dillon, S. Crosse, and M. Rath. 1996. The effect of closing date of pasture in autumn and turnout date in spring on sward characteristics, dry matter yield and milk production of spring-calving dairy cows. *Isr. J. Agric. Res.* 35:127–140.
- Roche, J. R., P. G. Dillon, C. R. Stockdale, L. H. Baumgard, and M. J. VanBaale. 2004. Relationships among international body condition scoring systems. *J. Dairy Sci.* 87:3076–3079.
- Roche, J. R., J. K. Kay, A. G. Rius, T. M. Grala, A. J. Sheahan, H. M. White, and C. V. C. Phyn. 2013. Short communication: Immediate and deferred milk production responses to concentrate supplements in cows grazing fresh pasture. *J. Dairy Sci.* 96:2544–2550.
- SAS Institute. 2006. User's Guide: Statistics. Version 9.1. SAS Institute Inc., Cary, NC.
- Stockdale, C. R. 1999. The nutritive characteristics of herbage consumed by grazing dairy cows affect milk yield responses obtained from supplementation with concentrates. *Aust. J. Exp. Agric.* 39:379–387.
- Stockdale, C. R. 2000. Levels of pasture substitution when concentrates are fed to grazing dairy cows in northern Victoria. *Aust. J. Exp. Agric.* 40:913–921.
- Stockdale, C. R. 2004. Effects of level of feeding of concentrates during early lactation on the yield and composition of milk from grazing dairy cows with varying body condition score at calving. *Aust. J. Exp. Agric.* 44:1–9.
- Tuñón, G., E. Kennedy, B. Horan, D. Hennessy, N. Lopez-Villalobos, P. Kemp, A. Brennan, and M. O'Donovan. 2014. Effect of grazing severity on perennial ryegrass herbage production and sward structural characteristics throughout an entire grazing season. *Grass Forage Sci.* 69:104–118.
- Urban, B., and J. P. Caudal. 1990. Herbometre automatisé (Automatic platemeter). Pages 57–59 in *Les journées de la mesure. Électronique, informatique, automatique*, Port Leucate, France. INRA, Paris, France.
- White, S. L., G. A. Benson, S. P. Washburn, and J. T. Green Jr.. 2002. Milk production and economic measures in confinement or pasture systems using seasonally calved Holstein and Jersey cows. *J. Dairy Sci.* 85:95–104.