Influence of Precalving Feed Allowance on Periparturient Metabolic and Hormonal Responses and Milk Production in Grazing Dairy Cows

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ABSTRACT

Fifty-two multiparous dairy cows were allocated to 4 treatments consuming 5.4, 8.2, 10.0, or 11.0 kg/d of pasture dry matter per cow for 27 ± 9.6 d precalving. This equated to 1.3, 1.9, 2.4, and 2.6% of body weight (BW; not including the conceptus weight). Following calving, all cows were fed ad libitum on pasture. Blood was sampled 17 d precalving, on day of calving, and on d 1, 2, 3, 4, 7, 14, 28, and 35 postcalving. Results suggest that the near-term grazing dairy cow requires 1.05 MJ of ME/kg of BW^{0.75} and that previous estimates of energy requirements were underestimated. Precalving plasma concentrations of glucose, insulin-like growth factor-1, and leptin increased quadratically with increasing pasture intake. This was associated with precalving plasma concentrations of growth hormone that declined linearly, and concentrations of nonesterified fatty acids and β -hydroxybutyrate that declined quadratically with increasing dry matter intake (DMI). Postcalving plasma concentrations of these metabolites showed no lasting effect of precalving feeding. The effect of precalving nutrition on milk production was small, and other than milk fat, was confined to wk 1 postcalving. Milk fat yield increased with increasing precalving DMI and calving body condition score until wk 3 postcalving, after which treatment effects were not evident. These results indicate that the level of feeding in grazing dairy cows during the last month before calving has only small effects on cow metabolic and hormonal status, and on milk production in the first 5 wk of lactation.

(Key words: transition cow, pasture, dry matter intake)

Abbreviation key: AST = aspartate aminotransferase, CLA = conjugated linoleic acids, DSI = Δ^9 -desaturase index, FA = fatty acid, GH = growth hormone; k_p = efficiency with which different energy sources are used

for pregnancy, ME = metabolizable energy, VA = vacenic acid.

INTRODUCTION

Even though energy requirements for pregnancy are minor compared with those for lactation, inadequate dry cow nutrition may result in a substantial drain of maternal nutrient reserves to sustain the developing fetus (Van Saun, 1991) and to meet the increasing energy demand of the mammary gland (Bell, 1995). However, the importance of DMI in the weeks preceding calving on subsequent milk production is unclear.

An increased level of feeding precalving and an associated increase in BCS at calving is generally believed to increase milk yield after calving (Ingvarsen and Andersen, 2000; Overton and Waldron, 2004). For example, Hutton and Parker (1973) fed 30 sets of identical twins to gain either 0.7 or 0 kg/cow per d during the last 4 wk of pregnancy. Higher BW gains in late gestation were associated with greater yields of milk and milk components, and lower DMI, and greater BW loss during early lactation. Similarly, Bertics et al. (1992), Grummer (1995), and Putnam et al. (1997) reported positive correlations between DMI precalving and DMI and lactation performance postcalving. Such an effect of precalving nutrition on milk production is supported by the physiological measurements of Breier et al. (1988). They reported lower concentrations of growth hormone (GH) receptor-1A in liver tissue in restricted steers, and consequently found an elevated concentration of GH and a lower concentration of IGF-I in blood. In comparison, Kobayashi et al. (1999) reported no relationship between level of feeding and hepatic concentration of GH receptor-1A. However, the duration and extent of the feed restriction investigated may have been insufficient to alter hepatic receptor levels.

Broster and Broster (1984) suggested that the effects of precalving feeding could be observed throughout lactation; however, they concluded that moderate underfeeding before calving could probably be offset by more generous feeding after calving. This is supported by recent research (Douglas et al., 1998; Holcomb et al., 2001; Agenas et al., 2003), which reported that precalving DMI appeared less important when cows were

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fed to appetite postcalving. In fact, cows that had DMI restrictions imposed precalving, generally increased DMI and milk yield postpartum at a faster rate than cows consuming the same precalving diet ad libitum.

Inconsistency in the effect of precalving DMI on milk production may be linked to changes in BCS before calving, actual BCS at calving, and level of feeding postcalving. The importance of BCS at calving on subsequent milk production is well documented (Grainger and McGowan, 1982; Ingvarsen and Andersen, 2000). However, in a recent review of literature, Stockdale (2001) concluded that the potential benefit of higher BCS at calving in pasture-based systems might be a result of level of feeding. The objective of the present study was to quantify the effect of level of feeding precalving on periparturient plasma metabolite and hormone concentrations and the subsequent milk production of dairy cows grazing pasture.

MATERIALS AND METHODS

This experiment was conducted at Lye Farm, Dexcel, Hamilton, New Zealand (37°46'S 175°18'E), during July and August 2003, and all procedures were approved by the Ruakura Animal Ethics Committee, Hamilton, New Zealand.

Experimental Design and Treatments

Fifty-two multiparous dairy cows, 27 ± 9.6 d (mean $\pm$ SD) precalving and selected to calve over a 21-d period (mean calving date of July 13, 2003), were randomly allocated to 1 of 4 dietary treatments (13 cows/treatment). Four precalving pasture allowances were offered to achieve a precalving DMI of 5.5, 8.0, 10.5, and 13.0 kg/d of DM per cow. In attempting to achieve these intakes, cows were offered 6.5 ± 0.19 , 10.1 ± 0.43 , 14.6 ± 0.86 , or 24.1 ± 2.4 kg of DM/d per cow of fresh pasture, respectively. After calving, all cows were grazed together and fed fresh pasture to appetite.

Treatments were balanced for milk production in the previous lactation (4109 ± 754 kg of milk; 200 ± 33.9 kg of milk fat; 150 ± 25.6 kg of milk protein), BW (480 ± 64 kg), BCS (3.1 ± 0.20), age (4 ± 1.2 yr), and proposed calving date.

Grazing Management

Cows were rotationally grazed similar to the method described by Roche et al. (2002). Briefly, cows had access to 35 paddocks (defined grazing area) of 1 ha/paddock, and these paddocks were grazed in rotational order. As a result, cows had access to a fresh allocation of pasture twice daily and only returned to the same area when

a minimum of 2 leaves had appeared on the majority (>66%) of perennial ryegrass (*Lolium perenne* L.) tillers.

Precalving, the 4 experimental treatment groups were grazed within the same paddock and separated by double strands of electric fence to control pasture allowances. Back grazing beyond the current day's allocation was prevented using electric fences, and the cows had access to water in their respective treatment areas. The pasture offered precalving consisted of 69% (± 10.9) perennial ryegrass leaf, 13% (± 7.3) perennial ryegrass stem, 3% (± 1.8) white clover (*Trifolium repens*), 0.2% (± 0.4) weeds and other grasses (*Dactylus glomerata*, *Holcus lanatus*, and some *Poa* species), and 14% (± 5.1) dead material on a DM basis.

As cows were grazed within the same paddock, pregrazing pasture height and mass did not differ between treatments. Average pregrazing pasture height was 9.8 ± 2.0 cm (9.4 ± 2.2 , 9.6 ± 2.1 , 9.9 ± 2.0 , and 10.6 ± 1.5 cm for 5.5, 8.0, 10.5, and 13.0 kg of DMI groups, respectively). Pregrazing pasture mass averaged 3808 ± 648 kg of DM/ha (3683 ± 695 , 3725 ± 685 , 3832 ± 646 , and 4043 ± 477 kg of DM for 5.5, 8.0, 10.5, and 13.0 kg of DMI groups, respectively).

To achieve different pasture allowances, and hence intakes, different sized areas were allotted to each treatment group, with area/group declining as cows calved and were removed from the treatment area. Area allocation (m^2/cow) was calculated by multiplying pregrazing pasture mass per m^2 by the desired allowance per cow. Daily group allocation was then calculated by multiplying the area allocation by the number of cows remaining in the precalving group. Precalving grazing areas averaged $16.5 (\pm 2.07)$, $25.8 (\pm 3.55)$, $37.3 (\pm 5.76)$, and $59.6 (\pm 10.93)$ m^2/d per cow for 5.5, 8.0, 10.5, and 13.0 kg of DMI groups, respectively.

Postcalving, cows from all 4 treatments were grazed together as a single herd and were fed fresh pasture to appetite. As cows were grazed within the same paddock, pregrazing pasture height and mass did not differ between treatments. Average pregrazing pasture height and mass were 9.8 ± 2.0 cm and 3808 ± 648 kg of DM/ha, respectively. The sward consisted of 81% (± 19.7) perennial ryegrass leaf, 4% (± 5.5) perennial ryegrass stem, 3% (± 1.8) white clover (*Trifolium repens*), 3% (± 7.8) weeds and other grasses (*Dactylus glomerata*, *Holcus lanatus*, and some *Poa* species), and 8% (± 4.3) dead material on a DM basis. The nutritive characteristics and mineral concentrations of the pasture offered pre- and postcalving are presented in Table 1.

Pasture Measurements

Compressed pasture height was measured pre- and postgrazing using a Rising Plate Meter installed with

Table 1. Mean ($\pm$ SD) nutrient (% of DM), metabolizable energy (ME; MJ/kg of DM), macro- (% of DM) and trace-mineral (mg/kg) composition, and dietary cation-anion difference (DCAD; meq/100 g of DM) of pasture offered to dairy cows pre- and postcalving.

	Pecalving		Postcalving	
	Mean	SD	Mean	SD
CP	19.2	2.3	25.3	3.7
NDF	43.6	2.1	36.1	1.8
ADF	23.9	1.5	18.2	1.4
Lipid	3.6	0.2	4.1	0.2
Soluble sugars	9.2	1.3	11.6	0.7
ME	10.3	0.39	11.6	0.26
Ash	10.3	0.3	9.9	0.2
Na	0.28	0.01	0.19	0.06
K	3.13	0.42	3.47	0.26
Cl	1.30	0.30	1.10	0.10
S	0.34	0.03	0.39	0.04
Ca	0.98	0.13	0.65	0.04
Mg	0.17	0.03	0.18	0.03
P	0.36	0.02	0.39	0.05
DCAD	34	2	42	7
Cu	7	1.4	7	1.6
Co	0.14	0.04	0.06	0.01
Se	0.04	0.01	0.11	0.09
I	0.25	0.06	0.3	0.11
Zn	36	1.0	38	4.0
Fe	203	38.5	126	17.8
Mn	78	6.7	64	3.0

an electronic counter (Farmworks, Palmerston North, New Zealand). On 3 d each week precalving, pre- and postgrazing pasture mass was calculated by cutting and drying samples representative of available and residual DM. Briefly, pasture samples ($n = 10$) from each treatment group were cut to ground level within rectangular quadrants (0.125 m^2) placed randomly within pasture allocations to be grazed the following day, and for residual DM, those grazed during the previous 24 h. Pasture samples were washed to remove soil contamination and dried at 100°C to constant weight (approximately 72 h). Resultant DM yields ($\text{g}/0.125 \text{ m}^2$) were multiplied by 80,000 to give DM yield/ha pre- and postgrazing. Compressed pasture heights were measured inside each 0.25-m^2 quadrant before cutting. These data were used to develop a regression equation relating pasture height to pasture mass:

$$\text{Pasture mass} = 156.7 \times \text{pasture height} + 945.4; r^2 = 0.69; n = 315.$$

Precalving, 200 pasture height measurements were made in pastures to be grazed, the pasture mass estimated, and this figure used to allocate desired grazing area. Each day before grazing, 100 pasture height measurements were made in each treatment area to ensure pasture allocation was correct.

Representative samples of pasture were collected daily by “plucking” pasture to grazing height from pad-

docks due to be grazed. Samples were bulked on a 2-wk basis, and duplicate samples were dried at 100°C for DM analysis, or 60°C for analysis of nutrient composition. All samples were dried at 60°C for 48 h, ground to pass through a 1.0-mm sieve (Christy Laboratory Mill, Suffolk, UK) and analyzed for CP, NDF, ADF, soluble sugars, fat, ash, and OM digestibility by near infrared spectroscopy (Corson et al., 1999) and for minerals by inductively coupled plasma emission spectroscopy. Pasture chlorine was measured using potentiometric titration following 2% nitric acid extraction. The metabolizable energy (ME) was derived directly from predicted OM digestibility, based on an in vitro cellulase digestibility assay (Roughan and Hollan, 1977; Dowman and Collins 1982), which was calibrated against in vivo standards (Corson et al., 1999).

Animal Measurements

DMI. Mean precalving group DMI was calculated as the product of the difference between the pre- and postgrazing pasture mass and area grazed, as outlined by Roche et al. (1996).

Mean postcalving energy intake was calculated from mean daily milk energy output during wk 3 to 5 postcalving plus cow maintenance requirements, and minus the contribution from true BW loss, assuming energy for milk production (k_m) was used with 65% efficiency, energy from BW mobilization (k_g) was used with 80% efficiency, and the maintenance requirements for lactating grazing dairy cows was $0.6 \text{ MJ/kg BW}^{0.75}$ (Holmes et al., 2002). Energy intake was divided by the mean pasture ME concentration to calculate DMI:

$$\text{DMI (kg of DM/d)} =$$

$$\frac{\text{Milk energy} + \text{Maintenance energy} - \text{true BW loss}}{\text{Pasture energy concentration}}$$

Because tissue mobilization in early lactation occurs concurrently with increasing feed intake, decreases in BW can be masked by enhanced gut fill, such that BW changes do not reflect actual changes in adipose and lean tissue weight (NRC, 2001). Therefore, true BW loss in this study was calculated from changes in BCS, assuming 1 BCS unit (1 to 10 scale; MacDonald and Roche, 2004) for Friesian-Jersey crossbred cows = 32.5 kg (calculated from Holmes et al., 2002).

Milk and BW. Individual milk yields were recorded daily (Westfalia Surge, Oelde, Germany). Fat, CP, and lactose concentrations of milk were determined by Milkoscan (Foss Electric, Hillerød, Denmark) on individual p.m. and a.m. aliquot samples collected on 2 d each week for the first 5 wk of lactation. Milk component data were verified by reference techniques for a subset

of milk samples (milk fat, Röse-Gottlieb; IDF, 1987; CP-Kjeldahl techniques; Barbano et al., 1991). Precalving, BW and BCS were determined every other week at approximately 0900 h. After calving, BW and BCS were determined weekly following the a.m. milking. Body condition score was assessed pre- and postcalving on a 10-point scale, where 1 = emaciated and 10 = obese (Macdonald and Roche, 2004). These scores were then converted to the 5-point scale of Wildman et al. (1982) using the regression equation generated by Roche et al. (2004; USA = $1.5 + 0.32 \text{ NZ}$). Calving BW and calf birth weight were recorded within 18 h of calving.

Milk fat. During wk 1 and 3 of the experimental period, milk fat was extracted from the fresh milk samples using the Röse-Gottlieb fat extraction procedure (IDF, 1987) and stored at -20°C until analysis for fatty acid (FA) composition.

Fatty acid methyl esters were prepared by the transmethylation procedure described by Christie (1982) with modifications (Chouinard et al., 1999) and quantified using a gas chromatograph (Hewlett Packard GC system 6890; Wilmington, DE) equipped with a flame ionization detector and a CP-7489 fused silica capillary column ($100 \text{ m} \times 0.25 \text{ mm i.d.}$ with $0.2 \mu\text{m}$ film thickness; Varian, Walnut Creek, CA). Initial oven temperature (50°C) was held for 1 min then increased at $5^{\circ}\text{C}/\text{min}$ to 160°C , where it was held for 42 min, and then increased at $5^{\circ}\text{C}/\text{min}$ to 190°C and maintained for 22 min. Inlet and detector temperatures were maintained at 250°C and the split ratio was 100:1. Hydrogen carrier gas flow rate through the column was $1 \text{ mL}/\text{min}$. Hydrogen flow to the detector was $30 \text{ mL}/\text{min}$, airflow was $400 \text{ mL}/\text{min}$, and the nitrogen make-up gas flow was $25 \text{ mL}/\text{min}$. Peaks in the chromatogram were identified and quantified using pure methyl ester standards (GLC60; Nuchek Prep, Elysian, MN; Matreya, Inc., Pleasant Gap, PA, anhydrous milk fat; R. T. Corp., Laramie, WY) and the conjugated linoleic acid (CLA) profile identified as previously described (Roach et al., 2002). A butter oil reference standard (anhydrous milk fat; R. T. Corp.) was used to determine recoveries and correction factors for individual FA (Baumgard et al., 2000).

Blood. One evacuated blood tube containing a sodium heparin pellet (100 IU of sodium heparin/mL of blood) to prevent coagulation was collected from each cow by coccygeal venipuncture before treatment allocation and on d 18 ± 9.6 precalving (d 9 of treatment), day of calving, and d 1, 2, 3, 4, 7, 14, 28, and 35 postcalving. Plasma was harvested ($1120 \times g$, 10 min, 4°C) and analyzed for NEFA, BHBA, glucose, aspartate aminotransferase (AST), urea, GH, IGF-I, leptin, insulin, Ca, and Mg. Nonesterified fatty acids (colorimetric method), BHBA (BHBA dehydrogenase assay), glucose (hexaki-

nase method), AST (IFCC UV test), urea (urease method), Ca (o-Cresolphthalein complexone), and Mg (xylylidyl blue reaction) analyses were performed on a Hitachi 717 analyzer (Roche, Basel, Switzerland) at 30°C by Alpha Scientific Ltd., Hamilton, New Zealand. The inter- and intraassay CV was $<2\%$ for all assays. Growth hormone (Downing et al., 1995), IGF-I (Gluckman et al., 1983), insulin (Hales and Randle, 1963), and leptin (Blache et al., 2000) were measured in duplicate by double-antibody radioimmunoassay with an inter- and intraassay CV $<6\%$.

Calculations

Cow BW refers to cow BW measured at the beginning of the study, less the conceptus weight, where conceptus weight = $\{18 + [(\text{days pregnant} - 190) \times 0.665] \times \text{calf birth weight}/45\}$ (NRC, 2001). Days pregnant was calculated from calving date (assuming calving was d 279 of gestation).

Precalving energy requirements (MJ/d) were calculated as the sum of the requirements for maintenance and pregnancy. Maintenance of dry pregnant grazing dairy cows was assumed to be $0.55 \text{ MJ}/\text{kg BW}^{0.75}$ (Holmes et al., 2002) and 0.45 MJ of ME/kg $\text{BW}^{0.75}$ (NRC, 2001), assuming 75% efficiency of use of ME for maintenance. An additional energy requirement for grazing of $0.002 \times \text{BW}$ (MJ of ME; NRC, 2001) was added to the maintenance requirement of NRC (2001).

The energy requirements of pregnancy (MJ/d) were calculated as:

$$42.9 \times \text{CBW}/40 \text{ (Holmes et al., 2002) or} \\ 4.186 \times [(0.00318 \times t - 0.0352) \\ \times (\text{CBW}/45)]/0.218 \text{ (NRC, 2001)}$$

where t = day of gestation and CBW = calf birth weight. Gestation length was assumed 279 d.

A Δ^9 -desaturase index (DSI), which acts as a proxy for Δ^9 -desaturase activity or expression, was calculated using the 4 FA pairs that represent product and substrates for Δ^9 -desaturase (*cis*-9 14:1/14:0, *cis*-9 16:1/16:0, *cis*-9 18:1/18:0, and *cis*-9, *trans*-11 CLA/ vaccenic acid (VA); Roche et al., 2005). The equation used was:

$$\frac{([\text{cis-9 14:1}] + [\text{cis-9 16:1}] \\ + [\text{cis-9 18:1}] + [\text{cis-9, trans11 CLA}])}{([\text{cis-9 14:1} + 14:0] + [\text{cis-9 16:1} + 16:0] \\ + [\text{cis-9 18:1} + 18:0] + [\text{cis-9, trans-11 CLA} + \text{VA}])}$$

Statistical Analyses

All data pertaining to animal measurements were analyzed using cows as the experimental unit and mea-

Table 2. Pretreatment BW and BCS, and daily DM and energy intake,¹ and BW and BCS change pre- and postcalving in dairy cows consuming either 1.3, 1.9, 2.4, or 2.6 DMI (% BW) of fresh pasture for 27 ± 9.6 d precalving and offered pasture to appetite postcalving.

Variable	Time, ² wk	Precalving DMI				SED ³	P		
		1.3	1.9	2.4	2.6		DMI	Linear	Quadratic
Pretreatment BW, kg		498	480	509	485	17.6	0.55	0.83	0.57
Pretreatment BCS		3.2	3.2	3.0	3.2	0.12	0.44	0.45	0.82
BW change, kg/d	-3 to -1	-1.2	-0.1	0.5	0.9	0.35	<0.001	<0.001	0.31
	0 to 5	-1.0	-1.3	-1.6	-2.0	0.25	<0.01	<0.001	0.99
BCS change, unit/wk	-3 to -1	-0.05	-0.04	0.04	0.06	0.035	<0.01	<0.001	0.87
	0 to 5	-0.07	-0.07	-0.10	-0.11	0.022	0.29	0.08	0.85
DMI, kg/d	-3 to 0	5.4	8.2	10.0	11.0	0.28	<0.001	<0.001	<0.001
	3 to 5	13.0	13.4	12.0	11.5	0.66	0.38	0.14	0.56
DMI, %BW	-3 to -1	1.3	1.9	2.4	2.6	0.08	<0.001	<0.001	<0.01
	3 to 5	3.1	3.1	2.8	2.6	0.25	0.24	0.06	0.59
Energy intake, MJ/d	-3 to -1	56	84	103	113	3.0	<0.001	<0.001	<0.001
	3 to 5	148	153	137	131	13.8	0.37	0.14	0.54
Milk, kg/d	1	15.3	17.4	16.7	18.5	1.15	0.07	<0.05	0.88
	2 to 5	20.6	21.8	20.0	21.6	0.95	0.18	0.72	0.81
FCM, kg/d	1	17.8	20.6	20.1	21.6	1.34	0.06	<0.05	0.49
	2 to 5	22.7	24.0	23.1	24.5	1.01	0.25	0.17	0.96
NE _L , MJ/d	1	58.4	69.0	65.1	70.3	4.31	<0.05	<0.05	0.39
	2 to 5	71.2	75.4	71.3	76.4	3.02	0.20	0.26	0.83
Fat, %	1	5.12	5.34	5.28	5.13	0.222	0.69	0.94	0.25
	2 to 5	4.67	4.82	4.95	5.01	0.116	<0.05	<0.01	0.61
Fat, kg/d	1	0.78	0.92	0.8	0.95	0.065	0.07	<0.05	0.41
	2 to 5	0.96	1.03	0.99	1.07	0.043	0.10	<0.05	0.93
Protein, %	1	4.47	4.79	4.66	4.49	0.162	0.17	0.89	<0.05
	2 to 5	3.55	3.57	3.56	3.53	0.065	0.94	0.78	0.57
Protein, kg/d	1	0.69	0.83	0.78	0.83	0.060	0.11	0.07	0.32
	2 to 5	0.73	0.77	0.72	0.76	0.032	0.31	0.81	0.81
Lactose, %	1	4.77	5.25	4.68	4.80	0.420	0.51	0.68	0.54
	2 to 5	4.97	4.95	4.94	4.98	0.052	0.89	0.98	0.48
Lactose, kg/d	1	0.73	0.86	0.78	0.88	0.053	<0.05	<0.05	0.77
	2 to 5	1.02	1.08	0.99	1.07	0.049	0.17	0.76	0.68

¹Precalving group DMI was calculated as the product of the difference between the pre- and postgrazing pasture mass and area grazed. Postcalving energy intake was calculated from daily milk energy output during wk 3 to 5 postcalving plus cow maintenance requirements, and minus the contribution from true BW loss.

²Week relative to calving.

³Standard error of the difference.

surements related to pasture mass were analyzed using daily grazing area as the experimental unit, as described by Roche et al. (2002).

For each cow, milk production measurements were averaged weekly (Everitt, 1995). Log₁₀ transformations were performed on SCS, AST, NEFA, BHBA, GH, IGF-I, leptin, and insulin data to stabilize the variance before statistical analysis. This had no effect on the statistical significance, and so untransformed data are presented.

Data were analyzed using REML, with cows as a random effect and linear and quadratic effects of precalving DMI as fixed effects. All data were analyzed using the statistical procedures in Genstat 5.4.1 (Genstat V, 1997). Pre-experimental measurements were used as a covariate where significant. A probability of < 0.05 was used to determine statistical significance unless otherwise noted.

RESULTS

Precalving DMI and energy intake increased quadratically with increasing pasture allowance (Table 2). On average, cows consumed 5.4, 8.2, 10.0, and 11.0 kg/d of DM precalving, or 1.3, 1.9, 2.4, and 2.6% of precalving BW (minus the conceptus weight). These equated to 56, 84, 103, and 112 MJ/d of ME per cow, respectively.

Postgrazing residual pasture height (2.4 ± 0.5 , 2.8 ± 0.5 , 3.7 ± 0.6 , and 4.2 ± 0.7 cm for 1.3, 1.9, 2.4, and 2.6% BW DMI groups, respectively) and mass (1439 ± 170 , 1561 ± 167 , 1843 ± 180 , and 2022 ± 220 kg of DM for 1.3, 1.9, 2.4, and 2.6% BW DMI groups, respectively) increased ($P < 0.001$) linearly with pregrazing pasture allowance, precalving.

Cows on the 2 lowest feed allowances lost BW and BCS during the final 3 wk precalving, and cows on the 2 highest feed allowances gained BW and BCS (Table

Figure 1. Postcalving change in BW in cows consuming a DMI of either 1.3 (◆), 1.9 (●), 2.4 (▲), or 2.6 (■) % BW of fresh pasture for 27 ± 9.6 d precalving and offered pasture to appetite postcalving (standard error of the difference is represented by the vertical bar).

2). As a result, BW and BCS at calving were positively ($P < 0.001$) associated with precalving level of feeding (424, 441, 458, and 468 kg of BW and 3.0, 3.1, 3.2, and 3.3 BCS units for 1.3, 1.9, 2.4, and 2.6% BW precalving DMI groups, respectively).

Average calculated DMI (% BW) during wk 3 to 5 postcalving tended ($P = 0.06$) to be negatively associated with precalving feed allocation (Table 2). The yields of milk, protein, and lactose were positively associated with precalving level of feeding during wk 1, but were not affected in subsequent weeks. Milk fat yield increased linearly with increasing precalving DMI during wk 1, 2, and 3 of lactation, and milk fat content was positively associated with precalving DMI for the first 5 wk postcalving.

Calf birth weight was not affected (linear contrast $P = 0.90$) by precalving level of feeding. Calves averaged 33.5, 36.4, 35.8, and 34.0 kg at birth for 1.3, 1.9, 2.4, and 2.6% BW DMI groups, respectively.

Changes in BW and BCS postcalving were inversely related to precalving DMI (Table 2), with cows consuming a DMI of 2.6% BW precalving losing 30 kg of BW and 0.16 BCS units more during the first 5 wk of lactation compared with cows with a DMI of 1.3% BW precalving. Most of this difference in BW loss (17.3 kg) occurred during the first week after calving (Figure 1).

There was very little effect of precalving DMI on DSI or milk FA content or origin during wk 1 and 3 postcalving, but the concentration of linolenic (18:3) and oleic

acids (*cis*-9 18:1) increased linearly with increasing precalving DMI on wk 1 and 3, respectively (Table 3).

The effects of precalving DMI on plasma metabolite concentrations are shown in Table 4 and 5. As DMI declined precalving (d -17), the concentration of NEFA and BHBA in plasma increased quadratically (Table 4). Plasma NEFA concentrations were increased further on day of calving and there was a negative linear relationship with precalving DM and energy intake. Following calving, there was no effect of precalving feeding level on plasma NEFA or BHBA concentrations.

There was no effect of precalving treatment on plasma AST concentrations throughout the measurement period (Table 4), although AST concentrations on the day of calving tended ($P < 0.10$) to decrease linearly with increasing DMI precalving. There was a positive linear association between plasma urea concentrations precalving and DMI.

The concentration of glucose in plasma increased quadratically precalving with increasing DMI, and there was a corresponding trend ($P = 0.11$) for insulin to increase linearly (Table 5). Precalving nutrition did not affect either of these metabolites following calving.

Precalving, plasma GH concentrations increased linearly and IGF-I concentrations declined quadratically with decreasing energy intake (Table 5). At calving and during the colostrum period, plasma concentrations of GH were negatively associated (quadratically) with precalving level of feeding, with cows consuming a DMI of

Table 3. Milk fatty acid profile (g/100 g) of dairy cows in early lactation that consumed 1.3, 1.9, 2.4, or 2.6 DMI (% BW) of fresh pasture for 27 ± 9.6 d precalving and were offered pasture to appetite postcalving.

Variable ²	Precalving DMI				SED ¹	<i>P</i>		
	1.3	1.9	2.4	2.6		DMI	Linear	Quadratic
Wk 1								
4:0 to 15:1	25.7	27.0	22.1	27.1	1.86	<0.05	0.89	0.17
16:0 to 16:1	28.1	28.7	30.6	28.0	0.80	<0.01	0.56	<0.01
17:0 to 20:0	46.2	44.3	47.3	44.9	2.34	0.58	0.93	0.91
Saturates	60.0	58.8	59.0	61.7	1.77	0.37	0.37	0.13
MUFA	31.8	31.3	31.0	30.7	1.87	0.95	0.55	0.96
PUFA	2.7	3.0	3.0	3.0	0.17	0.21	0.10	0.27
<i>trans</i> -10 18:1	0.25	0.30	0.20	0.30	0.023	<0.001	0.68	0.13
<i>trans</i> -11 18:1 ³	3.3	3.9	2.4	2.9	0.45	<0.05	0.08	0.81
<i>cis</i> -9 18:1 ⁴	25.4	24.0	25.9	24.4	1.83	0.69	0.87	0.97
CLA	0.75	1.03	0.64	0.79	0.124	<0.05	0.45	0.50
18:2 ⁵	0.97	0.98	1.17	1.02	0.064	<0.05	0.09	0.10
18:3 ⁶	0.91	0.91	1.03	1.06	0.071	0.08	<0.05	0.69
DSI	0.04	0.04	0.04	0.04	0.002	0.96	0.60	0.96
Wk 3								
4:0 to 15:1	26.2	29.9	22.7	25.9	1.22	<0.001	<0.05	0.69
16:0 to 16:1	29.2	28.6	31.0	27.3	0.83	<0.001	0.24	<0.05
17:0 to 20:0	44.6	41.5	46.3	46.8	1.58	<0.01	<0.05	0.10
Saturates	60.0	61.0	58.7	60.1	1.37	0.42	0.60	0.86
MUFA	30.7	29.0	30.9	32.9	1.38	<0.05	0.06	0.06
PUFA	2.8	3.2	3.2	2.8	0.24	0.15	0.96	<0.05
<i>trans</i> -10 18:1	0.32	0.32	0.23	0.28	0.032	<0.05	<0.05	0.41
<i>trans</i> -11 18:1 ³	3.1	3.7	2.6	3.3	0.40	0.07	0.59	0.96
<i>cis</i> -9 18:1 ⁴	24.2	21.7	25.3	26.2	1.36	<0.01	<0.05	0.08
CLA	0.75	1.00	0.74	0.86	0.125	0.14	0.97	0.47
18:2 ⁵	0.99	1.19	1.18	0.94	0.166	0.34	0.77	0.07
18:3 ⁶	0.92	0.94	1.10	0.90	0.068	<0.05	0.58	<0.05
DSI	0.04	0.03	0.04	0.04	0.002	0.16	0.15	0.17

¹Standard error of the difference.²MUFA = Monounsaturated fatty acids; PUFA = polyunsaturated fatty acids; CLA = *cis*-9, *trans*-11 conjugated linoleic acid; DSI = Δ^9 -desaturase index.³Vaccenic acid.⁴Oleic acid.⁵Linoleic acid.⁶Linolenic acid.

1.3% BW precalving displaying elevated levels compared with the other 3 treatments, which did not differ from each other. In comparison, precalving feeding level did not appear to have a consistent effect on postcalving plasma IGF-I concentrations, although concentrations were positively associated with precalving DMI on d 2 and 3 postcalving.

Concentrations of leptin in blood declined linearly with decreasing precalving DMI before calving, although the data suggests that the decline may have been curvilinear ($P = 0.10$). Precalving level of feeding did not affect blood leptin concentrations postcalving.

Precalving, plasma Mg concentrations increased linearly ($P < 0.001$) with increasing DMI, and this difference ($P < 0.05$) remained until the day following calving, after which precalving level of feeding did not influence plasma Mg status (Table 6). Plasma Ca concentration precalving was not affected by the level of feeding, however there was a trend ($P < 0.10$), on the day of calving,

for plasma Ca concentration to decline as precalving DMI increased. No further effect of precalving level of feeding on plasma Ca status was evident.

DISCUSSION

Although the importance of BCS at calving has been well documented (Stockdale, 2001), little has been reported regarding the energy requirements of “close-up” grazing dairy cows, or the implications of feeding more or less than these requirements in grazing dairy systems. The current study established the effect of precalving level of feeding on periparturient physiology measures and postcalving milk production, and allowed an estimate to be made of the energy requirements of grazing dairy cows during the month before calving.

Calculated requirements from NRC (2001) and Holmes et al. (2002) are compared because NRC (2001) is the nutrient requirement standard most accepted

Table 4. Periparturient plasma concentration (mmol/L) of NEFA, BHBA, aspartate aminotransferase (AST), and urea in cows consuming 1.3, 1.9, 2.4, or 2.6 DMI (% BW) of fresh pasture for 27 ± 9.6 d precalving and offered pasture to appetite postcalving.

Precalving DMI	Day relative to calving									
	-17	0	1	2	3	4	7	14	28	35
NEFA										
1.3	0.90	0.70	0.53	0.62	0.65	0.70	0.77	0.71	0.86	0.60
1.9	0.45	0.76	0.48	0.57	0.72	0.74	0.95	0.74	0.85	0.55
2.4	0.23	0.42	0.68	0.82	0.86	1.06	1.10	0.92	0.85	0.71
2.6	0.24	0.42	0.62	0.73	0.74	0.76	0.92	0.79	0.91	0.67
SED ¹	0.087	0.136	0.167	0.145	0.143	0.127	0.150	0.192	0.182	0.116
<i>P</i> (DMI)	<0.001	<0.05	0.70	0.45	0.61	<0.05	0.29	0.75	0.98	0.48
<i>P</i> (Linear)	<0.001	<0.05	0.42	0.26	0.38	0.25	0.28	0.49	0.79	0.34
<i>P</i> (Quadratic)	<0.001	0.76	0.96	0.86	0.42	0.09	0.14	0.59	0.78	0.98
BHBA										
1.3	0.71	0.50	0.46	0.50	0.54	0.56	0.71	0.55	0.64	0.57
1.9	0.40	0.56	0.53	0.47	0.46	0.52	0.60	0.46	0.86	0.40
2.4	0.40	0.47	0.51	0.60	0.65	0.61	0.83	0.72	0.99	0.70
2.6	0.38	0.44	0.51	0.58	0.56	0.54	0.68	0.63	1.11	0.80
SED ¹	0.069	0.119	0.080	0.064	0.068	0.067	0.161	0.266	0.446	0.368
<i>P</i> (DMI)	<0.001	0.19	0.91	0.09	0.06	0.55	0.63	0.23	0.69	0.22
<i>P</i> (Linear)	<0.001	0.09	0.68	0.07	0.33	0.87	0.79	0.20	0.24	0.14
<i>P</i> (Quadratic)	<0.001	0.38	0.63	0.88	0.96	0.80	0.88	0.93	0.91	0.32
AST										
1.3	36.9	62.5	65.5	69.1	69.7	65.9	69.8	62.1	84.1	86.6
1.9	34.8	54.4	62.0	59.7	59.0	61.2	60.9	56.7	68.4	67.9
2.4	34.0	47.4	57.8	54.0	44.6	49.0	53.8	60.9	76.1	73.6
2.6	36.7	50.0	54.3	68.2	87.0	79.9	79.5	62.9	64.5	68.1
SED ¹	3.86	5.63	8.47	12.60	22.52	17.99	18.60	14.79	21.65	11.30
<i>P</i> (DMI)	0.90	0.18	0.59	0.63	0.48	0.54	0.68	0.73	0.60	0.37
<i>P</i> (Linear)	0.94	0.07	0.17	0.75	0.77	0.72	0.81	0.49	0.29	0.16
<i>P</i> (Quadratic)	0.45	0.22	0.99	0.25	0.18	0.25	0.28	0.62	0.84	0.44
Urea										
1.3	5.8	7.3	6.8	6.2	6.3	6.3	5.8	5.5	6.8	7.5
1.9	6.2	6.5	6.3	5.2	5.4	5.5	5.5	5.8	7.4	7.1
2.4	6.1	7.4	6.3	6.1	6.1	6.3	5.6	5.4	6.8	8.2
2.6	6.7	7.0	6.3	6.0	5.6	5.9	5.4	5.3	6.5	8.0
SED ¹	0.26	0.49	0.56	0.41	0.44	0.46	0.54	0.64	0.72	0.50
<i>P</i> (DMI)	<0.01	0.35	0.72	0.08	0.24	0.33	0.95	0.84	0.68	0.14
<i>P</i> (Linear)	<0.001	0.94	0.40	0.84	0.32	0.73	0.56	0.66	0.50	0.12
<i>P</i> (Quadratic)	0.61	0.67	0.48	0.12	0.52	0.57	0.98	0.63	0.39	0.87

¹Standard error of the difference.

for dairy cows in TMR-fed systems, whereas nutrient recommendations from Holmes et al. (2002) are primarily used for pasture-based dairy systems. Calculated ME requirements in this experiment based on NRC (2001) and Holmes et al. (2002) were 67 ± 1.6 and 90 ± 1.2 MJ/d of ME per cow, respectively. Therefore, cows consumed 88, 125, 157, and 175% (NRC, 2001) or 65, 92, 116, and 130% (Holmes et al., 2002) of calculated ME requirements during the final 4 wk of gestation. The requirements of cows in the current study were significantly greater than those estimated by NRC (2001), and marginally higher than those estimated by Holmes et al. (2002) for pasture-fed dairy cows. Regressing precalving BW change with energy intake precalving ($\text{BW change} = 0.036 \text{ Energy Intake} - 3.16$; $R^2 = 0.99$) and assuming 0.51 kg/d per cow as the BW gain requirement to account for fetal and placental growth

(NRC, 2001), dairy cow requirements to maintain pregnancy without gain or loss of maternal body tissue were 102 MJ of ME or 1.05 MJ of ME/kg BW^{0.75}. This suggests that recommendations on the ME requirements of grazing dairy cows during the final month of gestation require upward revisions of approximately 50 and 13% for NRC (2001) and Holmes et al. (2002), respectively.

The reason for the difference between measured requirements in the current study and proposed requirements by Holmes et al. (2002) is unclear, but may be due to an underestimation of maintenance, activity, or pregnancy requirements.

Of more concern however, is the large difference between requirements recommended by NRC (2001) and those of Holmes et al. (2002). The reasons for this are not apparent. The difference in the proposed maintenance and grazing activity requirements is small ($47 \pm$

Table 5. Periparturient plasma concentration glucose (mmol/L), insulin (ng/mL), growth hormone (ng/mL), IGF-1 (ng/mL), and leptin (ng/mL) in cows consuming 1.3, 1.9, 2.4, or 2.6 DMI (% BW) of fresh pasture for 27 ± 9.6 d precalving and offered pasture to appetite postcalving.

Precalving DMI	Day relative to calving									
	-17	0	1	2	3	4	7	14	28	35
Glucose										
1.3	3.20	3.99	3.37	3.40	3.24	3.19	3.13	3.10	3.15	3.59
1.9	3.38	4.05	3.40	3.55	3.25	3.22	3.14	3.16	3.40	3.60
2.4	3.53	3.75	3.45	3.62	3.27	3.26	3.25	3.36	3.28	3.50
2.6	3.53	4.15	3.52	3.58	3.36	3.29	3.17	3.20	3.11	3.44
SED ¹	0.075	0.292	0.127	0.157	0.115	0.126	0.161	0.187	0.201	0.172
<i>P</i> (DMI)	<0.001	0.53	0.70	0.60	0.75	0.81	0.88	0.43	0.19	0.68
<i>P</i> (Linear)	<0.001	0.87	0.25	0.24	0.34	0.35	0.62	0.30	0.57	0.24
<i>P</i> (Quadratic)	<0.05	0.34	0.83	0.54	0.59	0.87	0.80	0.43	0.05	0.82
Insulin										
1.3	0.25	0.62	0.35	0.27	0.24	0.24	0.17	0.19	0.18	0.22
1.9	0.38	0.59	0.31	0.40	0.28	0.29	0.18	0.20	0.21	0.27
2.4	0.31	0.51	0.35	0.35	0.27	0.18	0.24	0.20	0.20	0.22
2.6	0.37	0.53	0.28	0.38	0.34	0.21	0.20	0.19	0.18	0.23
SED ¹	0.056	0.127	0.110	0.092	0.084	0.050	0.052	0.051	0.046	0.045
<i>P</i> (DMI)	0.09	0.86	0.73	0.62	0.62	0.20	0.47	1.00	0.87	0.56
<i>P</i> (Linear)	0.11	0.43	0.51	0.45	0.26	0.23	0.26	0.98	0.91	0.77
<i>P</i> (Quadratic)	0.41	0.84	0.82	0.46	0.88	0.71	0.54	0.91	0.44	0.49
Growth hormone										
1.3	6.03	34.32	24.68	22.41	17.09	13.32	8.53	6.10	5.93	7.85
1.9	4.03	11.39	12.57	9.92	6.54	6.26	5.57	5.78	5.49	6.97
2.4	3.94	11.72	12.09	9.22	7.32	4.12	6.31	4.02	7.18	6.58
2.6	3.81	14.15	9.11	10.24	9.46	6.35	6.90	5.76	6.33	7.04
SED ¹	0.892	4.250	4.312	3.351	3.221	2.489	2.246	1.503	2.149	2.583
<i>P</i> (DMI)	<0.05	<0.001	<0.001	<0.001	<0.01	<0.001	0.57	0.49	0.62	0.85
<i>P</i> (Linear)	<0.05	<0.001	<0.001	<0.001	<0.05	<0.01	0.49	0.49	0.44	0.44
<i>P</i> (Quadratic)	0.27	<0.001	0.14	<0.01	0.01	0.01	0.29	0.37	0.94	0.67
IGF-1										
1.3	10.92	5.27	7.02	6.49	5.31	7.46	7.48	6.38	6.61	6.89
1.9	15.55	5.50	6.72	6.78	6.47	4.91	6.64	6.41	7.04	8.41
2.4	20.04	5.92	6.44	9.81	7.10	6.00	8.56	6.38	6.78	7.91
2.6	16.95	5.35	8.72	8.75	8.56	7.66	8.43	7.38	7.78	8.00
SED ¹	2.381	1.199	1.472	1.682	1.224	1.075	1.209	1.020	1.271	1.239
<i>P</i> (DMI)	<0.01	0.93	0.43	0.12	0.10	<0.05	0.47	0.75	0.69	0.71
<i>P</i> (Linear)	<0.001	0.85	0.32	0.06	<0.05	0.61	0.26	0.42	0.36	0.49
<i>P</i> (Quadratic)	<0.001	0.61	0.24	0.53	0.78	<0.01	0.78	0.50	0.86	0.47
Leptin										
1.3	0.91	1.02	1.13	1.12	1.01	0.99	0.86	0.75	0.76	0.88
1.9	1.10	0.86	1.21	1.07	0.94	0.87	0.71	0.63	0.78	0.81
2.4	1.51	1.05	1.18	1.21	1.00	0.95	0.88	0.91	0.85	0.83
2.6	1.37	1.00	1.06	1.11	0.99	0.93	0.83	0.74	0.77	0.73
SED ¹	0.118	0.108	0.116	0.133	0.095	0.088	0.097	0.083	0.090	0.094
<i>P</i> (DMI)	<0.001	0.31	0.63	0.49	0.78	0.38	0.26	<0.05	0.74	0.38
<i>P</i> (Linear)	<0.001	0.74	0.57	0.72	0.93	0.71	0.77	0.28	0.69	0.13
<i>P</i> (Quadratic)	0.10	0.61	0.24	0.96	0.53	0.27	0.42	0.39	0.65	0.70

¹Standard error of the difference.

2.3 and 52 ± 2.1 MJ/d per cow for NRC, 2001 and Holmes et al., 2002, respectively), suggesting that the major discrepancy is in the expected requirement for pregnancy (19 ± 5.6 and 38 ± 2.8 MJ/d per cow for NRC, 2001 and Holmes et al., 2002, respectively). This may reflect differences in either the physiological processes (gestation and lactogenesis) contained in the energy requirement calculation, or differences in the efficiency with which different energy sources are used for pregnancy (k_p). The NRC (2001) recommendations are for

gestation and make no allowance for any energy required during lactogenesis. Requirements reported in Holmes et al. (2002) are for pregnancy (based on Agricultural Research Council, 1994), but requirements for gestation and lactogenesis cannot be separated. Bell (1995) reported that energy requirements for lactogenesis are small until the day before calving, thereby suggesting that there may be differences in the efficiency with which different energy sources are used for pregnancy. Waghorn and Barry (1987) show differences of

Table 6. Periparturient plasma concentration (mmol/L) of calcium and magnesium in cows consuming 1.3, 1.9, 2.4, or 2.6 DMI (% BW) of fresh pasture for 27 ± 9.6 d precalving and offered pasture to appetite postcalving.

Precalving DMI	Day relative to calving									
	-17	0	1	2	3	4	7	14	28	35
Calcium										
1.3	2.37	2.15	2.16	2.26	2.21	2.25	2.25	2.28	2.34	2.55
1.9	2.39	2.06	2.10	2.27	2.13	2.26	2.26	2.29	2.34	2.44
2.4	2.42	1.94	2.03	2.37	2.17	2.22	2.24	2.37	2.41	2.48
2.6	2.38	1.97	2.08	2.37	2.19	2.23	2.20	2.40	2.35	2.47
SED ¹	0.042	0.116	0.116	0.086	0.067	0.082	0.071	0.096	0.055	0.046
<i>P</i> (DMI)	0.64	0.28	0.79	0.41	0.65	0.93	0.89	0.62	0.52	0.10
<i>P</i> (Linear)	0.68	0.08	0.45	0.13	0.85	0.64	0.51	0.21	0.55	0.17
<i>P</i> (Quadratic)	0.36	0.49	0.56	0.88	0.29	0.98	0.67	0.83	0.47	0.13
Magnesium										
1.3	0.93	0.75	0.71	0.72	0.73	0.74	0.78	0.88	0.85	0.91
1.9	0.96	0.78	0.86	0.76	0.75	0.82	0.81	0.93	0.95	0.99
2.4	1.03	0.87	0.89	0.73	0.66	0.74	0.73	0.85	0.96	0.93
2.6	1.03	0.86	0.88	0.76	0.70	0.77	0.79	0.84	0.96	0.99
SED ¹	0.030	0.072	0.081	0.060	0.054	0.060	0.057	0.072	0.071	0.081
<i>P</i> (DMI)	<0.01	0.24	0.09	0.72	0.41	0.54	0.26	0.53	0.21	0.58
<i>P</i> (Linear)	<0.001	0.06	<0.05	0.62	0.36	0.92	0.76	0.38	0.09	0.40
<i>P</i> (Quadratic)	0.50	0.69	0.18	0.93	0.84	0.59	0.59	0.59	0.26	0.76

¹Standard error of the difference.

up to 42% in the efficiency with which ME is used for body tissue gain in sheep. It is therefore conceivable that different feeds will also have a different k_p . The Agricultural Research Council (1994) maintained that there were no data available to estimate the effect of source of ME on k_p . Based on results reported here, further research is necessary to understand the effect of energy source on k_p .

The positive effect of precalving energy intake on precalving BW change and plasma IGF-I, leptin, and insulin concentrations, and the negative effect exerted on plasma NEFA, BHBA, and GH concentrations all indicate that the cows consuming DMI of 1.3% and 1.9% BW were in negative energy balance, and are similar to the effects reported by Holtenius et al. (2003) and Block et al. (2003). A decrease in the number of GH receptors in liver tissue, and in particular GH receptor-1A, which is reported to decline during periods of negative energy balance (Breier et al., 1988), is probably responsible for the increased plasma GH concentration and the reduction in IGF-I observed precalving (Lucy et al., 2001). A decrease in liver GH receptor-1A would be expected to cause a decrease in GH action in the liver, with a resultant decrease in liver IGF-I synthesis and secretion (Liu et al., 1999), and a reduced uptake of nutrients by the mammary gland (McGuire et al., 1995; Bauman, 1999). The lack of difference in FCM after wk 1, when treatment effects on GH and IGF-I are no longer evident, supports this.

Lucy et al. (2001) hypothesized that a nutrition-mediated decline in IGF-I during the periparturient period

may prevent a full metabolic adaptation to the nutrient demands of lactation, and consequently reduce milk production (Drackley, 1999). In the study reported here, the effects of precalving nutrition on GH, IGF-I, leptin, glucose, insulin NEFA, or BHBA, were not expressed beyond the colostrum period, suggesting that precalving energy intake did not affect postcalving energy balance beyond the first week of lactation. This is further supported by BW data, where the extent of BW loss postcalving was inversely related to precalving DMI, but only in the first week postcalving, after which differences in BW loss were not affected by treatment. Holtenius et al. (2003), having found higher concentrations of leptin, glucose, and insulin 3 wk precalving in well-fed compared with restricted dairy cows, also reported no effect of treatment on postcalving plasma concentrations of these metabolites, suggesting that postcalving energy balance was not affected by precalving level of feeding.

The reported effect of precalving DMI on milk production in the literature appears inconclusive. Waltner et al. (1993) found FCM increased with increasing BCS at calving, and Klop et al. (1998) and Holcomb et al. (2001) reported milk fat content to be 0.2 to 0.8 percentage units higher during the first 5 wk of lactation for cows fed ad libitum, compared with those on a restricted diet during the dry period. In comparison, Garnsworthy and Topps (1982), Holcomb et al. (2001), and Agenas et al. (2003) reported no effect of prepartum DMI on postpartum milk production. In the current study, precalving level of feeding had little effect on milk produc-

tion, with the exception of wk 1 of lactation, other than a difference of less than 5 kg in milk fat yield.

There are a number of possible reasons for the apparent discrepancies in the reported effects of precalving energy intake on postcalving milk production. One reason may be an interaction between the effect of pre- and postcalving level of feeding on milk production. This idea was supported by Broster and Broster (1984) and, more recently, by Stockdale (2001) who suggested that although the effects of precalving feeding could be observed throughout lactation, moderate underfeeding before calving could be offset by more generous feeding after calving. Grainger and McGowan (1982) acknowledged that the effect of precalving feeding was less likely to be evident in cows that were fed well postcalving. Further research is required to understand the interaction between pre- and postcalving level of feeding on milk production.

A second possible reason for the smaller than anticipated milk production response in the current study is that all treatments calved at a BCS ≥ 3.0 , and the difference in BCS at calving between the most restricted and the best fed treatments was only 0.3 BCS units. Waltner et al. (1993) showed a 322-kg FCM gain in the first 90 d of lactation when cows calved at a BCS of 3 compared with 2. However, the difference between 3 and 4 was only 33 kg of FCM. The small effect of precalving DMI on postcalving FCM was also observed in the current study.

Without measured DMI data during wk 1 it is not possible to complete an energy balance. However, the increased milk production and greater energy expenditure in milk (NE_L) during wk 1 corresponds to the greater BW loss recorded in cows that were better fed precalving (Figure 1). Although this is consistent with the literature concerning the positive relationship between BCS at calving and subsequent BW loss (Waltner et al., 1993; Stockdale, 2001), the increased BW loss is not consistent with the GH data measured during wk 1. Growth hormone is a homeorhetic control that regulates lipid mobilization and the use of absorbed nutrients, both directly and indirectly, through GH-dependent somatomedins (Bauman and Vernon, 1993; Bell, 1995; Lucy et al., 2001). The greater GH around calving is believed to coordinate nutrient partitioning, preferentially targeting the mammary gland (Etherton and Bauman, 1998). The positive relationship between precalving level of feeding and plasma IGF-I concentrations during the colostrum period, and milk energy output is consistent with this (see review by Bauman and Vernon, 1993).

However, the negative association between BW loss during wk 1 and lower plasma GH concentrations is not consistent with the effect of GH as a lipolytic catalyst

(Kobayashi et al., 2002). The reason for this is not clear but may be related to the effect of the precalving level of feeding on GH receptor abundance in adipose tissue. Rhoades et al. (2004), using hyperinsulemic: euglycemic clamps reported a doubling of the amount of GH receptor in adipose tissue when insulin was infused in early lactation to mimic a positive energy balance. The linear decline in plasma insulin in the study reported here would be expected to reduce the abundance of GH receptor protein in the adipose tissue and reduce the responsiveness of adipose tissue to GH signaling in these cows. In other words, rather than the well-fed treatments exhibiting low GH concentrations in the present study, it is possible that restricted feeding precalving may reduce the sensitivity of adipose tissue to lipolytic signals.

In the current study, precalving DMI had little effect on the FA composition of milk. Milk fat 16:0, 18:0, and *cis*-9 18:1 were identified as the predominant FA in adipose tissue of periparturient dairy cows (Rukkwamsuk et al., 2000) and, along with 18:2 and 18:3, were the FA present in greatest concentration in serum and liver following lipolysis. Milk FA profile was not reported in these studies, but one would expect that the concentration of these FA in milk would be influenced to the greatest degree by differences in body tissue mobilization. In the present study, milk fat content of 18:3 and *cis*-9 18:1 increased linearly during wk 1 and wk 3, respectively, with increasing precalving DMI (calving BCS), suggesting increased lipolysis and contribution of body fat stores to milk fat in better-conditioned animals during very early lactation. This is supported by the negative relationship between precalving DMI and postcalving BW loss and is in agreement with the earlier work of Klop et al. (1998) and Holcomb et al. (2001).

The effect of precalving level of feeding on periparturient plasma Mg and Ca status was interesting. The linear decline in plasma Mg concentration observed with decreasing Mg intake was expected. Fecal endogenous loss of Mg is assumed constant (Underwood and Suttle, 1999), and therefore a declining Mg intake would be expected to result in a reduction in the amount of Mg absorbed and a lowering of plasma Mg.

What was not expected was the linear decline in plasma Ca on the day of calving, with increasing DMI precalving. The most plausible reason for this is the linear increase in milk yield during wk 1 of lactation, which would increase the amount of Ca secreted in milk and reduce the circulating pool of plasma Ca. Bell (1995) concluded that the major increase in nutrient uptake by the mammary gland was in the final day before calving, creating a drain on plasma Ca. This increased risk of hypocalcemia in cows that achieve higher DMI precalving is worth noting, especially as the apparent

benefit to feeding cows in excess of their energy requirements was relatively small.

CONCLUSIONS

Cows that are underfed precalving mobilize body reserves of fat and protein precalving and have higher plasma concentrations of GH, NEFA, and BHBA, and lower concentrations of IGF-I, glucose, insulin, and leptin before calving. The metabolic effects of precalving level of feeding did not extend past the first week of lactation. Cows that consumed less DM precalving had a higher DMI, and experienced less of a negative energy balance in early lactation. The impact of precalving DMI on subsequent milk production was small. Further research is required to define the interaction between pre- and postcalving level of feeding.

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