Requirements for zero energy balance of nonlactating, pregnant dairy cows fed fresh autumn pasture are greater than currently estimated

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ABSTRACT

Fifty-three nonlactating, pregnant Holstein-Friesian and Holstein-Friesian × Jersey cross dairy cows were grouped into 4 cohorts ($n = 15, 12, 13$, and 13) and offered 1 of 3 allowances of fresh, cut pasture indoors for 38 ± 2 d (mean $\pm$ SD). Cows were released onto a bare paddock after their meal until the following morning. Animals were blocked by age (6 ± 2 yr), day of gestation (208 ± 17 d), and body weight (BW; 526 ± 55 kg). The 3 pasture allowances [low: 7.5 kg of dry matter (DM), medium: 10.1 kg of DM, or high: 12.4 kg of DM/cow per day] were offered in individual stalls to determine the estimated DM and metabolizable energy (ME) intake required for zero energy balance. Individual cow DM intake was determined daily and body condition score was assessed once per week. Cow BW was recorded once per week in cohorts 1 and 2, and 3 times per week in cohorts 3 and 4. Low, medium, and high allowance treatments consumed 7.5, 9.4, and 10.6 kg of DM/cow per day [standard error of the difference (SED) = 0.26 kg of DM], and BW gain, including the conceptus, was 0.2, 0.6, and 0.9 kg/cow per day (SED = 0.12 kg), respectively. The ME content of the pasture was estimated from in vitro true digestibility and by near infrared spectroscopy. Total ME requirements for maintenance, pregnancy, and limited activity were 1.07 MJ of ME/kg of measured metabolic BW per day. This is more than 45% greater than current recommendations. Differences may be due to an underestimation of ME requirements for maintenance or pregnancy, an overestimation of diet metabolizability, or a combination of these. Further research is necessary to determine the reasons for the greater ME requirements measured in the present study, but the results are important for on-farm decisions regarding feed allocation for nonlactating, pregnant dairy cows.

Key words: maintenance energy, cattle, body weight gain, pregnancy

INTRODUCTION

The ME and net energy requirements for cow maintenance, activity, reproduction, and productive purposes have been estimated and are published in energy accounting systems (ARC, 1994; NRC, 2001; CSIRO, 2007). However, recommendations are not always consistent. For example, the NRC (2001) estimates maintenance to be approximately 0.54 MJ of ME/kg of BW^{0.75} for mature lactating cows, assuming a conversion of ME to net energy (the efficiency of use of ME for maintenance; k_m) of 0.62. This includes an additional allowance of 10% of maintenance for normal activity that is not expended when fasting heat production is measured (i.e., cows in calorimeters). In contrast, the ARC (1994) reported lower ME requirements from fasting heat production experiments with estimated maintenance values for a 500-kg cow of 0.45 to 0.47 MJ of ME/kg of BW^{0.75}, at a diet metabolizability of 0.70 or 0.60, respectively. The CSIRO (2007) developed a more complex prediction equation, incorporating species, sex, age, BW, potential milk production, k_m , energy requirements for grazing activity, and energy expenditure for ambient temperatures below the animal's lower critical temperature. However, actual requirements were not greatly different from those in NRC (2001); for example, a 6-yr-old dairy cow (500 kg of BW) in thermoneutral conditions would require 0.56 MJ of ME/kg of BW^{0.75}. The CSIRO (2007) values were used to predict the ME requirements of grazing dairy cows (Nicol and Brookes, 2007).

In addition to variations between nutrient requirement systems, Yan et al. (1997a,b) reported that ME requirements for maintenance in nonlactating and lactating cows were 12 to 15% greater than in the studies used to formulate the existing recommendations. These results support the reports by Garrett (1971) and Ferrell and Jenkins (1984) that maintenance ME requirements increase with genetic merit for milk production. Because of this, Nicol and Brookes (2007) increased the ME requirements for milk production in grazing dairy cows, leaving maintenance at previously recommended levels. Such a change would increase the total ME re-

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quirements of lactating cows, but would not adjust ME requirements in nonlactating cows. This is not consistent with Roche et al. (2005), who reported that ME requirements for maintenance, pregnancy, and activity in nonlactating pregnant dairy cows during the last month of gestation were greater than recommended, at 1.05 MJ of ME/kg of BW^{0.75}. Holmes and Grainger (1982) and Grainger et al. (1985) also reported greater requirements for cows grazing autumn pasture in mo 7 precalving (210 to 215 d of gestation) of up to 1.02 MJ of ME/kg of BW^{0.75}, indicating that ME requirements for maintenance, pregnancy, and activity in nonlactating, grazing cows may be greater than currently recommended. However, in these studies, DMI was only estimated from pre- and postgrazing residuals, and the reported energy requirements were, therefore, only estimates.

The objective of the present study was to determine the ME requirements for zero energy balance of pregnant, nonlactating, grazing dairy cows 2 mo precalving, by accurately measuring DMI, while still exposing cows to conditions similar to those found in grazing systems (i.e., cows were kept on a bare paddock in the afternoon and night).

MATERIALS AND METHODS

Trial Design and Measurements

As part of a larger experiment undertaken over 2 yr, 53 nonlactating, pregnant Holstein-Friesian and Holstein-Friesian × Jersey-cross dairy cows were offered 1 of 3 daily pasture allowances for 38 ± 2 d (mean ± SD) in 4 cohorts (n = 15, 12, 13, 13) at the DairyNZ Calan Gate (American Calan, Northwood, NH) freestall facility (Hamilton, New Zealand). The 4 cohorts were required because of space limitations in the indoor feeding facilities. Fresh autumn pasture offered was as follows: low = 7.5 kg of DM/cow; medium = 10.1 kg of DM/cow, and high = 12.4 kg of DM/cow. The low allowance was intended to provide the recommended requirements for maintenance based on the measured BW (0.55 MJ of ME/kg of BW^{0.75}; NRC, 2001; Holmes et al., 2002), with an additional allowance of 20 MJ of ME/d for pregnancy and activity (Bell et al., 1995; NRC, 2001).

Before treatment allocation, cows were blocked by age, day of gestation (**DOG**), and BW. On average, DOG was 208 ± 17 d, and BW and age were 526 ± 55 kg and 6 ± 2 yr, respectively. Cows were previously trained to the Calan Gate freestall facility, and all procedures were approved by the Ruakura Animal Ethics Committee. In total, 19, 17, and 17 cows were allocated to the low, medium, and high treatment groups, respectively.

Fresh autumn pasture was cut daily and offered to each cow at 0800 h. Cows had access to the pasture for approximately 7 h, after which they were released onto a neighboring, bare paddock (within 200 m of the feeding facilities) until the following morning. The amount of daily pasture offered and refused was recorded for individual cows, and representative pasture samples were dried in triplicate at 95°C for 48 h to determine DM content. Individual DMI was calculated as pasture DM offered (kg) minus DM refused (kg). A second sample of offered pasture was dried at 60°C for 72 h, ground to pass through a 2.0-mm sieve (Christy Lab Mill, Suffolk, UK), bulked weekly, and analyzed for feed composition and in vitro true DM digestibility (DairyOne, Ithaca, NY). Pasture ME content was estimated from in vitro true DM digestibility: ME = DM digestibility × 0.172 – 1.707 (CSIRO, 2007), as well as determined by near infrared spectroscopy (**NIRS**) at Hills Laboratory (Hamilton, New Zealand). Feed quality values are reported in Table 1.

In all experimental cohorts, individual BCS (Roche et al., 2004; 10-point scale) was recorded once per week by one experienced assessor. Individual BW was recorded once per week in cohorts 1 and 2 and 3 times per week in cohorts 3 and 4 (Gallagher Smart Scale 500, Hamilton, New Zealand). Calf birth weights were also recorded.

Table 1. Mean (±SD) composition (% DM, unless otherwise stated) in fresh autumn pasture

Item	Mean	SD
ME ¹ (MJ/kg of DM)	12.4	0.66
ME ² (MJ/kg of DM)	11.3	0.60
In vitro true digestibility, 24 h	82.0	3.81
CP	21.7	1.68
Crude fat	4.1	0.92
ADF	27.8	3.89
NDF	47.4	5.21
NDF digestibility, 24 h (% of NDF)	61.8	8.19
Lignin	4.9	1.67
Starch	1.2	0.99
Ethanol-soluble carbohydrates	7.8	2.87
Ca	0.7	0.30
P	0.4	0.09
Mg	0.2	0.02
K	3.1	0.38
Na	0.3	0.15
S	0.4	0.07
Fe (mg/kg)	221.0	147.60
Zn (mg/kg)	37.9	7.27
Cu (mg/kg)	7.0	1.02
Mn (mg/kg)	69.9	17.71
Mo (mg/kg)	0.8	0.93
Ash	10.2	1.30
DCAD (mEq/100 g)	31.6	13.05

¹Estimated using in vitro true digestibility (wet chemistry: DairyOne, Ithaca, NY).

²Determined by near infrared spectroscopy.

Calculations and Statistical Analyses

The profile of conceptus growth (kg/d) and ME requirements of the gravid uterus were estimated from calf birth weight using the equations reported by Bell et al. (1995):

$$\text{GUW (kg/d)} = (0.664 \times \text{DOG} - 102) \times (\text{CBW}/46), \quad [1]$$

$$\begin{aligned} \text{and GUER (MJ ME/d)} = & \{[0.00159 \times \text{DOG}^2 \\ & - 0.0352 \times \text{DOG} - 35.4] \times 4.186 \times \text{CBW}/46\} \\ & - \{[0.00159 \times (\text{DOG} - 1)^2 - 0.0352 \times (\text{DOG} - 1) \\ & - 35.4] \times 4.186 \times \text{CBW}/46\} / 0.14, \quad [2] \end{aligned}$$

where GUW = gravid uterus weight, DOG = day of gestation, CBW = calf birth weight (kg), and GUER = gravid uterus energy requirements. The assumed efficiency of use of ME for conceptus metabolism (k_p) was 0.14 (Ferrell et al., 1976; NRC, 2001). Activity requirements were calculated from Nicol and Brookes (2007).

Energy requirements for activity, estimated as 0.0037 MJ of ME/kg of BW per horizontal kilometer walked (Nicol and Brookes, 2007), were 2 MJ of ME/d, assuming the cows walked 1 km per day. The ME requirements for pregnancy and activity were added to the basic maintenance (0.55 MJ of ME/kg of measured $\text{BW}^{0.75}$) to obtain an estimate of the predicted feed allowance for zero energy balance.

Average BW gain/day for each cow was estimated by regressing BW against day using linear models. Individual daily ME intake was calculated as the product of estimated pasture ME and daily DMI for individual cows within each cohort. Associations between mean ME intake and BW change, and between mean ME intake/kg of $\text{BW}^{0.75}$ and BW change were calculated using linear models by fitting a regression line with BW change as the dependent variable and daily ME intake

and ME intake/kg of $\text{BW}^{0.75}$ as independent variables. To obtain daily ME requirements for zero energy balance, ME intakes and ME intakes/kg of $\text{BW}^{0.75}$ were calculated from the fitted equations by taking into account the estimated daily weight gain of the gravid uterus.

Differences in genetic merit were analyzed by dividing cows into 3 groups for breeding worth (low, medium, and high breeding worth). This grouping and its interaction with the independent variables were included in the regression analysis.

RESULTS AND DISCUSSION

Based on average calf birth weight (39 ± 7 kg), the estimated gravid uterus weight and daily gravid uterus weight change at 208 d of gestation were 30.1 ± 9.1 kg and 0.6 ± 0.13 kg, respectively. Average ME content of the pasture offered was 11.9 ± 0.38 , 12.7 ± 0.21 , 12.5 ± 0.96 , and 12.8 ± 0.17 for cohorts 1 to 4, respectively. Pasture composition and ME are presented in Table 1. Dry matter intake, ME intake, and BW and BCS data for cows receiving the low, medium, and high allowances are presented in Table 2.

Average DMI and ME intake (average $\pm$ SE) associated with zero BW change were 6.9 ± 0.32 kg/d and 86 ± 3.93 MJ/d, respectively. However, zero BW change does not account for growth of the gravid uterus. Following adjustment for gravid uterus weight change (0.6 kg/d), ME intake associated with zero energy balance of the dam was 117 ± 2.6 MJ/d ($R^2 = 0.63$; Figure 1a). This resulted in total ME requirements of 1.07 ± 0.025 MJ of ME/kg of measured $\text{BW}^{0.75}$ for maintenance, activity, and pregnancy ($R^2 = 0.56$; Figure 1b). Daily pregnancy ME requirements were estimated to be 15.8 MJ of ME (see Equation [2]), which is similar to the reported ME requirements at this stage of gestation for pasture-based cows carrying a 40-kg calf (15 to 20 MJ of ME/d; Nicol and Brookes, 2007).

Table 2. Pasture DMI, ME intake, daily BW change, and BCS change for cows on low, medium, and high pasture allowances

Item	Treatment ¹			SED ²	P-value
	Low	Medium	High		
DMI (kg of DM/d)	7.5	9.4	10.6	0.26	<0.001
ME intake/d (MJ of ME)	94.6	118.0	133.1	3.17	<0.001
BW change/d (kg)	0.22	0.59	0.89	0.117	<0.001
BCS change (units $\times 10^{-2}$ /d)	1.0	1.4	1.7	0.30	<0.05

¹Low = estimated maintenance (0.55 MJ of ME/kg of $\text{BW}^{0.75}$) plus a 20 MJ of ME allowance for pregnancy and limited activity; medium = low pasture allowance plus 2.5 kg of DM offered; high = low pasture allowance plus 5.0 kg of DM offered.

²Standard error of the difference of the means.

Figure 1. The relationship between (A) ME consumed (MJ/d), and (B) ME consumed per kilogram of metabolic BW (MJ of ME/kg of $BW^{0.75}$ per day) and daily BW change (kg/d) in nonlactating, pregnant Holstein-Friesian and Holstein-Friesian $\times$ Jersey dairy cows (526 ± 55 kg of BW; 208 ± 17 d of gestation). Individual standard errors of the regression equations are displayed.

Maintenance requirements are described as the energy required to maintain homeothermy and vital physiological processes at zero energy balance (no tissue gain or loss; ARC, 1994; NRC, 2001). Calorimetry and slaughter studies resulted in estimates for maintenance requirements of 0.43 MJ of ME/kg of $BW^{0.75}$ (Van Es, 1961; Moe and Tyrrell, 1972; ARC, 1994). These requirements were increased to 0.55 to 0.58 MJ of ME/kg of $BW^{0.75}$ for nonlactating grazing dairy cows and to 0.60 to 0.67 MJ of ME/kg of $BW^{0.75}$ for lactating grazing dairy cows (Holmes et al., 2002; Nicol and Brookes, 2007), which are consistent with NRC (2001) recommendations.

The results obtained in this study suggest ME requirements for maintenance, pregnancy, and activity of 1.07 MJ of ME/kg of $BW^{0.75}$ (or 117 MJ of ME/d). Using published literature to estimate ME require-

ments for maintenance (0.55–0.58 MJ of ME/kg of $BW^{0.75}$ = approximately 60 MJ of ME/d) and adding ME requirements for pregnancy and activity (approximately 20 MJ of ME/d), total ME requirements for zero energy balance of the dam would be approximately 80 MJ of ME/d (i.e., 0.73 MJ of ME/kg of $BW^{0.75}$). This suggests that current ME recommendations underestimate the requirements for zero energy balance of nonlactating grazing dairy cows in mid to late gestation by approximately 45%. These greater ME requirements are consistent with Roche et al. (2005), who reported that 1.05 MJ of ME/kg of $BW^{0.75}$ was needed to maintain zero energy balance in grazing dairy cows 1 mo before calving, and with Holmes and Grainger (1982) and Grainger et al. (1985), who reported values of up to 1.02 MJ for cows grazing autumn pasture and 0.71 MJ of ME/kg of $BW^{0.75}$ for cows fed fresh pasture indoors, respectively, at a stage of gestation similar to that of the present study. The reason for the greater ME requirements is not known; however, the most plausible reasons include inaccuracies in the previous recommendations in determining the metabolizability of the diet, errors associated with feed ME determination, differences in ME requirements for maintenance and pregnancy across breeds and genetic strains, and differences in the efficiency with which ME from different feeds is used for different physiological processes.

Diet Metabolizability

Some of the difference between results reported here and previous recommendations may be due to physiological state and the effect that this has on diet metabolizability. Moe et al. (1970) and Yan et al. (1997) reported that the efficiency of use of energy for tissue gain was 18 to 20% lower in nonlactating cows compared with lactating cows; this could be due to an increase in the intestinal passage rate of the digesta in late gestation, resulting in decreased digestibility of some feeds (Graham and Williams, 1962). The use of in vitro DM digestibility to calculate ME may, therefore, overestimate pasture ME for nonlactating cows. When using the ME obtained from near infrared spectroscopy analysis (Table 1), ME requirements for zero energy balance decreased to $0.97 (\pm 0.191)$ MJ of ME/kg of $BW^{0.75}$, but this is still more than 30% higher than requirements proposed in the literature. Moreover, when the estimated ME of pasture was reduced by the 18% reported by Moe et al. (1970) and Yan et al. (1997), pasture ME would decrease from 12.4 to 10.2 MJ/kg of DM. This would be unexpectedly low for green leafy pastures (Roche et al., 2009) and still would not account for the total difference between the ME requirements reported in the present study, and by Roche et

al. (2005) and Holmes and Grainger (1982), and those previously recommended (ARC, 1994; NRC, 2001; Holmes et al., 2002; Nicol and Brookes, 2007). Even with a reduced ME of pasture, the results presented here indicate that ME requirements for maintenance, pregnancy, and limited activity are 30% higher than previously recommended. Therefore, other contributing factors must exist.

In a study on heifers, Reynolds et al. (1991) reported differences in heat production and tissue energy retention with changing diet composition, even though ME intake was equal between treatment groups. Variances in the metabolizability of a particular diet might alter k_m . Hence, values reported for TMR-based systems may not be applicable for grazing dairy cows.

Another possible reason for the inconsistency in published estimates of ME requirements may relate to the method of their determination. For example, Larson and Johnson (1997) reported greater efficiencies of use of energy for BW gain from calorimetry experiments (fasting animals) than from slaughter experiments. This was presumed to be due to the short duration of calorimetry studies and the fact that energy from BW loss is used more efficiently than dietary energy (ARC, 1994). Use of energy from imperceptible BW loss in short-term calorimetry studies may explain some of the inconsistencies in reported requirements.

Maintenance

Metabolizable energy is used less efficiently for BW gain in autumn pasture than in spring pasture (Rook, 1964) or in alternative feeds such as maize silage and concentrate supplements (Mandok et al., 2012). It is plausible, therefore, that k_m is also lower in autumn pasture, which would explain at least some of the increased ME requirements reported here and by Roche et al. (2005) and Grainger et al. (1985), compared with alternative diets.

A further reason for the inconsistencies in recommended ME requirements for zero energy balance may relate to genetic differences in maintenance energy requirements. Ferrell and Jenkins (1984) reported that higher milk-yield breeds required over 20% more ME for maintenance than lower milk-yield breeds. In addition, Garrett (1971) reported that Hereford steers needed less ME for maintenance than Holstein-Friesian steers and were 12% more efficient in converting ME above maintenance into BW gain. These data indicate that k_m may be affected by cow genetics and, in particular, that selection toward greater milk production may increase maintenance ME requirements. We found no differences between k_m of cows with low or high genetic merit in the current experiment. However, it is

still plausible that the genetic strain of the cows used in this study had greater maintenance requirements than strains used in previous experiments, and further research should be undertaken to test this hypothesis in both grazing and TMR-based dairy systems.

Pregnancy

Net energy requirements for conceptus metabolism (k_p) are estimated from slaughter studies (Rattray et al., 1974; Garrett and Johnson, 1983) and heat production experiments. There is general agreement that k_p in ruminant species is low (NRC, 2001; CSIRO, 2007). Battaglia and Meschia (1978) reported differences in the permeability of the placenta to FFA, including short-chain fatty acids such as acetate. Acetate is the major energy substrate in the grazing, adult ruminant, but it can only cross the ruminant placenta in very limited amounts. This results in a relatively inefficient use of ME for conceptus metabolism. All energy systems have adopted a similar k_p (0.13–0.14; ARC, 1994; NRC, 2001; CSIRO, 2007), irrespective of diet. However, reports on the effect of physiological state and diet quality on the k_p in ruminants are inconsistent. Nicol and Brookes (2007) stated that there was no evidence that k_p changes through gestation or with the quality of the diet. Other researchers, however, have reported that DMI and metabolizability of the diet do affect k_p (Rook, 1964; Yan et al., 1997; Roche et al., 2005). In support of this, Robinson et al. (1980) reported a 20% reduction in k_p in pregnant sheep when ME intake decreased from 15 to 12 MJ of ME/d. This is consistent with Hutchings (1997), who predicted variation in the efficiency with which ME is used for conceptus metabolism (from 0.11 to 0.18) with changing diet metabolizability (from 0.40 to 0.80). Robinson et al. (1999) proposed similar differences in k_p (i.e., from 0.11 to 0.17) with increasing feed quality. Although autumn pasture is not particularly low in gross energy, considerable evidence suggests that it is used inefficiently for BW gain in ruminant species (Macrae et al., 1985; CSIRO, 2007). These data reflect deficiencies in autumn pasture that are not evident in standard laboratory analyses. Therefore, it is plausible that k_p is also less for autumn pasture, although further research is required to verify or refute this hypothesis.

CONCLUSIONS

Recommended ME requirements for zero energy balance of nonlactating, pregnant dairy cows fed fresh pasture are too low. Measurements reported here and by others indicate that values should be increased by 30 to 45%. Reasons for the difference between measured and recommended values are not clear, but the differ-

ence could be due to increased maintenance requirements in cattle selected for greater milk production, an underestimation of the ME requirements for pregnancy in mid to late gestation, an overestimation of the ME content of autumn pasture, or low efficiency of use of ME from autumn pasture for maintenance or conceptus metabolism. Even if the estimated ME content of pasture used in these calculations was too high, it would not fully explain the discrepancy between predicted and measured values. The effect of cow genetics and diet (i.e., supplementation or TMR) on the efficiency of ME use for maintenance and conceptus metabolism must be investigated. The current study does not allow the separation of maintenance and pregnancy requirements and this should be a focus of future research in this area. Nonetheless, at a dairy producer level, the greater requirements must be accounted for in feed budgeting.

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