Comparison of maintenance energy requirement and energetic efficiency between lactating Holstein-Friesian and other groups of dairy cows

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ABSTRACT

The objectives of the present study were to investigate the effects of cow group on energy expenditure and utilization efficiency. Data used were collated from 32 calorimetric chamber experiments undertaken from 1992 to 2010, with 823 observations from lactating Holstein-Friesian (HF) cows and 112 observations from other groups of lactating cows including Norwegian ($n = 50$), Jersey $\times$ HF ($n = 46$), and Norwegian $\times$ HF ($n = 16$) cows. The metabolizable energy (ME) requirement for maintenance (ME_m) for individual cows was calculated from heat production (HP) minus energy losses from inefficiencies of ME use for lactation, energy retention, and pregnancy. The efficiency of ME use for lactation (k_l) was obtained from milk energy output adjusted to zero energy balance ($E_{l(0)}$) divided by ME available for production. The effects of cow groups were first evaluated using Norwegian cows against HF crossbred cows (F_1 hybrid, Jersey $\times$ HF and Norwegian $\times$ HF). The results indicated no significant difference between the 2 groups in terms of energy digestibility, ratio of ME intake over gross energy intake, ME_m (MJ per kg of metabolic body weight, $MJ/kg^{0.75}$), or k_l . Consequently, their data were combined (categorized as non-HF cows) and used to compare with those of HF cows. Again, we detected no significant difference in energy digestibility, ratio of ME intake over gross energy intake, ME_m ($MJ/kg^{0.75}$), or k_l between non-HF and HF cows. The effects were further evaluated using linear regression to examine whether any significant differences existed between HF and non-HF cows in terms of relationships between ME intake and energetic parameters. With a common constant, no significant difference was observed between the 2 groups of cows in coefficients in each set of relationships between ME intake ($MJ/kg^{0.75}$) and ME_m ($MJ/kg^{0.75}$), $E_{l(0)}$ ($MJ/kg^{0.75}$), HP ($MJ/kg^{0.75}$), ME_m :ME intake, $E_{l(0)}$:ME intake, or HP:ME intake. However, ME_m values ($MJ/$

$kg^{0.75}$) were positively related to ME intake ($MJ/kg^{0.75}$), irrespective of cow group. We concluded, therefore, that cow groups evaluated in the present study had no significant effects on energy expenditure or energetic efficiency. However, the maintenance energy requirement ($MJ/kg^{0.75}$) was not constant (as adopted in the majority of energy rationing systems across the world) but increased with increasing feed intake.

Key words: maintenance energy requirement, energy utilization efficiency, cow group, lactating dairy cow

INTRODUCTION

Milk yield-oriented breeding programs for Holstein-Friesian (HF) dairy cows have made significant progress in the past few decades, with the HF population being the dominant dairy cow breed on the majority of United Kingdom (UK) dairy farms. However, it is now widely recognized that selection programs with a single production trait, namely milk production, have inadvertently resulted in production burden, metabolic stress, health, and fertility problems (Seykora and McDaniel, 1983; König et al., 2008). Several studies have demonstrated unfavorable genetic correlations between milk yield and ketosis (0.25 to 0.65), mastitis (0.15 to 0.68), and lameness (0.24 to 0.48; Lucy, 2001; Ingvarsten et al., 2003). For example, the fertility of HF dairy cows in the United States declined steadily from 1960 until the early to mid-2000s. Corrective action would take 20 to 30 yr to return those cows to the fertility levels they had 30 yr ago (Gary and Joan, 2011). Therefore, there is increasing interest in the use of non-HF breeds (e.g., Jersey, Norwegian) or crossbred (mainly HF based) dairy cows around the world, especially in New Zealand, where crossbreeding of Jerseys with HF cows accounts for more than 40% of the whole dairy population (Dairy NZ, 2014). In the UK, 87 different breeds of cattle were registered as of June 1, 2008, including 4.0 million purebred cattle and 4.8 million crossbred cattle (Defra, 2008).

The potential benefits of HF crossbred dairy cows can be achieved through combinations of inherent advantages from different groups of dairy cows. Schwager-

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Suter et al. (2001) compared differences in net energetic efficiency for HF, Jersey, and Jersey $\times$ HF cows, which was calculated as the ratio of milk energy to total net energy intake. Results showed that Jersey $\times$ HF cows had a higher net energetic efficiency compared with those of the HF and Jersey breeds, in agreement with the study of Prendiville et al. (2009), in which Jersey and Jersey $\times$ HF cows required approximately 8 and 11% less energy, respectively, to produce 1 kg of milk solids (fat + protein) compared with HF cows. In addition, with better fertility and udder health, Jersey-HF crossbred cows had a net profit of £39/cow per year over pure Holstein cows when managed under farm conditions of Northern Ireland (AgriSearch, 2012). Nevertheless, most research has been undertaken on the comparison of performance characteristics, health, or profitability traits among different cow groups. Few studies have been conducted on the comparison of maintenance energy requirement and energy utilization efficiency between lactating HF cows and other groups of dairy cows.

Therefore, the objectives of the present study were to perform a meta-analysis to investigate the possible effects of different groups of dairy cows on ME requirement for maintenance (ME_m) and the efficiency of utilization of ME for lactation (k_l) using data derived from 32 calorimeter experiments involving HF and other groups of dairy cows between 1992 and 2010.

MATERIALS AND METHODS

Animals and Feeds

In the current study, 935 observations were collated from 32 calorimetric chamber experiments undertaken between 1992 and 2010 at the Agri-Food and Biosciences Institute (Hillsborough, UK) including 823 observations from HF cows and 112 observations from the “other” group of dairy cows (**non-HF**) that included Norwegian ($n = 50$) and HF crossbred (F_1 hybrid, Jersey $\times$ HF, $n = 46$; Norwegian $\times$ HF, $n = 16$) cows. The majority of these studies were published in peer-reviewed scientific journals, and all references are presented in the Appendix. The HF group had a mean Profit Index value of £15 based on the calculation of PTA2010 proof and had relatively high production performance in the whole UK HF population. The HF crossbred animals, including Jersey $\times$ HF and Norwegian $\times$ HF, were the offspring of a breeding program in the herd of this institute, with the Norwegian cows representing the top 10% of the whole population in Norway when they arrived at this institute in 1999. The stage of lactation when measured in calorimeter chambers ranged from early to late lactation, with mean

postcalving days of 159 for HF cows, 158 for Norwegian cows, 179 for Jersey $\times$ HF cows, and 247 for Norwegian $\times$ HF cows, respectively.

Data used were derived from forage-only diets ($n = 66$) or a mixture of forage and concentrates ($n = 869$). The forage used in individual diets included grass silage ($n = 623$), mixture of grass silage and maize silage ($n = 160$), mixture of grass silage and whole-crop wheat silage ($n = 4$), mixture of fresh grass and straw ($n = 4$), maize silage ($n = 6$), whole-crop wheat silage ($n = 6$), straw ($n = 36$), fresh grass ($n = 42$), dried grass ($n = 20$), and dried lucerne ($n = 34$). The grass silages were produced from primary growth, primary regrowth, and secondary regrowth material with grass either unwilted or wilted before ensiling and ensiled with or without application of silage additives. The concentrates used included a mineral-vitamin supplement and some of the following ingredients: cereal grains (barley, wheat, or maize), by-products (maize gluten meal, molassed or unmolassed sugar-beet pulp, citrus pulp, or molasses), and protein supplements (soybean meal or rapeseed meal). The concentrate portion of the diet was offered in a complete diet mixed with forage or as a separate feed from forage.

Digestibility and Calorimeter Measurements

Energy intake and output data used in the present study were measured in digestibility trials and by indirect open-circuit respiration calorimeter chambers. Before the commencement of nutrient utilization measurements, all dairy cows were offered their experimental diets for at least 3 wk in group-housed cubicle accommodation with free access to water. Afterward, animals were transferred to metabolism units and remained in individual stalls for between 5 and 8 d with measurement of total feed intake and total collection of feces and urine undertaken during the final 3 to 6 d. Animals were then housed in calorimeter chambers for 3 to 5 d with total measurement of gaseous exchange (CH_4 , CO_2 , and O_2) taking place during the final 2 to 4 d. All equipment, sampling procedures, analytical methods, and calculations used in the calorimetric studies were described by Gordon et al. (1995) and calibration of the chambers by Yan et al. (2000).

Calculation of Maintenance Energy Requirement and Energetic Efficiency

The ME_m (MJ/d) for individual cows was estimated from heat production (**HP**, MJ/d) minus energy losses from the inefficiencies of ME use for lactation, tissue change, and pregnancy (Eq. [1] and [2]), with HP, milk energy output (E_l , MJ/d), and tissue energy change

(E_g , MJ/d) measured in the present study, and energy for pregnancy (E_p , MJ/d) estimated using models of AFRC (1993):

$$\text{if } E_g < 0, ME_m = HP - (1 - k_l(\text{AFRC})) \times E_l - (1 - k_t) \times E_g - (1 - k_p) \times E_p, \quad [1]$$

or

$$\text{if } E_g > 0, ME_m = HP - (1 - k_l(\text{AFRC})) \times E_l - (1 - k_g) \times E_g - (1 - k_p) \times E_p, \quad [2]$$

where $k_l(\text{AFRC})$ is the efficiency of ME use for lactation ($= 0.35ME/GE + 0.42$, where GE = gross energy), k_g is the efficiency of ME use for weight gain ($= 0.95 \times k_l(\text{AFRC})$), k_t is the efficiency of utilization of mobilized tissue energy for lactation (0.84), and k_p is the efficiency of ME use for pregnancy (0.133). All these efficiencies are from the recommendation of AFRC (1993). The E_p (MJ/d) was calculated using Eq. [3] and [4] (AFRC, 1993):

$$\log_{10}(E_t) = 151.665 - 151.64 \times e^{-0.0000576t}, \quad [3]$$

$$E_p = 0.025 \times W_c \times (E_t \times 0.0201e^{-0.0000576t}), \quad [4]$$

where E_t is total energy retention (MJ), W_c is calf birth weight, and t is days from conception.

The k_l for individual cows used in the present study was calculated as below:

$$k_l = E_{l(0)}/(ME \text{ intake} - ME_m), \quad [5]$$

where ME_m (MJ/d) was derived from Eq. [1] or [2], and $E_{l(0)}$ is milk energy output adjusted to zero energy balance (MJ/d) and was calculated from Eq. [6] and [7]:

$$\text{if } E_g > 0, E_{l(0)} = E_l + 0.95 \times E_g, \quad [6]$$

$$\text{if } E_g < 0, E_{l(0)} = E_l + 0.84 \times E_g. \quad [7]$$

Statistical Analysis

The effects of cow group on energy expenditure and energetic efficiency were evaluated using 2 analytical packages: ANOVA and linear regression. All analyses were carried out in GenStat volume 16.2 (Payne et al., 2013).

ANOVA. Two steps were used to evaluate the effects of cow groups. The effects were initially examined between Norwegian ($n = 50$) and HF crossbred groups

($n = 62$). Because we found no significant difference between these 2 groups in any variable of energetic efficiency (reported in Results section), data from these 2 groups were combined (categorized as non-HF group) and used to compare with data of HF dairy cows. All variables were analyzed using the linear mixed model methodology. Experiment and animal within experiment were fitted as random effects in all models, and cow group (HF vs. non-HF) was fitted as a fixed effect. Additional combinations of the covariates, when appropriate, were also fitted as supplementary fixed effects for evaluation of energetic efficiencies, which included milk yield, parity, DIM, days in pregnancy, dietary forage proportion, and dietary contents of NDF, CP, and ME. The significance, or otherwise, of the fixed effects was assessed by comparing a Wald statistic against the appropriate F-distribution. If any of the additional fixed effects was not significant ($P > 0.05$), then it was removed from the analyses in equations and the model refitted. If the effect of cow group (HF vs. non-HF) proved to be significant, additional pair-wise differences were established using Fisher's least significant difference test.

Linear Regression. The linear regression technique was used to determine if any significant difference existed in coefficients or constants between HF and non-HF groups in the relationship between energetic efficiencies and ME intake. The relationship between each response variable and each explanatory variable was fitted as a linear mixed model using the REML commands. Experiment and animal within experiment were fitted as random effects in all models, and the explanatory variable was a fixed effect. Additional combinations of the covariates, when appropriate, were also fitted as supplementary fixed effects for evaluation of energetic efficiencies, which included milk yield, parity, DIM, days in pregnancy, dietary forage proportion, and dietary contents of NDF, CP, and ME. The significance or otherwise of the fixed effects was assessed by comparing a Wald statistic against the appropriate F-distribution. If any of the additional fixed effects was not significant ($P > 0.05$), then it was removed from the analyses and the model was refitted. Several different models were fitted to each pair of response/explanatory variables in turn. First, a single line was fitted, then a common intercept with a different slope for HF and non-HF was fitted, and finally a common slope with a different intercept for HF and non-HF was fitted. For the latter 2 models, pair-wise differences between the different intercepts and slopes were also calculated if the main effect was significant using Fisher's least significant difference test. Finally, an assessment of the goodness-of-fit of each model was made by calculating

a pseudo R^2 value (calculated in each case as the square of the correlation of the fitted values from the model with the observed values for the response variable).

RESULTS

Data on animal performance and diet nutritive values for Norwegian and HF crossbred groups evaluated using the ANOVA test are presented in Table 1. We detected no significant differences between HF crossbred and Norwegian dairy cows in terms of BW, BCS, DIM, DMI, milk yield, ECM yield, diet forage proportion, or diet concentrations of CP, NDF, or ME ($P > 0.05$). The cow groups also showed no significant effects on energy intake and output, energy digestibility, utilization efficiencies, or energy partitioning between milk and body tissue ($P > 0.05$; results not presented). The ME_m (0.683 vs. 0.684, MJ per kg of metabolic BW, MJ/kg^{0.75}) and k_l (0.650 vs. 0.654) calculated for individual cows were very similar between HF crossbred and Norwegian cows ($P > 0.05$; results not presented).

Because we detected no significant difference between HF crossbred and Norwegian dairy cows in terms of animal performance, maintenance energy requirement, or energetic efficiencies, data from these 2 groups were combined (categorized as non-HF cows) and used to compare with those of HF cows. The results of the ANOVA for animal performance and diet nutritive values are presented in Table 2, and those for energy utilization efficiencies are presented in Table 3. Although non-HF cows had a significantly higher BCS ($P < 0.001$) and lower milk yield ($P < 0.05$) than HF cows, BW, DIM, ECM yield, and DMI did not differ significantly between the 2 groups ($P > 0.05$). Diet forage proportion and concentrations of CP, NDF, and ME were all similar between HF and non-HF groups ($P > 0.05$). The cow groups had no significant effect

on ME intake, heat production, milk energy output, or retained energy ($P > 0.05$); consequently, we detected no significant difference in energy digestibility, utilization efficiencies, or energy partitioning between milk and body tissue ($P > 0.05$) between the 2 groups of cows. Cow group had no significant effects on ME_m or k_l ($P > 0.05$).

The effects of cow group (HF vs. non-HF cows) on maintenance energy requirement and energetic efficiency were further examined by comparing coefficients (with a common constant) or constants (with a common coefficient) in each set of linear relationships between ME intake and energetic efficiencies. These results for comparison of coefficients (with a common constant) are presented in Table 4 and Figures 1 and 2. All relationships were highly significant ($P < 0.001$), with R^2 values ranging from 0.38 to 0.86 (Eq. [1a] to [6b]). We found a positive linear relationship between ME intake and ME_m , $E_{l(0)}$, HP, and $E_{l(0)}$:ME intake, whereas ME_m :ME intake and HP:ME intake were negatively related with ME intake. With a common constant, we found no significant difference in any pair of coefficients in the relationships between ME intake and ME_m ([1a] vs. [1b]), $E_{l(0)}$ ([2a] vs. [2b]), HP ([3a] vs. [3b]), ME_m :ME intake ([4a] vs. [4b]), $E_{l(0)}$:ME intake ([5a] vs. [5b]), or HP:ME intake ([6a] vs. [6b]) between HF and non-HF cows. The ME_m values calculated from Eq. [2a] and [2b] using the constant divided by coefficients were similar (0.688 vs. 0.686 MJ/kg^{0.75}) between the HF and non-HF groups. A similar result was obtained when the 2 constants (with a common coefficient) were compared in each pair of linear relationships between HF and non-HF groups. The difference in the 2 constants did not reach significance ($P > 0.05$) in any pair of relationships between ME intake and ME_m , $E_{l(0)}$, HP, ME_m :ME intake, $E_{l(0)}$:ME intake, or HP:ME intake (results not presented).

Table 1. Comparison of animal performance and diet nutritive values between Holstein-Friesian crossbred (HF crossbred)¹ and Norwegian dairy cows

Item	HF crossbred	Norwegian	SE	P-value
No. of cows	62	50		
BW (kg)	546	519	25.7	0.201
BCS	2.71	2.82	0.056	0.311
DIM (d)	222	222	21.6	0.200
Milk yield (kg/d)	22	20.5	1.81	0.397
ECM yield (kg/d)	22.6	21.7	0.66	0.577
DMI (kg/d)	17.7	16.6	0.90	0.192
Diet nutritive values				
Forage proportion (g/kg of DM)	526	521	49.1	0.93
CP content (g/kg of DM)	190	188	14.0	0.717
NDF content (g/kg of DM)	472	453	60.3	0.412
ME content (MJ/kg of DM)	12.3	11.9	0.23	0.083

¹Holstein-Friesian crossbred animals included Jersey × Holstein-Friesian (n = 46) and Norwegian × Holstein-Friesian (n = 16) dairy cows.

Table 2. Comparison of animal performance and diet nutritive values between Holstein-Friesian (HF) and the non-HF group of dairy cows¹

Item	HF	Non-HF	SE	P-value
No. of data	823	112		
BW (kg)	558	554	7.6	0.605
BCS	2.54	2.81	0.058	<0.001
DIM	164	173	12.4	0.366
Milk yield (kg/d)	22.1	20.1	1.13	0.016
ECM yield (kg/d)	21.8	21.1	1.10	0.343
DMI (kg/d)	16.6	16.5	0.52	0.944
Diet nutritive values				
Forage proportion (g/kg of DM)	562	559	36.7	0.833
CP content (g/kg of DM)	178	179	5.2	0.691
NDF content (g/kg of DM)	415	424	16.8	0.183
ME content (MJ/kg of DM)	11.6	11.7	0.17	0.361

¹Non-HF animals included Norwegian (n = 50) and Holstein-Friesian crossbred dairy cows (n = 62).

In addition, we detected a positive relationship between ME_m values and ME intake for both HF and non-HF cows (Eq. [1a] and [1b], and Figure 3). These 2 relationships indicated that the ME_m value ($MJ/kg^{0.75}$) for a cow was not constant but increased proportionately by 0.065 and 0.062 ($MJ/kg^{0.75}$) per 1-unit increase in ME intake ($MJ/kg^{0.75}$) for HF and non-HF cows, respectively. Currently, a single ME_m value expressed per unit of metabolic weight is used to ration dairy cows in the majority of energy feeding systems across the world.

DISCUSSION

Effect of Cow Group on Maintenance Energy Requirement

The energy feeding system currently used to ration dairy cows in the UK is mainly based on the *Feed into Milk* models (Agnew et al., 2003). A major difference

between *Feed into Milk* models and the systems of Agricultural and Food Research Council (AFRC, 1993) is that the former increased ME_m by approximately 35% compared with the latter. However, these systems were developed for rationing HF cows and have limited consideration for possible differences in metabolic rates between pure HF cows and their crossbreeds when using these systems to ration HF crossbred dairy cows. With increasing interest in using HF crossbreeds (e.g., HF × Jersey and HF × Norwegian) to overcome the poor health and fertility condition of HF dairy cows, there is an urgent need to evaluate whether maintenance metabolic rates differ between HF and their crossbreeds.

The present study was undertaken to evaluate the effects of cow group on energetic efficiency using a meta-analysis of calorimeter chamber data. The analysis found no significant difference in ME_m values between HF and non-HF (HF crossbred and Norwegian) dairy cows, irrespective of the technical methods used to estimate ME_m values. The ME_m values were similar between the

Table 3. Comparison of energy intake and output and energetic efficiency values between Holstein-Friesian (HF) and the non-HF group of dairy cows¹

Item	HF	Non-HF	SE	P-value
No. of data	823	112		
Energy intake and output (MJ/d)				
ME intake	193.0	194.4	7.04	0.773
Heat production	122.5	121.9	3.27	0.793
Milk energy	67.7	65.5	3.40	0.343
Retained energy	2.3	7.6	2.61	0.068
Energetic utilization efficiency ²				
DE:GE	0.735	0.739	0.0102	0.213
ME:GE	0.630	0.632	0.0088	0.681
ME:DE	0.859	0.857	0.0032	0.310
Milk energy:ME intake	0.352	0.339	0.0115	0.188
Retained energy:ME intake	0.008	0.030	0.0272	0.109
ME_m ($MJ/kg^{0.75}$)	0.686	0.678	0.0161	0.831
k_l	0.641	0.641	0.0031	0.681

¹Non-HF animals included Norwegian (n = 50) and Holstein-Friesian crossbred dairy cows (n = 62).

²GE = gross energy; DE = digestible energy; ME_m = ME requirement for maintenance; k_l = the efficiency of ME use for lactation.

Figure 1. Linear regressions of milk energy output adjusted to zero energy balance ($E_{l(0)}$) against ME intake for lactating Holstein-Friesian (HF) and the non-HF group (included Norwegian and Holstein-Friesian crossbred dairy cows) of dairy cows.

Figure 2. Linear regressions of heat production (HP) against ME intake for lactating Holstein-Friesian (HF) and the non-HF group (included Norwegian and Holstein-Friesian crossbred dairy cows) of dairy cows.

2 groups of cows using either HP minus energy losses from the inefficiencies of ME use for lactation, energy retention, and pregnancy (0.686 vs. 0.678 MJ/kg^{0.75}) or by calculating from the linear regression of milk energy output adjusted to zero energy retention against ME intake (0.688 vs. 0.686 MJ/kg^{0.75}). These results are in line with those obtained by Xue et al. (2011) using data derived from a repeated factorial design study with 8 Holstein and 8 Jersey-Holstein crossbred dairy cows, who found similar ME_m values for Holstein and Jersey-Holstein cows (0.71 vs. 0.67 MJ/kg^{0.75}). An early study by Ferris et al. (1999) also reported no difference in ME_m values between high- and medium-genetic-merit HF cows. These results indicate that crossbreeding of HF cows may have little effect on the basal metabolic

rates of HF dairy cows, and the maintenance energy requirement derived from HF cow data can be used to ration HF crossbred cows.

It is interesting to note that, in the present study, ME_m values (MJ/kg^{0.75}) calculated for individual cows were positively related to ME intake (MJ/kg^{0.75}). With each increase of 1 unit of ME intake (MJ/kg^{0.75}), ME_m values (MJ/kg^{0.75}) were increased proportionately by 0.065 or 0.062 MJ/kg^{0.75} (with a constant of 0.556 MJ/kg^{0.75}) for HF or non-HF dairy cows. This may reflect the increased metabolic burden caused by additional feed intake. An increase in feed intake is always accompanied by increases in gut fill, oxygen consumption, cardiac output, and blood flow to digest, absorb, and deliver nutrients to the mammary gland (Reynolds,

Table 4. Comparison of linear relationships between ME intake and energetic variables (with a common constant) for Holstein-Friesian (HF) and the non-HF group of dairy cows¹

Group	Variable ²	Equation			R ²	Equation
		Slope	Constant			
HF	ME _m =	0.065 _(0.0121)	ME intake	0.556 _(0.0236)	0.38	[1a]
Non-HF		0.062 _(0.0135)	ME intake			[1b]
HF	E _{l(0)} =	0.644 _(0.0113)	ME intake	−0.443 _(0.0223)	0.86	[2a]
Non-HF		0.646 _(0.0126)	ME intake			[2b]
HF	HP =	0.300 _(0.0090)	ME intake	0.566 _(0.0184)	0.78	[3a]
Non-HF		0.298 _(0.0101)	ME intake			[3b]
HF	ME _m :ME intake =	−0.197 _(0.0073)	ME intake	0.742 _(0.0143)	0.63	[4a]
Non-HF		−0.195 _(0.0081)	ME intake			[4b]
HF	E _{l(0)} :ME intake =	0.178 _(0.0072)	ME intake	0.055 _(0.0142)	0.55	[5a]
Non-HF		0.177 _(0.0080)	ME intake			[5b]
HF	HP:ME intake =	−0.218 _(0.0068)	ME intake	1.021 _(0.0133)	0.65	[6a]
Non-HF		−0.215 _(0.0075)	ME intake			[6b]

¹Non-HF animals included Norwegian (n = 50) and Holstein-Friesian crossbred dairy cows (n = 62). No significant difference was found between slopes in any pair of the relationships; values in subscript parentheses are SE.

²Unit = MJ/kg^{0.75} for ME intake, ME_m (ME requirement for maintenance), E_{l(0)} (milk energy output adjusted for zero energy balance), and HP (heat production).

1996). These activities in return can increase the internal organ size and the metabolizable burden, which consequently produces more heat than that of muscle (Baldwin et al., 1985). However, in the majority of energy feeding systems currently adopted in North America (e.g., NRC, 2001) and Europe (e.g., AFRC, 1993; INRA, 1989; Van Es, 1978), a single fixed maintenance energy requirement value ($\text{MJ/kg}^{0.75}$) is used to ration all dairy cows, irrespective of levels of production. Therefore, using these systems may underestimate the maintenance energy requirement for high-yielding dairy cows.

Effect of Cow Group on Energetic Efficiency for Lactation

In the present study, the k_l value was determined on an individual-animal basis using milk energy output adjusted to zero energy retention divided by differences between ME intake and ME_m , with the latter calculated from the present data set (described previously). The ANOVA test found no significant difference in k_l values between Norwegian and HF crossbreds (0.654 vs. 0.650) or between HF and non-HF groups (0.641 vs. 0.641). These values are all close to that of 0.64, calculated using equations recommended by AFRC (1993) and SCA (1990; $k_l = 0.35 \times \text{ME}/\text{GE} + 0.42$), and 0.62, calculated by Van Es (1978) and INRA (1989; $k_l = 0.24 \times \text{ME}/\text{GE} + 0.463$).

Evidence indicates that k_l values remain relatively constant over a wide range of conditions such as dietary composition, animal genotype, and production level (Agnew and Yan, 2000), whether they are calculated from linear regression (relating adjusted milk energy output to ME intake) or from multiple regression (relating ME intake to metabolic BW, milk energy output, and energy balance; Van Es et al., 1970). Within the same breed (HF), Gordon et al. (1995) reported that k_l values were similar for low-, medium-, and high-merit cows (0.59 vs. 0.58 vs. 0.58), although these values were smaller than those obtained in the present study. Ferris et al. (1999) also found that k_l values for high- and medium-merit HF cows were similar, indicating that genetic merit has little effect on the partial efficiency of ME utilization for lactation. Yan et al. (2006) reported that HF cows, compared with Norwegian dairy cows, had the ability to partition more energy into milk and less into body tissue. However, when both milk energy and body tissue energy were taken into account for in calculation of k_l values, breed had no significant effect on k_l values (Yan et al., 2006). A similar result was obtained by Xue et al. (2011), in that crossbreeding of Holstein cows with Jersey (Holstein vs. Jersey-Holstein) had no significant effect on k_l values calculated for a pe-

Figure 3. Linear regressions of ME requirement for maintenance (ME_m) against ME intake for lactating Holstein-Friesian (HF) and the non-HF group (included Norwegian and Holstein-Friesian crossbred dairy cows) of dairy cows.

riod from early to late lactation. These results support the view that dietary and animal factors have little effect on k_l values when accounting for both milk energy output and body tissue energy retention (Agnew and Yan, 2000).

CONCLUSIONS

The effects of cow group on maintenance energy requirement and energetic efficiency were examined in a meta-analysis using a large calorimeter chamber data set with lactating dairy cows. The statistical analysis demonstrated no significant difference in ME requirement for maintenance or the efficiency of ME use for lactation between Norwegian dairy cows and HF crossbred with Jersey or Norwegian dairy cows. The data from these cows were combined (categorized as non-HF) and compared with data from HF dairy cows. The results again indicated that different groups of dairy cow (HF vs. non-HF) had no significant effect on ME requirement for maintenance or the efficiency of ME use for lactation. However, the present study found that the ME requirement for maintenance ($\text{MJ/kg}^{0.75}$) was not a constant value, as currently adopted in the majority of energy feeding systems around the world, but increased with increasing ME intake ($\text{MJ/kg}^{0.75}$). Using these systems to ration dairy cows may underestimate the maintenance energy requirement for high-yielding animals.

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