Relationships Between Energy Balance and Health Traits of Dairy Cattle in Early Lactation

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ABSTRACT

The objective of the study was to calculate phenotypic relationships between energy balance in early lactation and health and reproduction in that lactation. Data were 26,701 daily records of dry matter intake and milk production, periodic measures of milk composition and body weight, and all health and reproductive information from 140 multiparous Holstein cows. Daily energy balance was calculated by multiplying feed intake by the concentration of energy of the ration and subtracting the amount of energy required for maintenance (based on parity and body weight) and for milk production (based on yield and concentrations of fat, protein, and lactose). Six measures of energy balance were defined: mean daily energy balance during the first 20, 50, and 100 d of lactation; minimum daily energy balance; days in negative energy balance; and total energy deficit. Measures of health were the numbers of occurrences of each of the following during lactation: all udder problems, mastitis, all locomotive problems, laminitis, digestive problems, and reproductive problems. Reproductive traits were the number of days to first observed estrus and number of inseminations. Several significant relationships between energy balance and health were observed. Increased digestive and locomotive problems were associated with longer and more extreme periods of negative energy balance.
(**Key words:** energy balance, health, reproduction, dairy cattle)

Abbreviation key: ALL = all health problems, **DAYS** = number of days in negative energy balance, **DIG** = digestive problems, **DTFH** = days to first heat or breeding, **EB** = energy balance, **EB20** = mean of energy balance during d 10 to 20 of lactation, **INSEM** = number of inseminations, **LAM** = laminitis, **LOCO** = all locomotive problems, **MAST** = mastitis, **MEB** = minimum energy balance, **NEB** = negative energy balance, **REPRO** = reproductive problems, **TED** = total energy deficit, **UDDER** = all udder problems.

INTRODUCTION

Feed costs are a major operating expense associated with the production of milk. Increasing the efficiency of feed utilization could have a significant impact on profit. Feed efficiency can be defined as the output of milk divided by the input of feed. An increase in milk production and a decrease in feed intake can increase feed efficiency. However, during certain stages of lactation, a decrease in feed intake may be detrimental to the health of the cow.

In early lactation, dietary intake is unable to meet the demands of high milk production. The cow therefore enters a period of negative energy balance (**NEB**), which leads to mobilization of body reserves to balance the deficit between food energy intake and milk energy production (3). The process of mobilization seems to affect the well being of the cow, and other biological pathways are compromised as intake energy is directed toward production. Knight et al. (13) used the terms metabolic load and metabolic stress to describe effects of high production on dairy cattle. According to Knight et al. (13), metabolic load can be defined as "the burden imposed by the synthesis and secretion of milk" and metabolic stress can be defined as "that amount of metabolic load which cannot be sustained, such that some energetic processes, including those that maintain general health, must be down regulated."

Some health and reproductive problems may be a result of the increased stress that high producing cows are under in early lactation. Effects of NEB and metabolic stress on reproductive performance have been investigated and were reviewed by Butler and Smith (7) and

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Nebel and McGilliard (19). Results generally suggest that NEB compromises reproductive performance. Butler et al. (6) and Canfield et al. (8) found that NEB extended the postpartum interval to first ovulation. Domenq et al. (10) reported that decreases in BCS during the first month of lactation were associated with decreased conception rate. Body condition scores decrease as body reserves are mobilized to compensate for NEB. Some indications of relationships between NEB and other health problems have been reported. Manson and Leaver (16) and Wells et al. (33) reported that increased lameness was associated with decreased BCS.

The objective of this study was to estimate phenotypic relationships between EB of dairy cattle in early lactation and health and reproductive performance during that lactation.

Table 1. Typical chemical analysis of the standard total mixed ration[1] for early lactation cows at the Lennoxville research station.

Nutrient	Composition
Forage:Concentrate	41:59
ADF,[2] % DM	20.20
NDF,[2] % DM	37.30
Net energy of lactation,[3] Mcal/kg	1.63
NSC, % DM	34.60
Fat, % DM	3.30
Protein,[4] % DM	16.30
Nondegradable proteins (% DM)	5.60
Calcium,[5] % DM	0.91
Phosphorus,[5] % DM	0.50
Selenium,[5] % DM	0.29

[1]Dry matter for grass hay and concentrates method 7.003 (2).

[2]According to Van Soest et al. (31).

[3]Gross energy determined by adiabatic bomb calorimeter (model #1241, Gallenkamp, Cambridge, UK), [$NE_L = 2.2 \times (0.866 - 0.007 \times$ ADF %)] as used by Wright et al. (34).

[4]According to method 7.016 (2).

[5]According to method 7.077 (2).

MATERIALS AND METHODS

Data

Data used for this study consisted of information on single lactations from 140 multiparous Holstein cows at the Agriculture and Agri-Food Canada Dairy and Swine Research and Development Centre in Lennoxville, Quebec, Canada. Each cow was involved in one of four experiments (e.g., 11, 24) that were conducted at the farm between 1992 to 1997. Extensive data were collected for these cows, including daily records of milk yield and feed offered and refused, periodic measures of milk composition (monthly and sometimes weekly) and BW (every 100 d of lactation, monthly, or weekly), and all health and reproductive information. In addition, most of the cows were evaluated by the type classification program of the Canadian Holstein Association, and these data were obtained from a database maintained by the Canadian Dairy Network (Guelph, ON, Canada).

Cows were fed with an automated feeding system capable of providing individual TMR. At the beginning of lactation, all cows were fed a similar ration balanced for high production (>36 kg/d). Table 1 shows the basic chemical analysis of the typical diet. After cows passed peak production and began to increase body condition they were fed a ration balanced for production. This change usually occurred in mid to late lactation after cows reached positive EB and was, therefore, not expected to affect the results of this study. The diet (Table 1) was slightly modified according to the protocol of the experiments being conducted (e.g., 11, 24) but these modifications were typically in levels of certain feed additives that made up a relatively small proportion of the diet and were not expected to greatly influence intake. Nevertheless, the respective treatment for each cow was recorded and accounted for in all analyses.

The data were used to obtain daily estimates of energy balance (**EB**) and, subsequently, several measures of EB in early lactation relating to: 1) severity of NEB, 2) duration of NEB, and 3) total energy deficit, or metabolic load. Daily EB was calculated by multiplying DMI (kilograms of feed offered minus refused) by the concentration of net energy in the TMR and subtracting the expected (NRC) amount of energy required for maintenance, based on parity and BW (18) and for milk production, based on yield and concentrations of fat, protein, and lactose (30). Because BW and milk composition were not available on a daily basis, estimates of daily values for these measurements were obtained by linear extrapolation between the days upon which actual measurements were taken.

Net energy for maintenance (Mcal/day) was calculated as $(0.08 * BW^{0.75}) * C_P$, where BW is body weight (in kg) and C_P was a constant that varied according to parity. C_P = 1.2, 1.1, and 1.0 for first, second, and third or later parities, respectively (18).

Estimates of the NE_L (Mcal/kg) of the TMR were calculated using the Cornell Net Carbohydrate and Protein System (27), with modifications to the fat factor in the total digestible nutrient calculation (32). If these estimates of NE_L were not available, the NE_L (Mcal/kg) of the TMR were calculated according to Wright et al. (34), using the following equation:

$$NE_L \text{ of the TMR} = 2.2 \times (0.866 - 0.007 \times \text{ADF } \%). \quad [1]$$

The following equations of Tyrrell and Reid (30) were used to calculate net energy required for milk production (kcal/d), depending on whether lactose percent was measured.

$$\text{Milk energy (kcal/kg)} = 41.63\ (\text{fat }\%) + 24.13\ (\text{protein }\%) + 21.60\ (\text{lactose }\%) - 11.72, \text{ or} \quad [2]$$

$$\text{Milk energy (kcal/kg)} = 40.72\ (\text{fat }\%) + 22.65\ (\text{protein }\%) + 102.77 \quad [3]$$

Six EB traits were derived from the daily measures of EB, namely minimum daily energy balance (**MEB**), number of days in negative energy balance (**DAYS**), total energy deficit (**TED**), and mean daily energy balance during different periods of early lactation. The MEB was a measure of the severity of NEB and was defined for each cow as the mean energy deficit during the particular 5-d period for which the energy deficit was the most severe. The first 5 d of lactation were not included because milk composition changes drastically during that period and no actual measurements were available. The DAYS was a measure of the duration of NEB. DAYS was difficult to determine precisely because the transition in daily energy balance from consistently negative to positive rarely occurred over the course of a single day. Rather, EB varied from day to day and tended to move gradually from negative to positive by alternating above and below zero for several days. Therefore, to establish the end of NEB, sequential 20-d periods of EB data were examined for each cow. The end of NEB was defined as the earliest 20-d period during which the cow was in positive EB for at least 10 d. The DAYS was defined as the 10th day of this 20-d period. This approach was based on Tukey's (29) medians of n (n = 20) method of smoothing. Twenty days was chosen because lower numbers tended to yield underestimates of length of NEB and greater numbers produced results that differed little from n = 20. The TED was the sum of daily EB from calving to the end of NEB as determined by DAYS. Finally, EB20, EB50, and EB100 were calculated as the mean daily EB during days 10 to 20, 10 to 50, and 10 to 100 of lactation, respectively. The purpose of three different mean values was to determine if any of the three intervals better helped to determine which proportion of early-lactation NEB was most detrimental to health of dairy cattle.

An alternative approach for deriving the six EB traits was examined. Rather than using the observed values of daily energy balance directly to derive the EB traits, we used the daily measures of EB to fit a curve for EB across the lactation. Estimates of daily EB from this curve were then used to calculate several of the EB traits. The regression equation of Ali and Schaeffer (1) was chosen because it was shown to accurately fit the lactation curve, and the EB curve is nearly a mirror image of the lactation curve:

$$Y = a + b\ (\text{dim}/305) + c\ (\text{dim}/305)^2 + d\ ln\ (305/\text{dim}) + e\ (ln\ (305/\text{dim}))^2 + \varepsilon, \quad [4]$$

where Y is observed EB on a given day in milk, a, b, c, d, and e are the regression coefficients, and ε is a random residual. The coefficient a is associated with minimum EB, d and e are associated with the decreasing slope of the curve, and b and c are associated with the increasing slope.

The primary reason for using this curve-fitting method was to obtain a distinct estimate of the day when the cows reached positive EB, but MEB and TED were also estimated from the curve. This procedure has the potential to be particularly useful when intake is not measured daily.

Health and reproductive data were recorded during weekly routine veterinary visits; any health care performed by the farm employees between veterinary visits was also recorded. Included in the data were every action taken by attending veterinarians and the dates of events such as dates of birth, inseminations, dry periods, and calvings. Also, dates of changes in behavior, such as estrus, and treatments performed by the farm staff for common diseases, such as mastitis and lameness, were recorded. The frequencies of most diseases were too low for reasonable analyses to be performed, so the approach of Lyons et al. (15) was used to combine diseases into four categories, 1) all udder problems (**UDDER**), 2) all locomotive problems (**LOCO**), 3) reproductive problems (**REPRO**), and 4) digestive problems (**DIG**). Table 2 shows the four major health categories and the diseases included in each. Mastitis (**MAST**) and laminitis (**LAM**)

Table 2. Individual traits included in each health category.

Health category	Individual trait
Mammary	Mastitis
	Udder or teat injury
	Udder edema
Locomotive	Laminitis
	Leg problems
	Hock problems
	Inflamed thigh
Digestive	Milk fever
	Ketosis
	Displaced Abomasum
	Significantly reduced appetite (>50%)
	Diarrhea
	Indigestion
Reproductive	Cystic ovaries
	Retained placenta
	Uterus infection
	Metritis
	Vaginitis

Table 3. Measures of incidence for the various diseases.

Health Trait[1]	Lactational incidence	Maximum
	(%)	(N)
UDDER	37.1	10
MAST	35.0	10
LOCO	35.0	8
LAM	25.7	8
DIG	19.3	6
REPRO	16.4	5
ALL	67.8	10

[1]UDDER = All udder problems, MAST = mastitis, LOCO = all locomotive problems, LAM = laminitis, DIG = digestive problems, REPRO = reproductive problems, ALL = any disease.

occurred at high enough frequencies that they were identified as their own categories, but were also included within the udder and locomotive categories, respectively. To determine if general health was related to NEB, a final category was defined that included all health problems that occurred (**ALL**). Table 3 lists the different disease categories, with the lactational incidence (percentage of cows affected) by each health category, the percentage of cows with repeated episodes (N > 1) and the maximum number of cases per cow. The number of inseminations (**INSEM**) and days to first heat or breeding (**DTFH**) were calculated as additional reproductive traits.

The type traits included those traits of the cow's first lactation linear classification record that described the size and shape of the cow. These traits included frame and capacity, stature, size, chest width, body depth, and dairy character. Only 98 of the cows in the data set had linear classifications available.

Analyses

Several analyses were conducted. Phenotypic relationships between health traits and each of the EB traits were estimated by regressing each EB trait on the health traits by using the following model:

$$Y_{ijkl} = \mu + p_i + t_j + X_k B_k + e_{ijkl}, \qquad [5]$$

where Y_{ijkl} is the EB trait, μ is the overall mean, p_i is the fixed effect of parity i, t_j is the fixed effect of experimental treatment j, X_k is the number of occurrences of disease k, B_k is the regression coefficient of the EB trait on number of occurrences of disease k, and e_{ijkl} is a random residual. The fixed effect of experimental treatment included 16 subclasses that accounted for the four experiments that the respective cows were involved in and their respective treatments. The Lennoxville research herd is managed in a seasonal calving program, so the treatment affect also accounted for year and season effects. Health traits were analyzed as: 1) number of occurrences of the disease (within the lactation), 2) a dichotomous variable (0 indicating the absence of disease and 1 indicating one or more occurrences of the disease within a lactation), and 3) a square root transformation of number of occurrences of disease. These three definitions of the health traits were created to determine if EB had a linear relationship with the number of occurrences of a given health problem. For comparison, an additional set of analyses was performed to account for possible effects of parity and treatment on health. In these analyses, the health and EB traits were both used as dependent variables in the model with parity and treatment as independent variables. Correlations were calculated between the residuals for these models.

Phenotypic relationships between type traits and each of the EB and health traits were estimated by linear regression. Each of the type traits was regressed on the health traits using the following model:

$$Y_{ijkl} = \mu + p_i + t_j + X_k B_k + e_{ijkl}, \qquad [6]$$

where Y_{ijkl} is the linear score (adjusted for effects of classifier, date of visit, and age and stage of lactation) that cow l received for a given type trait, μ is the overall mean, p_i is the fixed effect of parity i, t_j is the fixed effect of experimental treatment j, X_k is either the number of occurrences of the health trait within lactation i, or the measure of EB trait k, B_k is a regression coefficient, and e_{ijkl} is a random residual.

RESULTS

Phenotypic means and standard deviations of various traits are in Table 4. Means were based on daily records from 5 to 100 d of lactation to emphasize the early part of lactation when NEB is most severe. Compared to Oldenbroek and Veerkamp (22), the cows in this study produced more milk, were heavier, consumed slightly less energy, required more energy for maintenance, and had a greater average EB during the first 100 d of lactation.

Residual correlations among EB traits are shown in Table 5. The EB traits were moderately to highly correlated. All correlations were positive with the exception of correlations with DAYS, which increased when other measurements of EB decreased.

Several of the health and disease and reproductive traits were highly correlated with each other (Table 6). Correlations of UDDER with MAST (0.983) and of LAM with LOCO (0.886) were close to unity, as expected due to part-whole relationships. Likewise, the correlations of ALL with each of the disease categories were significantly greater than zero. The trait INSEM was moderately correlated with REPRO (0.369), indicating that

Table 4. Means and standard deviations of daily[1] components of energy balance and of the calculated actual (A) and fitted (F) energy balance traits[2].

Variable	Mean	S.D.
Daily milk yield, kg	35.0	8.5
Daily DMI, kg	18.9	3.8
Live weight, kg	591	70
Net energy for milk, kcal	23778	5610
Net energy for feed, kcal	30895	6415
Net energy for maintenance, kcal	10732	800
EB100, kcal	–3312	3358
EB50, kcal	–5109	3610
EB20, kcal	–6867	5007
MEB_A, kcal	–10340	6139
MEB_F, kcal	–10874	5954
$DAYS_A$, days	63	42
$DAYS_F$, days	87	57
TED_A, kcal	–337646	245607
TED_F, kcal	–358201	296659

[1]Days 5 to 100 of lactation.

[2]EB100 = Mean energy balance during days 10 to 100 of lactation, EB50 = mean energy balance during days 10 to 50 of lactation, EB20 = mean energy balance during days 10 to 20 of lactation, DAYS = number of days in negative energy balance, MEB = minimum energy balance, and TED = total energy deficit.

more inseminations were performed on animals experiencing reproductive problems in early lactation.

Correlations between residuals of health and EB traits are also shown in Table 6. Locomotive traits, LAM in particular, and DIG had the strongest relationships with NEB, compared with other health traits. LAM and LOCO were more strongly associated with MEB and TED, whereas DIG had a greater correlation with DAYS. A somewhat less significant ($P < 0.10$) relationship was observed between DAYS and REPRO (–0.209). Correlations of EB50 and EB100 with LOCO and LAM were moderate and negative but were not as closely associated with health traits as were the other EB traits. No relationships were found with UDDER, MAST, reproductive performance (DTFH and INSEM), and any EB traits.

To help to quantify and illustrate relationships between health and EB, Table 7 has the mean difference in EB for affected and unaffected cattle for several of the health traits and EB measures for which a significant ($P < 0.10$) difference was observed. Cows with laminitis had lower EB in the first 100 (–792 kcal) and 50 (–1064 kcal) d of lactation, a more severe TED (–116,124 kcal) and MEB (–11,690 kcal), and were in NEB 12 d longer than cows that did not have laminitis. Cows with digestive problems had lower MEB, longer DAYS, and lower TED, than did healthy cows. Digestive problems were associated with a –7820 kcal lower MEB, 12 additional days of NEB, and a greater total energy deficit (–68,594 kcal). On average, the period of NEB was reduced by 14 for cows experiencing reproductive disorders.

A square root transformation of the number of cases of each disease and the addition of a quadratic term did not improve the fit of the regression model to analyze relationships between health and EB. Relationships of health with measures of EB were similar to the results observed when disease values were linear or dichotomous variables and P values tended to be lower.

The means and standard deviations of the EB traits found by 1) using the actual daily observations (actual), and 2) by using the daily measures of EB to fit a smooth curve [4] for EB across the lactation (fitted) are given in Table 4. Fitting the curve tended to yield a significantly greater ($P < 0.001$) mean for DAYS, but on average, MEB and TED were only slightly different (nonsignificantly) from actual values. The fitted value of DAYS for some cows was influenced by measures of daily EB long after a state of positive EB was initially achieved. For various reasons, some cows experienced a short period of low or negative EB in mid or late lactation. For these cows, the fitted curve for EB was flat, resulting in a greater estimate for DAYS. When the EB traits from the fitted curve were regressed on the health traits, results were similar to those from the actual observed values, but generally less significant statistically.

No significant ($P < 0.10$) relationships were found between the type traits and EB traits. Residual correlations between type traits and health traits are shown in Table 8. UDDER and MAST were positively correlated with frame and capacity, size, and chest width, with correlations ranging from 0.28 to 0.41, indicating that the phenotypically larger cows had more udder problems. A favorable relationship was found between LOCO and chest width. LAM, REPRO, and DIG were unrelated to type.

Table 5. Residual correlations[1] among all energy balance traits[2].

	EB50	EB20	MEB	DAYS	TED
EB100	0.75	0.53	0.57	–0.45	0.62
EB50		0.74	0.72	–0.34	0.69
EB20			0.58	–0.18	0.57
MEB				–0.39	0.67
DAYS					–0.77

[1]$P < 0.001$.

[2]EB100 = mean energy balance during days 10 to 100 of lactation, EB50 = Mean energy balance during days 10 to 50 of lactation, EB20 = mean energy balance during days 10 to 20 of lactation, MEB = minimum energy balance, DAYS = number of days in negative energy balance, TED = total energy deficit.

DISCUSSION

Our results indicated that mobility problems were phenotypically associated with NEB (Tables 6 and 7). In particular, mobility problems were associated most strongly with MEB and TED, measures of excessive imposed metabolic load, rather than strictly the duration

Table 6. Residual correlations between energy balance health and reproductive traits[1].

	Health							Reproductive	
	LOCO	LAM	DIG	REPRO	UDDER	MAST	ALL	INSEM	DTFH
EB100	−0.16†	−0.21*	−0.10	0.04	0.03	0.02	−0.08	0.11	−0.04
EB50	−0.15†	−0.21*	−0.08	0.02	−0.02	−0.03	−0.11	0.11	−0.08
EB20	−0.02	−0.20	0.04	−0.04	0.04	0.03	0.02	0.10	−0.05
MEB	−0.20**	−0.30***	−0.17*	0.04	0.04	0.04	−0.12	0.09	0.05
DAYS	0.15†	0.20*	0.28***	−0.21*	−0.09	−0.05	0.05	0.04	−0.05
TED	−0.25**	−0.33***	−0.18*	0.08	0.04	0.02	−0.13	0.06	−0.03
LOCO		0.89***	0.11	−0.03	−0.07	−0.07	0.48***	0.06	−0.10
LAM			0.06	−0.00	−0.06	−0.06	0.42***	0.02	−0.11
DIG				−0.05	0.07	0.06	0.44***	0.12	−0.09
REPRO					0.07	0.09	0.30***	0.37***	−0.02
UDDER						0.98***	0.73***	0.16†	0.00
MAST							0.72***	0.16†	0.00
ALL								0.28***	−0.08
INSEM									0.05

[1]EB100 = Mean energy balance during days 10 to 100 of lactation, EB50 = mean energy balance during days 10 to 50 of lactation, EB20 = mean energy balance during days 10 to 20 of lactation, MEB = minimum energy balance, DAYS = number of days in negative energy balance, TED = total energy deficit, LOCO = all locomotive problems, LAM = laminitis, DIG = digestive problems, REPRO = reproductive problems, UDDER = all udder problems, MAST = mastitis, ALL = all health problems, INSEM = number of inseminations, DTFH = days to first heat or breeding.

†$P < 0.10$, *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$.

of metabolic load (DAYS). Laminitis can be caused by the cow's inability to consume sufficient DM during early lactation to meet the demands of high production. A dairy herd manager often tries to compensate for this inability by increasing feeding more concentrates with readily digestible forms of carbohydrates, which increases the energy concentration of the diet. As the amounts of concentrates are increased, fiber in the diet is decreased, and saliva production and rumination time decrease, which decreases ruminal pH (21). As pH decreases, histamine and other endotoxins are released into the blood, which can cause vasodilation, ultimately damaging the network of blood vessels in the hoof (5). In turn, the function of cells that produce claw tissue is disrupted, decreasing the quality of the hoof. Disease conditions such as sole ulcers and heel erosion can result partly because a decrease in sole quality increases wear.

Table 7. Differences[1] in the means of energy balance traits for cows affected and unaffected by various diseases.

Health Trait[2]	Energy Balance Trait[3]	Difference in Means
LOCO	MEB	−6882 kcal†
	TED	−98116 kcal***
LAM	EB100	−792 kcal†
	EB50	−1064 kcal*
	MEB	−11690 kcal**
	DAYS	12 days*
	TED	−116124 kcal***
DIG	MEB	−7820 kcal*
	DAYS	12 days*
	TED	−68594 kcal*
REPRO	DAYS	−14 days*

†$P < 0.10$, *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$.

[1]Affected minus unaffected.

[2]LOCO = All locomotive problems, LAM = laminitis, DIG = digestive problems, REPRO = reproductive problems.

[3]EB100 = Mean energy balance during days 10 to 100 of lactation, EB50 = mean energy balance during days 10 to 50 of lactation, DAYS = number of days in negative energy balance, MEB = minimum energy balance, TED = total energy deficit.

The pain of laminitis can compound the problems associated with NEB. Cows tend to spend more time resting and less time eating when laminitis causes severe discomfort. Several studies report associations between indirect measures of NEB and lameness. In a study that evaluated clinical lameness in 24 herds in Minnesota, Wisconsin, and Virginia, Boettcher et al. (4) reported that lameness was most common during the first 50 d of lactation, when NEB would be most severe. Logue et al. (14) reported a significantly higher prevalence and incidence of clinical lameness in a high-input herd (unrestricted quota, fed ad libitum forage and concentrates, milked 3×) compared with a low input herd (restricted quota, restricted feeding, milked 2×). Manson and Leaver (16) and Wells et al. (33) reported that, phenotypically, increased lameness was associated with decreased BCS. A decrease in condition is evidence of tissue mobilization to compensate for NEB, but cause and effect would be difficult to infer because the pain of laminitis could cause NEB due to lowered intake. Results reported by Treacher et al. (28) suggested that significantly more cases of disease (mastitis, retained placenta, ketosis, milk fever, and lameness) occurred after calving in overconditioned cows than in the underconditioned cows. Overconditioned cattle with inadequate feed intake in early

Table 8. Residual correlations between the type and health traits[1].

	UDDER	MAST	LOCO	LAM	REPRO	DIG
Frame and capacity	0.30**	0.28**	–0.10	–0.07	0.09	–0.03
Stature	0.33***	0.32***	0.15	0.14	0.10	0.10
Size	0.36***	0.34***	–0.08	–0.08	0.04	0.04
Body depth	0.11	0.13	0.12	0.13	–0.13	0.06
Chest width	0.41***	0.38***	–0.18*	–0.15	0.05	0.01
Dairy character	0.09	0.07	–0.00	–0.08	0.05	–0.05

[1]UDDER = All udder problems, MAST = mastitis, LOCO = all locomotive problems, LAM = laminitis, REPRO = reproductive problems, DIG = digestive problems.

*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$.

lactation have more problems dealing with the increased tissue mobilization (26).

As mentioned earlier, REPRO was the only reproductive trait with a significant relationship with EB (–0.21 with DAYS, Table 6). This relationship indicated that cows with reproductive disorders tended to reach a stage of positive energy balance more quickly. Most of these reproductive disorders likely occurred at calving or in the early stages of lactation (12) and may have depressed milk production, which reduces energy needs and possibly allows cows to reach positive EB more quickly. The average milk production of the 23 cows that experienced a reproductive problem was 29.92 kg, which was significantly ($P < 0.05$) less than the 31.99 kg average for the remaining 117 cows.

The reproductive performance traits DTFH and INSEM had no significant relationships with EB (Table 6) which conflicts with results of several previous studies (6, 7, 8). Butler and Smith (7) reported that NEB and the rate of mobilization of body reserves appeared directly related to the postpartum interval to first ovulation and lower conception rate. Canfield et al. (8) found that days to minimum energy balance was phenotypically correlated ($r = 0.75$) with days to first ovulation.

No studies that we are aware of have reported relationships between type and energy balance. Very few studies have reported relationships between type and health. Rogers et al. (25) found that stature and body depth were unfavorably correlated to somatic cell score in Jerseys. Higher somatic cell scores would be indicative of mastitis. In the present study, frame and capacity, stature, size, and chest width were unfavorably correlated with mastitis, whereas body depth was the only body trait that was not correlated to mastitis. The relatively low number of observations in our study makes it difficult to draw general conclusions about relationships between type and health traits. Parke Jr. et al. (23) reported numerous phenotypic relationships between milk yield, energy intake, feed efficiency, BW, and body size type traits. Capacity, size, and stature were highly related to BW, with phenotypic correlations ranging from 0.36 to 0.43. In addition, feed efficiency was negatively correlated with BW (–0.29), capacity, size, and stature (all –0.12). These results suggest that BW and related type traits should have a negative selection emphasis placed upon them.

A next logical step in examining health and EB traits would be to determine if observed relationships among the traits have a genetic basis. If so, then selection could be used to help avoid severe NEB and associated health problems. In a previously reported study using this data (9), estimates of heritabilities for all energy balance traits were zero, but with large standard errors. Previously reported estimates of heritability for similarly defined measures of EB in dairy cattle have been variable, ranging from essentially zero (20) to moderately high, 0.51 (22). A common feature of our study and most others dealing with EB in cattle is that the data are too few for reliable estimates of genetic parameters.

A common feature of our study and most others dealing with EB in cattle is that the data are too few for reliable estimates of genetic parameters. Several approaches to gathering more data to estimate genetic parameters could be taken. The first is to combine small sets of data already collected from research stations and perform an analysis of the pooled data. A second approach involves collection of intake in the field, possibly on a test day rather than on a daily basis to save costs, and predicting EBV for energy balance by fitting a lactation curve. A similar approach was practiced on a selection of Quebec herds, although test-day estimates of concentrate intake were based on amounts of feed offered, and estimates of forage intake were based on BW (17). A third approach would be to use indirect measures of energy balance, such as condition scores. All approaches would require comprehensive recording of health and reproductive data and would be costly, but may be justified given the expense of feed and health problems such as laminitis.

CONCLUSIONS

Several significant phenotypic relationships were found between EB and health. Specifically, both digestive and locomotive problems were unfavorably associated with measures of EB. In particular, a strong relationship was observed between the maximum amount of metabolic load (MEB) and laminitis. The importance of genetic effects on these relationships needs to be considered, because continued selection for high production may increase the proportion of cows in extreme NEB during early lactation.

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