Energy balance in first-lactation Holstein, Jersey, and reciprocal F₁ crossbred cows in a planned crossbreeding experiment

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ABSTRACT

The Virginia Tech crossbreeding project began in the fall of 2002 by mating Holstein (H) and Jersey (J) foundation females to Holstein and Jersey bulls to create HH, HJ, JH, and JJ genetic groups, where the sire breed is listed first followed by dam breed. Collection of individual daily feed intakes began in September 2005 and continued through November 2008, resulting in observations on 43, 34, 41, and 22 HH, HJ, JH, and JJ cows, respectively. Intakes were measured for 2 wk out of every 6-wk period for first-lactation cows less than 310 d in milk. The ration was analyzed for dry matter and nutrient content, which was used to calculate net energy of lactation (NE_L, Mcal/kg). Body and milk weights were collected daily with milk components measured monthly. The NE_L requirements for maintenance, growth (in the form of retained energy), pregnancy, and production were calculated using National Research Council (2001) equations. Random regression models were used to predict consumed NE_L and NE_L required for production, maintenance, and body weight at every week in lactation. Energy required for growth was calculated for each cow at each stage of lactation using five 2-mo stages. Energy balance was estimated by subtracting the predicted energy required for production, maintenance, growth, and pregnancy from the predicted NE_L consumed. A linear model with fixed effects of genetic group, year-season of calving group, and a linear and quadratic effect of age at calving was used to analyze the energy terms. The HJ and JH groups were not different in any of the analyses for energy terms. The HH cows consumed more energy than did HJ and JJ cows. There were no genetic group differences for total energy for pregnancy. The HH, HJ, and JH groups were not different from each other for energy required for production but required more energy for production than the JJ. The JH allocated a lower percentage of their energy intake to maintenance than the HH (25.7 to 27.4%) and the JJ allocated less

energy to growth than the HH and HJ. Genetic group explained significant variation for percentage of energy partitioned to production with the JJ allocating more energy to production than the HH (66.3 vs. 60.9%). Genetic group differences in characterization of energy balance warrant further study.

Key words: crossbreeding, dairy cow, energy balance

INTRODUCTION

Energy balance (EB) in dairy cattle is of increasing importance because selection for higher milk production has increased the use of body reserves in early lactation (Coffey et al., 2001; Koenen et al., 2001). Heavier reliance on body reserves in early lactation has a negative effect on fertility and health (Hansen, 2000; Banos et al., 2006). Energy balance reflects the difference between consumption of energy in the diet and usage of energy by the body to support maintenance, growth, milk production, and reproduction. When the animal is in negative EB, stored body fat and tissue are mobilized to meet extra needs or energy output is decreased. High-producing dairy cows do not usually eat enough in early lactation to maintain a positive EB. Extended periods of negative EB may lead to health problems, poor reproductive performance, and reduced production, and may lead to early culling or death (Collard et al., 2000; De Vries and Veerkamp, 2000; Coffey et al., 2004).

Several studies have investigated EB across lactations (Coffey et al., 2002; Banos et al., 2005; Friggens et al., 2007) and EB and the relationships to health and fertility traits (De Vries et al., 2000; Banos et al., 2006). A few studies have compared EB across genetic lines (Coffey et al., 2004; Friggens et al., 2007; Patton et al., 2008). Coffey et al. (2004) found that cows selected for high productivity were predisposed to use body energy reserves to support production. However, a study in Ireland found no differences between New Zealand Holstein-Friesians and North American Holstein-Friesians for energy balance, although the number of animals was limited in the study (Patton et al., 2008). Friggens et al. (2007) found significant differences in

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energy balance between breeds (Danish Holstein, Danish Red, and Jersey). The study found an interaction of breed by parity in the first half of lactation. The Jerseys mobilized more body energy in the first half of their first lactation compared with other breeds in the study. Advantages for crossbreds in EB terms (e.g., shorter return to positive EB) may exist; however, this has received minimal attention in the literature.

Crossbreeding is of current interest in the dairy industry, and the number of crossbreds has increased in the United States in the last 10 yr (VanRaden and Sanders, 2003). Crossbreeding has been shown to improve milk components, fertility, and productive life (VanRaden and Sanders, 2003; Anderson et al., 2007; Heins et al., 2008a,b). A few studies have investigated crossbreeding and feed efficiency, but they have produced mixed results. Heins et al. (2008b) and Wang et al. (1992) found that crossbreds did not differ from purebred Holsteins for feed efficiency, whereas Schwager-Suter et al., (2001) found crossbreds to have a greater feed efficiency. Prendiville et al. (2009) also found that net energy intake per unit of fat- and protein-corrected milk was more favorable for the Jersey and crossbred than for the pure Holstein in a pasture-based system. The literature contains little information on reciprocal crosses with both parental breeds in the same management setting.

The objectives of this study were to compare first-lactation purebred Holsteins, Jerseys, and reciprocal crosses for differences in EB and components of EB under a single management system.

MATERIALS AND METHODS

Experimental Design

The crossbreeding project at Virginia Tech (Blacksburg) began in the fall of 2002. The study was designed as a classical diallele scheme having Holstein (**H**) and Jersey (**J**) foundation females mated to 4 Holstein bulls and 4 Jersey bulls to create **JJ**, **HH**, **JH**, and **HJ** genetic groups, where sire breed is listed first. The foundation females were mated using heterospermic semen that consisted of a mix of one Holstein sire paired with one Jersey sire as explained by Kasimanickam et al. (2006). The first heifers from the project were born in June 2003, and calved for the first time between June 2005 and June 2008. A more detailed description of the study design was given by Olson et al. (2009) and only animals from the Virginia Tech dairy were included in this work. Only 14 Jerseys cows were available for this trial, partly because of the lower fertilization rates for the Jersey sperm compared with Holstein sperm in the heterospermic fertilization study (Kasimanickam et

al., 2006). We added 8 Jerseys that were offspring of project Jerseys, sired by 3 additional Jersey bulls, thus increasing total Jerseys to 22 cows. A total of 140 cows were used in the study, with 43, 34, 41, and 22 **HH**, **HJ**, **JH**, and **JJ**, respectively.

Data

Data collected contained daily DMI observations from first-lactation Holsteins, Jerseys, and reciprocal crosses. Individual daily feed intakes were measured in 2-wk intervals out of every 6-wk period (2 wk on, 4 wk off) using the Calan door system (American Calan, Northwood, NH). The 4 genetic groups were housed together and fed a common TMR ad libitum once a day throughout the study. The TMR was balanced periodically to accommodate forage and ingredient changes. Feed offered and refused was recorded each day for individual cows. Feed offered was adjusted over time so that refusal rates were approximately 10% of that offered on an as-fed basis. Forages, grains, and concentrates were submitted for standard nutrient analyses to Cumberland Valley Analytical (Hagerstown, MD) at least once during each trial period. Dry matter intake was calculated from nutrient analyses and as-fed intakes. Net energy for lactation (Mcal) concentration in the feed was calculated for each trial period using ration nutrient values and the NE_L from the feed analysis for each component of the TMR. The specific NE_L calculation for each component of the feedstuff can be found in the Appendix.

Intakes began in September 2005 and continued through November 2008. Each intake period included approximately 30 cows, but ranged from 8 cows in September 2005 to 48 cows in July 2007. All cows were housed in a single pen during the intake period, regardless of genetic group. Cows were required to be more than 2 wk in milk to be included in an intake period and were returned for subsequent intake collection periods until completion of 305 DIM. A total of 21 cows did not have the opportunity to complete a full lactation before data collection ended. Cows that had not finished a 305-d record as of November 2008 included 7 **JJ**, 12 **JH**, and 2 **HJ**. However, all of the cows were over 150 DIM by the end of the final intake period. Observations of milk weights, BW, and pregnancy status were discarded after the last feed intake collection.

A total of 32 feed intake observation periods were conducted including 4 trials from other nutrition feeding trials where intakes were unrestricted by ration or feed offered. Total feed intake data collected included 11,957 unedited daily observations. Daily intakes in terms of NE_L intake (**NEI**) were edited for equipment malfunctions and removal of cows that became notice-

Table 1. Means and ranges for intake, BW, and production traits in different genetic groups¹ in first lactation

Item ²	HH		HJ		JH		JJ	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
NEI (Mcal/d)	35.2	12.6–55.9	33.9	8.1–47.4	32.9	18.9–49.7	28.1	10.7–36.2
NEM (Mcal/d)	9.41	7.02–11.90	8.67	6.53–10.88	8.35	6.16–10.30	7.23	6.00–8.93
NEP (Mcal/d)	21.52	7.50–47.19	21.17	7.02–34.23	21.15	4.64–32.40	19.13	5.54–31.42
BW (kg)	576	390–788	517	354–700	492	328–651	406	316–538
BCS	2.81	1.75–4.25	2.84	1.00–4.50	2.65	1.50–3.75	2.74	1.75–4.00
DMI (kg)	21.37	7.55–34.05	20.28	5.35–28.58	20.00	11.37–29.24	17.05	6.35–21.97
Milk (kg)	31.78	5.59–58.16	27.87	4.42–58.16	28.97	5.00–51.77	23.42	4.58–40.65
Protein (%)	3.03	2.40–4.20	3.32	2.50–4.80	3.22	2.60–4.20	3.44	2.60–5.00
Fat (%)	3.45	1.60–9.50	4.19	2.50–6.50	3.91	2.50–6.50	4.74	3.10–9.80

¹Breed of sire listed first: Holstein (H), Jersey (J).

²NEI = NE_I intake; NEM = net energy for maintenance; NEP = net energy for milk production.

ably sick during the trial and removal was advised by a veterinarian, decreasing data from 11,957 to 11,844 observations. The first 5 d of the first observation period for a cow were discarded along with the first 2 d of subsequent observation periods, to allow time for adaptation to the Calan doors. This decreased the feed intake data set to 9,725 daily observations. Daily NEI observations were further edited by calculating a confidence interval for each cow within each trial. Intakes that fell 4 standard deviations (SD) outside of the mean were discarded. This restriction reduced the data by 1.4% to 9,589 daily intakes on 140 cows with 3,539, 2,246, 2,531, and 1,273 observations for HH, HJ, JH, and JJ, respectively. The number of observations per cow after edits ranged from 23 to 208 with the average cow having 68 observations. Daily NEI were then averaged by cow and week of lactation (**WOL**). There were 685, 507, 562, and 304 weekly mean observations on HH, HJ, JH, and JJ, respectively.

Body weights and milk weights were recorded twice daily by using the Afifarm herd management software (S.A.E. Afikim, Kibbutz Afikim, Israel). Body weights were measured automatically with a walk-through scale as cows left the milking parlor. In the summer of 2008, 1 of the 2 scales malfunctioned and consequently BW were not measured on every cow at every day during this period, but BW were used from the correct scale. Both BW and milk weights were used from 18 to 305 DIM. A weekly average BW was used to account for large variations within daily BW. There were 1,648, 1,298, 1,439, and 767 weekly BW for HH, HJ, JH, and JJ cows.

Milk weights were edited by partitioning the lactation into 5 stages of 60 d each, and a mean and SD were determined within genetic group within stage. Originally, records that were 3 SD outside of the mean for genetic group within stage were discarded; using this method, 4 cows lost more than 15 records and 353

total records were discarded. However, when the edit restriction confidence interval was increased to 4 SD, no cow lost more than 10 records in her lactation; thus, the confidence interval of 4 SD was implemented. A total of 38,445 edited records of daily milk weights were available, including 11,953, 9,531, 10,885, and 6,076 records for HH, HJ, JH, and JJ, respectively. Discarded daily milk records included 25, 9, 22, and 19 for HH, HJ, JH, and JJ, which were less than 1% for all genetic groups.

Dairy Herd Improvement record tests were performed monthly and provided estimates of fat and protein percentage. Milk components and daily milk weights were then combined using the test-day closest to the milk weight observation. Milk and components were then averaged over WOL. Daily milk weights were converted to 1,703, 1,341, 1,522, and 836 weekly means for HH, HJ, JH, and JJ. Body condition scores were assigned using the 5-point system from 0 (thin) to 5 (fat) with increments of 0.25 as described by Wildman et al. (1982). Cows were assigned BCS every 5 wk from calving until 305 DIM by a single evaluator.

Day in gestation was determined from the date of the observation and the breeding date of the confirmed pregnancy (confirmed by a veterinarian). There were 3 seasons defined for a year with just over 3 years' worth of data, resulting in 10 year-season calving groups. Stage of lactation was defined as five 2-mo periods from wk 3 in lactation through wk 43 of lactation.

Net energy requirements (Mcal/d) were calculated for maintenance (**NEM**), milk production (**NEP**), retained energy (**NEG**), and pregnancy (**NEY**) using the weekly averages using the NRC (2001) equations. The raw means and ranges for the different variables in the data are located in Table 1.

A full description of the calculation for the net energy required calculations are provided in the Appendix. Retained energy (**RE**) was used for the estimate of growth

requirement using BW and ADG. The NRC (2001) does not account for energy requirements for pregnancy until d 190 in gestation. Therefore, estimates of energy requirements for pregnancy do not begin until d 190 in gestation as shown in the Appendix.

Calculations of EB

A random regression model using orthogonal polynomials (Schaeffer, 2003) was used to estimate separate curves for each cow for NEI, NEP, NEM, and BW. An animal model with 3 generations of ancestors for each cow in the study was used. The random regression models using fixed and random effects were estimated using ASREML software (Gilmour et al., 2006). The random regression used model was

$$Y_{ijklqm} = G_i + YS_j + \beta_1 age + \beta_2 (age)^2 + \sum_m^{f-1} b_m P_m W_q + \sum_m^{k-1} a_{lm} P_m W_q + \sum_m^{s-1} PE_{lm} P_m W_q + e_{ijklqm}, \quad [1]$$

where Y_{ijklqm} was the observation (NEI, NEP, NEM, or BW); G_i was the fixed effect of genetic group i ; YS_j was the fixed effect of year-season of calving j ; β_1 and β_2 were the linear and quadratic coefficients on age at calving; W_q was the week q of lactation; P_m was the m th orthogonal polynomial of week q ; b_m the fixed regression coefficient associated with the overall curve for the m th orthogonal polynomial; a_{lm} was the random regression coefficient associated with animal l for the m th orthogonal polynomial; PE_{lm} was the random permanent environment associated with animal l for the m th orthogonal polynomial; and e_{ijklqm} was the random residual effect. The parameters f , k , and s are the order of the fixed, random additive, and random permanent environment polynomials, respectively. The selection of the model for the order of the polynomials was based on convergence and Akaike's information criterion (AIC). In most instances, with the exception of NEP, the highest order achieved while still converging had the lowest AIC. Net energy for milk production converged at a higher order polynomial for permanent environmental effects but produced a higher AIC so a lower order polynomial was used. The parameters f , k , and s for NEP were fourth, fourth, and third. The order of polynomials for BW and NEM was second, fourth, and third and for NEI was fourth, third, and third for f , k , and s , respectively.

Five residual error classes were fit from wk 3 to 43 of lactation. The residual classes were defined as stage of lactation and partitioned as wk 3 to 9, 10 to 18, 19 to

27, 28 to 35, and >35. The residual variances were estimated per residual class, with the variance within each class being homogeneous, and the covariance between classes assumed to be zero.

Body condition scores are useful for predictions of lipid mobilization and we intended to include this in our analysis; however, the covariance between adjacent BCS was high and convergence was not achieved using random regression models. Accordingly, our definition of energy balance does not include a term for the mobilization of body lipid loss. However, BCS was analyzed by stage of lactation to investigate possible differences in lipid mobilization between the genetic groups. This analysis used the PROC MIXED procedure of SAS (SAS Institute, 2004) with a random effect of cow and fixed effects of genetic group, stage, genetic group by stage interaction, year-season of calving, and a linear and quadratic effect of age at calving.

To estimate NEG, the predicted energy required for RE was used. Retained energy was calculated using the BW predictions from the random regression analysis. Attempts to estimate RE directly by random regression failed because the model did not converge. In a second attempt, RE was calculated weekly using random regression solutions for BW, but the weekly RE estimates were highly variable. Ultimately, RE was calculated from BW predictions by stage of lactation. The RE was calculated using the difference between the first and last BW in a stage. The RE for stage of lactation for each cow was then used for NEG.

The animal solutions obtained from the random regression analyses were used to calculate weekly average phenotypic values for all animals in the data set at all WOL (wk 3 to 43). Energy balance was calculated using the predictions of NEI minus the predictions for NEM, NEP (from random regression models), NEG, and NEY by WOL. Total net energy intake (**TNEI**), total net energy required for milk production (**TNEP**), total net energy required for maintenance (**TNEM**), total net energy for growth (**TNEG**), total net energy required for pregnancy (**TNEY**), and overall total cumulative energy balance (**TEB**) across the lactation were calculated as the sum of the weekly averages multiplied by 7. Ratios of energy required for maintenance, growth, pregnancy, and production to energy intake were calculated (e.g., TNEP/TNEI). Return to positive balance within week (**PEBW**) was defined as the first week when EB was positive. A return to overall positive EB (**WPEB**) was defined as the first week when the cumulative EB calculation became positive. A cumulative energy balance at wk 21 was calculated (**TEB₂₁**) to investigate EB at the stage of lactation at which producers would like the cows to be pregnant.

Table 2. Cumulative net energy intake (TNEI), and cumulative net energy required for growth (TNEG), maintenance (TNEM), pregnancy (TNEY), and production (TNEP) for Holsteins (H), Jerseys (J), and reciprocal crosses over wk 3 to 43 of their first lactation¹

Item (Mcal)	HH		HJ		JH		JJ	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Intake (TNEI)	9,813 ^a	122	9,309 ^b	136	9,487 ^{ab}	121	7,969 ^c	176
Growth (TNEG)	669 ^a	35	599 ^{ab}	40	496 ^{bc}	35	334 ^c	51
Maintenance (TNEM)	2,666 ^a	21	2,468 ^b	24	2,425 ^b	21	2,085 ^c	30
Pregnancy (TNEY)	27	7	32	8	33	7	21	10
Production (TNEP)	5,968 ^a	136	6,057 ^a	151	6,162 ^a	135	5,259 ^b	196

^{a-c}Genetic groups with different superscripts are significantly different ($P < 0.05$).

¹Breed of sire listed first.

The GLM procedure of SAS (SAS Institute, 2004) was used for the statistical analyses of PEBW, WPEB, TEB₂₁, TEB, TNEI, TNEP, TNEY, TNEG, TNEM, and the ratios for each of the energy terms. The model was defined as

$$Y_{ijk} = \mu + G_i + YS_j + \beta_1 age + \beta_2 (age)^2 + e_{ijk}, \quad [2]$$

where G_i is the i th genetic group; YS_j is the j th year season of calving; β_1 and β_2 are linear and quadratic regression coefficients for age at calving; and e_{ijk} is the random residual for the k th cow in the i th genetic group from the j th year-season of calving. A Tukey adjustment for least squares means for genetic groups was used to account for simultaneous comparisons across genetic groups. Heterosis was calculated as contrasts between the purebred groups and the crossbred groups and then converted to the percentage deviation from the mid-parent average.

RESULTS AND DISCUSSION

Components of EB

Table 2 includes least squares means of TNEI, TNEP, TNEM, TNEG, and TNEY for each genetic group. The reciprocal cross genetic groups (HJ and JH) were not different from one another for any of the energy terms, suggesting that breed maternal effects were not significant. There were genetic group differences for TNEI. The HH group consumed more energy ($P < 0.05$) than the HJ and JJ groups but were not different from the JH group. The JJ consumed the least amount of energy. Genetic group differences for TNEM were significant, reflecting the differences in BW among the genetic groups. The HH required more energy for maintenance than all the other genetic groups, and the crosses (HJ and JH) had higher TNEM requirements than the JJ. Compared with the other components of energy balance, TNEG and TNEY were small. The HH required more

energy for growth (TNEG) than the JH and JJ groups, the HJ required more than the JJ, but the crosses were not different from each other. There were no statistical differences between any of the genetic groups for TEY. The HH, HJ, and JH groups required more energy for milk production than the JJ group.

The average curves by genetic group for NEI, NEP, and BW are in Figures 1, 2, and 3, respectively. The average NEI curves in Figure 1 show that the HH consumed more energy than the JJ, with the crossbreds intermediate but closer to HH, showing the heterosis for intake. Figure 2 shows the NEP curves by genetic group, where the HH, HJ, and JH were similar and required more energy for lactation than the JJ. The BW curves in Figure 3 show that cows in all genetic groups grew during first lactation, with relatively small differences in gain or rate of growth.

Jerseys are known to be smaller and to mature earlier than Holsteins, but there is little in the literature on heterosis levels for Jersey $\times$ Holstein for size and growth rate. The TNEM was 21.78% higher for HH than for JJ. The heterosis level for TNEM was significant ($P = 0.005$) at 3.02%. This is an unfavorable heterosis value in that the F₁ crossbred was expected to require 3.02% more energy for maintenance than that required for the mid-parent average. The 3.02% heterosis for maintenance is similar to the 3.2 to 3.5% heterosis reported for BW in first lactation (McDowell et al., 1969; Robison et al., 1980; Prendiville et al., 2009). The HH required twice as much for TNEG as the JJ. The heterosis for TEG was 8.97%, but was not significant ($P = 0.279$).

In our study, pure Holsteins consumed 23.14% more energy than pure Jerseys and 4.33% more than the crossbred average. Prendiville et al. (2009) also found that Jerseys had lower intake with 13% less than the Holstein-Friesian, and the crosses had 4% less than the Holstein-Friesian. That study was in a pasture-based system, which may account for the scale of the difference with the purebred groups. Heterosis for energy

Figure 1. Average predicted energy intake (NEI) by week in lactation for first-lactation Holsteins (♦), Jerseys (×), Holstein sired by Jersey dam F₁ crossbreds (■), and Jersey sired by Holstein dam F₁ crossbreds (▲).

Figure 2. Average predicted net energy for milk production (NEP) by week in lactation for first-lactation Holsteins (♦), Jerseys (×), Holstein sired by Jersey dam F₁ crossbreds (■), and Jersey sired by Holstein dam F₁ crossbreds (▲).

Figure 3. Average BW (kg) by week in lactation for first-lactation Holsteins (♦), Jerseys (×), Holstein sired by Jersey dam F₁ crossbreds (■), and Jersey sired by Holstein dam F₁ crossbreds (▲).

consumed had a P -value <0.001 and was 5.7%, which was numerically lower than the heterosis for production.

The HH, HJ, and JH were not different for total energy for production, which is consistent with current literature. Prendiville et al. (2009) found the F₁ (Holstein-Friesian $\times$ Jersey) was not different from pure Holstein-Friesians for solids-corrected milk and found a tendency for the F₁ to have a higher content of fat plus protein. We used energy-corrected milk, which would account for differences in milk protein and fat content. The heterosis value for TNEP was 8.83% ($P = 0.003$), which was higher than the 6.2% heterosis for milk and 7.2% for fat found by Ahlborn-Breier and Hohenboken (1991) and considerably higher than the 3.4, 4.4, and 4.1% for milk, fat, and protein, respectively, reported by VanRaden and Sanders (2003). The heterosis value for TNEP encompasses heterosis on milk, fat, and protein, all of which drive milk energy output.

The TNEP was converted to energy-constant milk based on a 4% fat- and 3.2% protein-corrected basis to compare the estimates to more traditional production terms. Estimates for total yield for ECM from d 18 to 305 were 8,024, 8,143, 8,285, and 7,121 kg for HH, HJ, JH, and JJ, respectively. The HH, HJ, and JH were not statistically different from each other in TNEP, so

their production was not different from each other on this basis, but they were statistically different from JJ. These estimates are 18 d shorter than the typical 305-d lactation. Additionally, yield may seem lower than the production of a typical HH, but it is consistent with the downward correction in yield associated with the use of 4% fat and 3.2% protein as a base.

Energy Allocation

Table 3 shows the proportion of energy consumed that was used for growth, maintenance, pregnancy, and production. No statistical differences were found between the genetic groups for percentage of energy used for pregnancy, the smallest partition of energy use studied. Genetic group had a P -value of 0.020 for the amount of energy partitioned to production and the JJ allocated more energy to production than the HH (66.2 vs. 60.8%). The HJ and JH were not different from any other genetic groups for production. Genetic group accounted for differences in the percentage of energy allocated to maintenance ($P = 0.036$). The JH allocated less energy to maintenance than the HH (25.7 vs. 27.4%). The JH, HJ, and JJ groups and the HH, HJ, and JJ groups were not different from each other for allocation of energy into maintenance. Genetic

Table 3. Least squares means for predicted percentage of energy consumed used for growth, maintenance, pregnancy, and production for Holsteins (H), Jerseys (J), and reciprocal crosses from wk 3 to 43 of their first lactation¹

Item	HH		HJ		JH		JJ	
	Mean %	SE	Mean %	SE	Mean %	SE	Mean %	SE
Growth	6.9 ^a	0.4	6.6 ^{ab}	0.5	5.3 ^{bc}	0.4	4.2 ^c	0.6
Maintenance	27.4 ^b	0.4	26.7 ^{ab}	0.4	25.7 ^a	0.4	26.2 ^{ab}	0.6
Pregnancy	0.3	0.1	0.3	0.1	0.4	0.1	0.3	0.1
Production	60.9 ^b	1.2	64.8 ^{ab}	1.3	64.9 ^{ab}	1.2	66.3 ^a	1.7
Total ²	95.5	1.1	98.3	1.2	96.2	1.1	97.0	1.5

^{a-c}Genetic groups with different superscripts are significantly different $P < 0.05$.

¹Breed of sire shown first.

²The total energy accounted for by the least squares means: (energy used/energy consumed) $\times$ 100.

group differences accounted for difference in proportion of energy allocated to growth ($P < 0.001$). The HH allocated proportionally more energy to growth than did the JH and JJ. The JJ allocated proportionally less to growth than the HJ, and there were no differences between the reciprocal crosses for proportion of energy allocated to growth. Other significant variables were calving group for growth and pregnancy; no other variables were significant in any of the other analyses of proportion of energy used for growth, maintenance, pregnancy, and production ($P < 0.05$).

Our results for proportion of energy used for milk production and maintenance are similar to those reported by Friggens et al. (2007) who found ranges between the different lactations and breeds to be from 66 to 79% for milk production and between 20 and 24% for maintenance. Additionally, Friggens et al. (2007) found that a low percentage of energy went to growth in first lactation ($<1\%$). Our study indicates a higher allocation of energy to growth in first lactation, with variation between the different genetic groups. Differences could be due to the method of calculation of growth or it could be a product of the different genetic lines used. In our study, growth was calculated from an estimate of BW through the end of lactation, Friggens et al. (2007) calculated growth as the difference between the lean body mass at wk 16 of the first and second lactation. It should be noted that energy partitioned to growth in first lactation could be more favorably partitioned to other processes (e.g., milk production) in subsequent lactations.

The proportion of energy used for milk production can be a measure of feed efficiency. In feed efficiency terms, defined in our study as energy required for milk/energy consumed, our results agree with those of Heins et al. (2008b), in which the J $\times$ H cross was not different from the pure Holstein for feed efficiency, which they defined as ECM/DMI. Our results indicate that the JJ group was more efficient than the HH group in

first lactation on this basis. Prendiville et al. (2009) also found that the Jerseys tended to have a higher conversion of consumed DM to milk fat and protein.

The total amount of energy accounted for ranged between 95.5 and 98.3%, indicating a relatively close match between predicted energy intake and predicted energy use. Genetic groups were not different from each other for the total amount of energy accounted for. These results are similar to Friggens et al. (2007), who accounted for 94% to 103% of all energy. We did not account for activity in the equations; however, the NRC (2001) includes a 10% allowance for activity in its maintenance requirement, which is likely adequate to cover energy expenditures for locomotion in a freestall facility.

EB

Table 4 represents the analyses for PEBW, WPEB, TEB, and TEB₂₁. Genetic group differences were not significant for any of these measures of energy balance, but trends for PEBW and WPEB indicated that animals of intermediate ages at calving reached positive EB faster than younger and later calving animals. Figure 4 shows the average EB for each genetic group by WOL.

The PEBW in which cows returned from a daily negative EB to positive did not differ significantly between genetic groups, with solutions being wk 10, 12, 9, and 13 for HH, HJ, JH, and JJ, respectively. Results are consistent with the 10- and 11-wk returns to positive balance reported in the literature (Coffey et al., 2002; Friggens et al., 2007; Patton et al., 2008). The analysis of return to cumulative positive energy balance had least squares means of 20, 26, 24, and 25 for HH, HJ, JH, and JJ, respectively.

The TEB for the lactation was 483, 152, 370, and 268 NE_L (Mcal) for HH, HJ, JH, and JJ. These numbers are quite small relative to the TNEI in Table 2. The differ-

Figure 4. Average predicted energy balance by week in lactation for first-lactation Holsteins (♦), Jerseys (×), Holstein sired by Jersey dam F₁ crossbreds (■), and Jersey sired by Holstein dam F₁ crossbreds (▲).

ences for TEB are consistent with results in Table 3 in that we were not able to account for a small percentage of energy use in all genetic groups.

Body condition scores were not used for the EB calculations; however, the BCS across stages of lactation were analyzed by genetic group to investigate possible body lipid changes. Significant effects ($P < 0.05$) in the model were stage and year-season calving group, and trends ($P < 0.10$) were genetic group and genetic group by stage interaction. Results of the analysis can be found in Table 5. The linear and quadratic terms for age at calving were not significant. The genetic group solutions were 2.84 ± 0.05 , 2.86 ± 0.06 , 2.67 ± 0.05 , and 2.80 ± 0.08 for HH, HJ, JH, and JJ, respectively,

across all stages of lactation. The trend was that HH and HJ carried more body condition than the JH group ($P < 0.10$). These results do not agree with Heins et al. (2008b), where the crossbreds had a higher BCS than did the pure Holsteins. Solutions for stage of lactation, defined in 2-mo periods after calving, were 2.58 ± 0.03 , 2.70 ± 0.03 , 2.80 ± 0.03 , 2.91 ± 0.03 , and 2.99 ± 0.03 for stages 1, 2, 3, 4, and 5, respectively. Solutions for stage of lactation were different ($P < 0.001$) from each other.

Most animals started in negative energy balance at the beginning of lactation. A total of 26 cows (8 HH, 5 HJ, 11 JH, and 2 JJ) in this analysis did not start in negative energy balance, but of these, 9 had $EB < 1 \text{ NE}_L$

Table 4. Least squares means for week of lactation when cows returned to positive energy balance, week of lactation when cows achieved total cumulative energy balance, total energy balance for the lactation, and total energy balance at wk 21 for first-lactation Holsteins (H), Jerseys (J), and reciprocal crosses¹

Item	HH		HJ		JH		JJ	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
PEBW ² (wk)	9.8	1.0	11.9	1.2	9.2	1.0	12.8	1.5
WPEB ³ (wk)	19.6	2.4	25.5	2.7	19.6	2.4	24.4	3.4
TEB ⁴ (NE _L , Mcal)	483	101	152	113	370	100	268	146
TEB ₂₁ ⁵ (NE _L , Mcal)	49.1	53.4	−56.8	59.6	6.8	53.2	−97.5	77.0

¹Breed of sire listed first.
²PEBW = first week where energy balance was positive.
³WPEB = week where cumulative energy balance was positive.
⁴TEB = total cumulative energy balance at wk 43.
⁵TEB₂₁ = total cumulative energy balance at wk 2.

Table 5. Least squares means for BCS across stage of lactation by genetic groups¹ in first lactation

DIM	HH		HJ		JH		JJ	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
<70	2.67	0.06	2.58	0.07	2.47	0.06	2.61	0.09
70–133	2.75	0.06	2.71	0.07	2.60	0.06	2.72	0.09
134–196	2.84	0.06	2.89	0.07	2.69	0.06	2.80	0.09
197–252	2.91	0.06	3.07	0.07	2.77	0.06	2.88	0.09
>252	3.06	0.06	3.05	0.07	2.86	0.06	2.98	0.09

¹Breed of sire shown first: Holstein (H), Jersey (J).

at wk 3. One explanation for the number of cows not in negative EB could be that the experiment did not start until wk 3 into lactation, which may have given some cows enough time to establish a weekly positive balance. First-parity animals mobilize less energy from body tissue than do multiparous animals (Friggens et al., 2007), so it is not surprising that not all cows had negative EB at some point in their first lactation.

All cows reached positive energy balance at some point; however, 36 cows did not reach cumulative positive energy balance by the end of 43 WOL. This group included 10, 9, 11, and 6 HH, HJ, JH, and JJ, respectively, that did not reach cumulative positive energy balance, of which 9 of the 19 Holstein sired cows were sired by the same Holstein bull. This was consistent with the work of Coffey et al. (2003), which found that daughters from certain sires were in chronic negative energy balance through the lactation and never fully regained the energy lost in early lactation by the end of lactation. Our data were similar, as one-fourth of the total cows and half of the Holstein-sired cows that did not reach a positive TEB by the end of lactation were sired by the same bull. It should be noted that this same Holstein bull had the lowest genetic evaluations of the 4 Holstein sires used for daughter pregnancy rate and productive life based on USDA genetic evaluations for April 2010. Potentially, some of the cows that did not reach positive energy balance could simply be more efficient with respect to maintenance or other energy use conversion, which would also cause this apparent deficit. Another possible explanation for cows not reaching positive TEB could be that cows did not eat as much in the Calan doors as when they were under routine herd management. Such an effect could make intake appear to be insufficient to support the production and BW recorded when they were not in the Calan doors.

Linear, quadratic, and cubic regressions for TNEP on EB were significant ($P < 0.05$). When TNEP increased, EB decreased within the constraints observed in this study TNEP. This is consistent with results from Coffey et al. (2004), who found that cows with higher milk production had higher mobilization of body tissue.

Figure 4 shows some disjointedness between wk 9 and 10, wk 18 and 19, wk 27 and 28, and wk 34 and 35. The NEG calculation used an ADG that was calculated between each stage, so the disjointedness is due to the changes in ADG between stages. Energy requirement for pregnancy begins to affect EB in the later stages of lactation, which would contribute to an overall decrease in the EB curves for those later weeks in lactation.

CONCLUSIONS

Crossbred cows ate the same amount or less energy than the HH, required less energy for maintenance than the HH, and required the same or less for growth than the HH, but gave the same energy in milk as the HH. There was a nonsignificant trend for a greater proportion of consumed energy allocated to milk production in the HJ and JH groups and a significant increase in the JJ groups compared with the HH group. This could be because of the HH allocating more energy into maintenance and growth, where differences were significant between JH and HH, and growth where differences were statistically different between some genetic groups. Most of the EB traits were not significantly different between the genetic groups. The trend was for the HH to have a larger EB at the end of the lactation. There is potential for the energy partitioned to growth in first-lactation HH to become a more favorable partitioning of that energy to production in later lactations. However, an early maturing animal favors a more rapid return on investment in rearing expenses. Heterosis was in an unfavorable direction for energy needed for maintenance, but was favorable for energy for production. The number of Jerseys was limited in this study and additional research is required to establish economic differences between genetic groups.

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APPENDIX

Calculation of NE_L in Feedstuffs

Calculation for NE_L for feedstuffs using the Pennsylvania equations from Cumberland Valley Analytical (Hagerstown, MD).

Legumes:

$$NE_L \text{ (Mcal/kg)} = [1.044 - (0.0119 \times \text{ADF})] \times 0.4536;$$

Mixed forages:

$$NE_L \text{ (Mcal/kg)} = [1.0876 - (0.0127 \times \text{ADF})] \times 0.4536;$$

Corn silage:

$$NE_L \text{ (Mcal/kg)} = [1.044 - (0.0124 \times \text{ADF})] \times 0.4536;$$

Small grain forages:

$$NE_L \text{ (Mcal/kg)} = [0.7936 - (0.00344 \times ADF)] \times 0.4536;$$

Grain mixture:

$$NE_L \text{ (Mcal/kg)} = [(total \text{ digestible nutrients} \times 0.0234) - 0.5448] \times 0.4536;$$

Shelled corn:

$$NE_L \text{ (Mcal/kg)} = [0.950 - (0.0026 \times ADF)] \times 0.4536;$$

Small grains:

$$NE_L \text{ (Mcal/kg)} = [0.9265 - (0.00793 \times ADF)] \times 0.4536.$$

Mature BW and Calf Weight Assumptions

Crossbred mature BW was calculated from the mid-parent average mature BW plus 5.6% heterosis. Calf birth weight was estimated in the same manner and the calculation can be found in the table below.

Relevant Equations from the NRC (2001) to Calculate Energy Components

Lactation requirements:

$$NE_L \text{ (Mcal/kg)} = 0.0929 \times \text{Fat \%} + 0.0563 \times \text{True Protein \%} + 0.192$$

Pregnancy requirements:

$$NE_L \text{ (Mcal/d)} = [(0.00318 \times D - 0.0352) \times (CBW/45)]/0.218,$$

where D is day of gestation between 190 and 279; CBW is calf birth weight assumed to be 42.7, 39.9, 39.9, and 32.7 kg for HH, HJ, JH, and JJ, with $CBW = 0.06275 \times MW$.

Maintenance requirements:

$$NE_L \text{ (Mcal/kg)} = 0.080 \times MBW,$$

where MBW is metabolic BW ($BW^{0.75}$).

Retained energy/net energy for growth calculations:

$$MSBW \text{ (mature shrunk BW)} = 0.96 \times \text{mature weight};$$

mature weight for the different breeds was assumed to be 680.40, 635.04, 635.04, and 521.64 kg for HH, HJ, JH, and JJ, respectively.

$$SBW \text{ (shrunk body weight)} = 0.96 \times BW,$$

$$SRW \text{ (standard reference weight) to MSBW} = 478/MSBW,$$

$$EQSBW = \text{equivalent shrunk BW (kg)} \\ \text{and } CW = \text{conceptus weight},$$

$$CW = \{18 + [(days \text{ pregnant} - 190) \times 0.665] \times (calf \text{ birth weight}/45)\},$$

$$EQSBW = (SBW - CW) \times SRW \text{ to MSBW},$$

$$EQEBW = \text{size-scaled empty BW} = 0.891 \times EQSBW,$$

$$EQEBG = \text{size-scaled empty BW gain} = 0.956 \times ADG,$$

$$\text{Retained energy (RE)} = 0.0635 \times (EQEBW^{0.75}) \times (EQEBG^{1.097}).$$

For the purpose of this study we defined the net energy for growth (NE_G) = RE.

Table A1. Assumptions of mature BW and calf birth weight made for HH, HJ, JH, and JJ for energy calculations for pregnancy and growth.

Genetic group ¹	Mature weight (kg)	Calf birth weight ² (kg)
HH	680	42.7
HJ	635	39.9
JH	635	39.9
JJ	522	32.7

¹Breed of sire listed first. H = Holstein; J = Jersey.

²Calculated as $0.06275 \times \text{mature weight}$.