Using genetic evaluations for growth and maternal gain from birth to weaning to predict energy requirements of Line 1 Hereford beef cows[1,2]

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ABSTRACT: The maintenance energy required to sustain the cow herd is a major cost of beef production. This work proposes modifying parameter estimates for a population-specific lactation curve with genetic evaluations for the maternal genetic effect on calf gain from birth to weaning to provide inputs for a commonly used prediction of energy requirement. Daily milk production (y) was modeled as a function of stage of lactation (T, d) using the function $y = AT^{B}\exp(-CT)$ modified to incorporate effects of genetic evaluation for the maternal effect on calf gain from birth to weaning and age of dam. A 1-kg increase in predicted maternal breeding value for calf gain from birth to weaning from within-herd genetic evaluation increased the lactation curve parameter A by 10.3 ± 4.6% and reduced the B parameter by 1.0 ± 0.6%. Similarly, a 1-kg increase in maternal breeding value for gain from birth to weaning from national cattle evaluation increased the A parameter by 1.7 ± 0.2%. Corresponding estimates of peak milk yield and time of peak lactation were derived for individual animals from their genetic evaluation. Additional inputs for predicting maintenance energy requirements were derived from genetic evaluations for birth weight and mature size. The methodology is demonstrated using genetic evaluations of sires from the Miles City Line 1 Hereford population. Further refinement and application of this methodology may facilitate characterization of beef cattle seedstock for their potential genetic contributions to profitability.

Key Words: Feed Intake, Genetic Improvement, Milk Production

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Introduction

Net effects of selection for improved efficiency of beef production depend on a large number of interacting effects within the production system (Cartwright, 1974). The cow herd consumes approximately two-thirds to three-fourths of the feed energy used in beef production systems (Gregory, 1972; Heitschmidt et al., 1996). Body weight, days after calving to peak milk yield, and maximum daily milk produced are indicators of energy requirements used by the NRC (1996) and others for developing feeding programs.

Genetic evaluation systems for beef cattle predict breeding values (**BV**) or EPD for some traits related to the energy requirements of beef cows. However, these predictors are in units of measure inconsistent with straight-forward prediction of the energy required for maintenance or production based on NRC (1996) methods. Due to the cost incurred in direct measurement of energy requirements of beef cows, it is unlikely that sufficient data can be collected to allow estimation of the genetic parameters needed for multiple-trait prediction of BV for energy requirements from correlated traits. The objective of this research was to illustrate a system for incorporating traditional BV in the prediction of energy requirements for beef cows.

Materials and Methods

Cattle used in this research came from the Line 1 Hereford population at Fort Keogh Livestock and Range Research Laboratory, Miles City, MT (Knapp et al., 1951; MacNeil et al., 1992). At this location annual precipitation averages 34 cm, with 21 cm occurring during March through July. Average temperatures are –9°C in January and 23°C in July. Broken badlands and plains rangelands typical of eastern Montana and the Northern Great Plains region provide annual support for a cow-calf pair on approximately 14 ha with some supplemental feed during winter. Native vegeta-

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Table 1. Age and weight of Line 1 Hereford calves when weigh-suckle-weigh records of 12-h milk production were collected

	Age, d			Weight, kg	
Measurement	Mean	Oldest	Youngest	Mean	SD
1	51.5	87	9	81.3	16.4
2	92.5	132	53	113.4	20.6
3	136.9	180	93	150.8	25.0
4	179.9	215	137	181.0	27.5

tion has been predominantly western wheatgrass, Sandberg bluegrass, blue grama grass, buffalo grass, needle-and-thread, green needle grass, thread leaf sedge, greasewood, and silver and big sagebrush. Annual brome grasses were increasingly prevalent in the 1980s and early 1990s.

Management and Data Recording. Calving commenced in mid-March and continued until mid-May of each year. All calves were weighed at birth. Cow-calf pairs were moved to native range spring pasture a few days after birth. In early June, the cow-calf pairs were moved to smaller breeding pastures of 222 to 549 ha. At this time, the first of four estimates of 12-h milk production were obtained by the weigh-suckle-weigh procedure. Two subsequent estimates of 12-h milk production were obtained at approximately equal intervals between the first estimated milk production and the final estimate at weaning in early October. Briefly, cow-calf pairs were gathered from native range pastures to a central handling facility in the afternoon preceding the data collection. Calves were separated from their dams from approximately 1500 until 1800 then reunited with their dams and allowed to nurse. Following nursing, the calves were again separated from their dams and remained apart until 0600 the next morning, when they were weighed, allowed to nurse until either satiated or milk was no longer available, and quickly reweighed. The difference between weights was assumed to reflect the milk consumed by the calf and to measure milk produced by the cow during the preceding 12 h. Data were collected from 1994 to 1998. The 12-h milk production data were doubled to estimate 24-h milk production. Weights of calves and the range in their ages when each of the four estimates of milk production was obtained are presented in Table 1. There were 76 cows 2 yr old, 83 cows 3 yr old, 59 cows 4 yr old, and 113 cows 5 yr old or older. Prior to 1995, cows were weighed four times each year, approximately 6 wk before the beginning of calving, before and after the breeding season, and at weaning. Since 1995, cows were weighed at calving and at weaning.

Inputs required for prediction of energy required for maintenance or production include mature cow weight, calf birth weight, peak milk yield, and the time when peak milk yield occurs (NRC, 1996). To derive the necessary inputs for birth weight and mature weight, predictors of the direct breeding values from MacNeil et al. (1998, 2000) were simply added to the estimate of the mean for the base population. A description of the process used to incorporate effects of maternal breeding value for gain from birth to weaning follows.

Results from exploratory linear model analyses were used to refine the model for describing 24-h milk production to a reduced model containing only effects that approached significance ($P < 0.1$). The most complete model was $y_{ijkl} = \mu + aod_i + yr_j + sex_k + \beta_1 m_{ijkl} + \beta_2 t_{ijkl} + \beta_3 t^2_{ijkl} + \text{interactions} + e_{ijkl}$, where y_{ijkl} = an observation of 24-h milk production by the l^{th} cow of the i^{th} age (k = 2 to ≥ 5) having maternal breeding value for calf gain from birth to weaning m_{ijkl}, nursing a calf of the k^{th} gender (bull or heifer), on the $t_{ijk}{}^{th}$ day of lactation in the j^{th} year. Predictions of the maternal breeding value for gain from birth to weaning were calculated by MacNeil et al. (2000).

Subsequently, the entire data set was fit to a modified form of the nonlinear model for the lactation curve presented by Wood (1969) that incorporated only those effects approaching significance in the exploratory linear model. This model was again reduced to arrive at the final model used to describe lactation in this population. That model was $y_{ijkl} = A'T^{B'} \exp(-CT)$, where $A' = A(1 + a_1 m_{ijkl} + a_2 aod_i)$, $B' = B(1 + b_1 m_{ijkl})$, and $T = t_{ijkl}$. Estimates of the parameters a_1 and a_2 are proportional changes in the A parameter of the generalized lactation curve associated with unit increases in maternal breeding value for gain from birth to weaning (m_{ijkl}) and age of cow (aod_i), respectively. Likewise, the estimate of b_1 is the proportional change in the *B* parameter of the generalized lactation curve associated with a unit increase in maternal breeding value for calf gain from birth to weaning. Similar analyses were conducted replacing the maternal breeding value for calf gain from birth to weaning with maternal weaning weight or milk BV (2EPD) from the most recent Hereford national cattle evaluation (American Hereford Association, 1998).

Based on Wood (1969), time of peak yield is B/C. Thus, based on the modified lactation curve proposed here, time of peak yield incorporating variation among cows in maternal breeding value for calf gain from birth to weaning equals $B(1 + b_1 m_{ijkl})/C$. Similarly, peak milk yield is equal to $A'(B'/C)^{B'}\exp(-B')$ and is estimated by replacing A′ with $A(1 + a_1 m_{ijkl} + a_2 aod_i)$ and B′ with $B(1 + b_1 m_{ijkl})$.

To demonstrate the utility of these procedures, an illustrative example was constructed. Predicted energy requirements for mature cows were calculated using the NRC (1996) Beef Cattle Requirements Table Generator software. Breeding values of Line 1 Hereford sires from within-herd analyses provided the genetic characterizations used to derive the inputs. These sires represent generations 0 and 3 to 4 of a selection experiment comparing selection by independent culling levels for below-average birth weight and high yearling weight with mass selection for high yearling weight (MacNeil et al., 1998). Inputs for mature weight, birth weight, peak milk yield, and time of peak milk yield were calculated as described previously. Age of cows at calving and duration of lactation were set to 60 mo and 26 wk, respectively. Remaining inputs were set to default values for the Hereford breed. Direct breeding values for growth, feed intake, and carcass characteristics of these sires were previously reported (MacNeil et al., 1999).

Results and Discussion

Milk Production. The full exploratory model using predicted BV for maternal calf gain from birth to weaning estimated within herd accounted for 44% of the variation in 24-h milk production and resulted in a residual SD of 1.9 kg. Using BV for maternal weaning weight from the Hereford national cattle evaluation in place of the within-herd breeding values similarly accounted for 42% of the variation in 24-h milk production with a residual standard deviation of 1.9 kg. The slight difference between these genetic evaluations in explaining variation in weigh-suckle-weigh estimates of milk production may stem from more accurate modeling of fixed effects in the within-herd evaluation (MacNeil and Snelling, 1996) balanced against greater amounts of information coming from relatives in the national cattle evaluation.

Effects of year, sex, and the interactions of year and sex with other terms in the model were deemed unimportant ($P > 0.1$) and eliminated from the models. The inability to detect differences in milk production of cows nursing male and female calves is consistent with several previous studies (e.g., Reynolds et al., 1978; Marston et al., 1992). However, some studies have suggested that milk yield of the cow depends, in part, on the sex of calf (e.g., Rutledge et al., 1971). Differences in weather from year to year have profound effects on the quantity and quality of forage produced in the environment of this study (Adams and Short, 1988). However, year effects on milk production were not detected ($P > 0.1$). The lack of year effects may indicate that forage production and quality were sufficient to similarly meet nutrient requirements for lactation in all years, given the relatively modest levels of milk production expected from Hereford cattle (Notter et al., 1978).

The final (i.e., reduced) nonlinear regression model incorporating predicted BV from the within-herd genetic evaluation accounted for 37% of the variation in 24-h milk production and resulted in a residual SD of 1.9 kg. Again, results using BV from the national cattle evaluation were similar.

An increase of 1 kg in predicted maternal breeding value for calf gain from birth to weaning increased the A parameter by 10.3 ± 4.6% and reduced the B parameter 1.0 ± 0.6% (Table 2). Increasing age of the cow by 1 yr over the range from 2 to 5 yr (cows older than 5 yr were coded as 5 yr old) of age increased the A parameter by 17.5 ± 4.7% when results from the within-herd genetic evaluation were used. The effect of age of dam was smaller (i.e., 0.06, vs 0.17) when the maternal breeding value for calf gain from birth to weaning derived from the Hereford national cattle evaluation was included in the model than when that breeding value came from the within-herd genetic evaluation. This may be a consequence of the systematic error in prediction of maternal genetic effect on calf gain from birth to weaning in national cattle evaluation that results from inaccurate preadjustment of calf gain for age of dam (MacNeil and Snelling, 1996).

Shown in Table 3 are estimated parameters for the modified Wood (1969) lactation curve and properties of lactation curves for mature cows (5 yr old) over the approximate range in genetic evaluations for maternal calf gain from birth to weaning of the cows studied. For any constant change in genetic evaluation, the resulting change in predicted total milk is less when using results from national cattle evaluation than when using results from within-herd genetic evaluation.

Meyer et al. (1994) and Miller and Wilton (1999) both reported genetic correlations between maternal gain from birth to weaning and total milk yield of approximately 0.8. Marston et al. (1992) found that a 1-kg change in the EPD for maternal weaning weight corresponded with 42.1- and 69.3-kg changes in total milk yield of Angus and Simmental cows, respectively. Present results are similar at low within-herd genetic evaluations but are reduced at high levels of inferred milk production. The present results are thus consistent with a greater proportion of energy from milk being used by the calf for maintenance at low levels of total milk production and the proportion of energy from milk used for growth increasing with increased milk production. Predictions using results from the Hereford national cattle evaluation infer consistently smaller changes in total milk yield per kilogram of change in preweaning weight gain than have been found elsewhere in the literature.

Predicted Energy Requirements. The American Hereford Association does not include mature size in their national cattle evaluation. Therefore, only the within-herd genetic evaluations are used in the subsequent prediction of energy requirements. Including more economically important traits, either directly or through indicator traits, in national cattle evaluation can facilitate lower costs of beef production and(or) increased revenues (Harris and Newman, 1992). The attempt here to predict the annual feed required by beef cows

Table 2. Lactation curve parameter estimates incorporating breeding value for maternal genetic effects on calf gain from birth to weaning (m, kg) and age of dam (aod, yr) on parameter estimates for predicting milk yield (y) of Line 1 Hereford cows at time T of lactation (after Wood, 1969)[a]

Item	Parameter					
	A	a_1	a_2	B	b_1	C
	Within-herd genetic evaluation[b]					
Estimate	1.19 ± .39	.10 ± .05	.17 ± .05	.29 ± .07	−.010 ± .006	−.0082 ± .0008
	National cattle evaluation[c]					
Estimate	2.82 ± .65	.017 ± .002	.06 ± .01	.25 ± .07	—	−.0081 ± .0008

[a]The parameters a_1 and a_2 are multiplicative adjustments to account for effects of breeding values for maternal genetic effect on calf gain from birth to weaning and age of dam on the lactation curve parameter A. Likewise, b_1 is a multiplicative adjustment to account for effects of breeding values for maternal genetic effect on calf gain from birth to weaning on the estimate of the lactation curve parameter B.

[b]$y = A'T^{B'}\exp(-CT)$, where $A' = A(1 + a_1m + a_2aod)$ and $B' = B(1 + b_1m)$.

[c]$y = A'T^{B}\exp(-C^{*}T)$, where $A' = A(1 + a_1m + a_2aod)$.

is one tentative step in the process of improving economic efficiency.

Monthly maintenance energy required by beef cows of genetic characterization similar to that of the sires evaluated here is presented in Figure 1. It seems that three to four generations of selection by independent culling levels for below-average birth weight and high yearling weight had little effect on energy requirements of mature cows. There was very little difference in breeding values for maternal genetic effect on calf gain from birth to weaning of sires representative of this selection line and of the base population. Hence, it seems that the observed increase in breeding value for mature size would slightly increase energy requirement, but the reduction in breeding value for birth weight partly offset this effect in the line selected by independent culling levels. In contrast, in the yearling weight selection line breeding values for all three inputs into the NRC (1996) model were greater than in either of the other lines. Thus, mass selection for high yearling weight alone was predicted to require more energy for support of the greater genetic levels of production. In earlier studies with young cattle, increased performance levels were also both genetically and phenotypically correlated with increased energy requirements (MacNeil et al., 1991; Nieuwhof et al., 1992).

In this research, genetic predictions of maternal calf gain from birth to weaning were used to account for between-animal variation through their effects on parameter estimates of the lactation curve for the population. Previously, Clutter and Nielsen (1987) and Miller and Wilton (1999) employed a philosophically similar approach to shift an empirical population lactation curve based on the deviation of each animal's individual milk production estimates from the population average. Another alternative approach would be to fit lactation curves to weigh-suckle-weigh estimates of milk production for individual cows. However, to fit a nonlinear

Table 3. Parameter estimates and properties of lactation curves[a] for mature cows (5 yr old) over the range in breeding values (BV, kg) from within-herd genetic evaluation (WHE) and from national cattle evaluation (NCE) for maternal gain from birth to weaning representative of the cows studied

	Parameter estimates			Characteristics of lactation		
BV	A	B	C	Peak yield, kg	Time of peak yield, d	Total yield, kg
WHE						
−5	1.62	.306	.00821	3.61	37.3	514
5	2.84	.278	.00821	5.73	33.9	805
15	4.06	.251	.00821	7.44	30.5	1,028
25	5.28	.223	.00821	8.82	27.1	1,194
NCE						
−20	2.75	.249	.00812	5.03	30.7	697
−10	3.23	.249	.00812	5.91	30.7	819
0	3.71	.249	.00812	6.79	30.7	940
10	4.19	.249	.00812	7.66	30.7	1,062
20	4.67	.249	.00812	8.54	30.7	1,183

[a]Yield at time $T = At^{B}\exp(-CT)$.

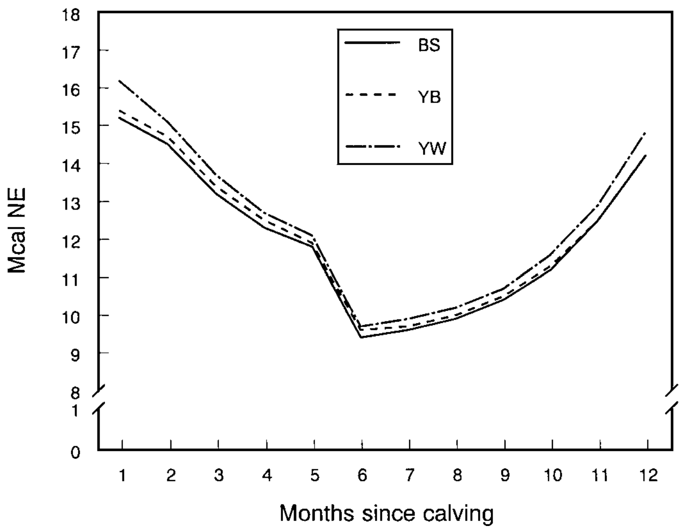

Figure 1. Total predicted daily feed energy requirement (i.e., the sum of NE required for maintenance, growth, lactation, and gestation [NRC, 1996]) of mature beef cows in the base population (BS), in a subline selected by independent culling levels for below-average birth weight and high yearling weight (YB), and in a subline selected for high yearling weight (YW).

model of the lactation curve with three or more parameters, estimates of milk production should be obtained far more frequently with the latter approach than the four times during lactation when data were collected in the present research. Averaging of relatively few measures of milk production spanning the lactation period (e.g., Freking and Marshall, 1992) may adequately characterize differences among animals in milk production but provides little basis for quantitative inference beyond a particular experiment. Differences in stage of lactation among cows may also be unaccounted for using this latter procedure.

Several studies characterizing between-breed variation have demonstrated a positive relationship between maintenance energy requirement per kilogram of metabolic body weight and milk production (e.g., Jenkins and Ferrell, 1983; Ferrell and Jenkins, 1984). The existence of a similar relationship within a breed may be postulated. However, to the best of our knowledge, this effect has not yet been quantified. Thus, although the NRC (1996) Table Generator software implements proportional scaling of maintenance energy requirement per kilogram of metabolic body weight, a constant relationship between body size and the maintenance energy requirement has been assumed throughout this research. In the event that future research were to clarify this relationship on a within-breed basis, modification of the procedure proposed here should be straightforward.

There is a fundamental problem in indirectly predicting genetic merit for a trait such as energy requirement exclusively from predicted breeding values for other traits. Individual animals whose genetic potentials are interrelated differently from the pattern characterized by the population covariances are not identified. This hampers multiple-trait selection to simultaneously improve both feed required and output traits. However, indirect prediction of genetic differences among individuals in energy requirement for production enables assessment of trade-offs between the inputs and outputs and thus facilitates matching genotype and environments.

Before adapting this technology in national cattle evaluation potential sources of error should be evaluated. First, the Line 1 Hereford population is relatively unique in comparison with the general Hereford population of North America. Furthermore, the production environment of the Fort Keogh Livestock and Range Research Laboratory is relatively harsh in comparison to that of a majority of purebred Hereford herds (MacNeil et al., 1992). Both the preceding factors point to concern for potential genotype × environment interaction, if present, compromising the generality of these results. Validation studies across a greater diversity of Hereford germ plasm and production environments would be desirable. Second, statistical properties of the predictors of genetic differences in energy requirements are unknown. It is known that a linear function of best linear unbiased predictors results in BLUP of the solution (Henderson, 1963). This property has been extended to quadratic functions (Wilton et al., 1968) but does not necessarily extend to other more complex functions (Ronningen, 1971). Thus, using BLUP estimates of breeding values for driving variables (inputs) to the NRC (1996) model for predicting energy requirements most likely does not yield BLUP solutions. Harris and Newman (1992) concluded that this problem had only minor effects on development and use of breeding objectives. However, further research is needed to develop robust, highly accurate, and affordable predictors of genetic differences in the inputs required for producing beef.

Implications

Current systems of genetic evaluation focus almost exclusively on the quantity of output produced, with essentially no consideration of costs of production. The method presented here allows indirect assessment of the energy required by beef cows to achieve levels of production indicated by their genetic evaluation. It also provides a basis to link genetic evaluation systems and the methods used to predict nutritional requirements.

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