Predicting Requirements for Growth, Maturity, and Body Reserves in Dairy Cattle

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ABSTRACT

The 1996 National Research Council Nutrient Requirements of Beef Cattle equations used to compute growth requirements, target weights, and energy reserves were modified and evaluated for use with dairy cattle. Coefficients used to compute target weights during growth and equations used to predict body weights (BW) for each condition score in computing energy reserves were modified. Equations used to compute net energy and protein requirements for growth were evaluated with data from studies of body composition changes in Holstein heifers; this model accounted for 96% of the variation in energy retained with a 4% bias. Coefficients used to compute target growth rates and BW were evaluated with data from Holstein heifer growth studies. Actual and target shrunk weight gain and BW values were before first pregnancy, 0.82 versus 0.87 kg/d with a 370-kg weight at first pregnancy versus a target of 352 kg; during the first pregnancy, 0.63 versus 0.69 kg/d with a weight at post first calving of 533 versus 545 kg; and first lactation, 0.136 versus 0.104 kg/d with a second post-calving weight of 592 kg versus 590 kg. The equations used to predict body reserves from BW and condition score were evaluated with data from a study of body composition associated with body condition score in Holstein cows; the revised model accounted for 96% of the variation in body fat and predicted 80 kg shrunk BW change per body condition score compared to 85 kg observed.
(**Key words:** energy requirements, protein requirements, heifer growth)

Abbreviation key: see Table 1.

INTRODUCTION

Recent research (8, 29) has identified optimum growth rates for dairy heifers to minimize replacement costs and maximize first lactation milk production. Once cows are mature, their weight changes reflect fluxes in body reserves, which must be managed to optimize reproduction and milk production (8). Accurate prediction of the energy and protein required for a target rate of gain depends on accurate prediction of the energy required for maintenance and composition of gain, which is related to proportion of mature weight at a particular weight (24). The 1996 National Research Council Nutrient Requirements of Beef Cattle (1996 Beef NRC) (24) provides a model that computes target growth rate and requirements to achieve target weights for any mature size. The 1996 Beef NRC predicts the energy and protein contained in weight change after the animal reaches maturity, from BW and condition score, to account for changes in body reserves.

We (11) published a modification of the 1996 Beef NRC model to account for the effects of environment on the maintenance requirements of dairy cattle to more accurately predict energy available for growth, lactation, and body reserves in unique production situations. In this article we present a model developed from the 1996 Beef NRC for predicting requirements for growth, maturity, and body reserves for dairy cattle. The growth model developed is for dairy heifers that have been transitioned to a ruminant state and that weigh at least 100 kg. Evaluations that use data with body composition of dairy cattle are presented.

MATERIALS AND METHODS

Table 1 contains a list of abbreviations used in equations.

Predicting Energy and Protein Requirements for Dairy Heifer Growth

Computing BW for use in the equations. The 1996 Beef NRC uses several different BW measurements including full (FBW), shrunk (SBW), or empty (EBW). These different weight measurements are BW used because of the BW that were used to derive the maintenance and growth equations. The net energy for maintenance requirement is computed with SBW, which accounts for fasting metabolism and tempera-

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TABLE 1. Definition for abbreviations used.

Abbreviation	Definition
ADG_{preg}	Average daily gain during pregnancy, kg/d
AF	Proportion of empty body fat
AP	Proportion of empty body protein
BCS	Body condition score
CBW	Calf birth weight, kg
CI	Calving interval, d
CW	Conceptus weight, kg
e	Base of natural logarithms
EBW	Empty BW, kg
EBWG	Empty BW gain, kg/d
EQEBW	Equivalent EBW, kg
EQSBW	Equivalent shrunk BW (equivalent to standard reference cow), kg
ER	Energy reserves, Mcal
FBW	Full BW (synonymous with BW), kg
LWG	Live weight gain, with no adjustment for fill, kg/d
ME	Metabolizable energy
MP_G	Metabolizable protein required for growth, g/d
MSBW	Mature shrunk BW, kg
NE_G	Net energy required for growth, Mcal/d
NE_{GA}	Net energy available for growth, Mcal
NE_R	Net energy retained
NP_G	Net protein retained, g
NP_R	Net protein required for growth, g/d
SBW	Shrunk BW, kg
SBWG	Shrunk BW gain, kg/d
t	Time pregnant, d
$TACSBWG_1$	Target SBWG after first calving, kg/d
$TACSBWG_2$	Target SBWG after second calving, kg/d
$TACSBWG_3$	Target SBWG after third calving, kg/d
$TAPSBWG_1$	Target SBWG after first pregnancy, kg/d
$TBPSBWG_1$	Target SBWG before first pregnancy, kg/d
TCA_1	Target first calving age, d
TCW_1	Target weight postcalving for first lactation cows, kg
TCW_2	Target weight postcalving for second lactation cows, kg
TCW_3	Target weight postcalving for third lactation cows, kg
TCW_4	Target weight postcalving for fourth lactation cows, kg
TF	Total fat, kg
TP	Total protein, kg
TPA_1	Target first pregnant age, d
TPW_1	Target first pregnant weight, kg

ture maintenance of gut contents (22). The equation for computing shrunk BW gain (SBWG) allowed by the net energy available for growth (NE_{GA}) and equations used to compute target SBWG use SBW, which is defined as 96% of FBW and is generally equivalent to weight after an overnight fast without feed or water. The net energy required for a target SBWG is computed from EBW (89.1% of SBW) and EBW gain (EBWG) (96.6% of SWG). Empty weights were used in the development of this equation because net energy requirements are a function of the proportion of fat and protein in the empty body tissue gain (14).

Predicting net energy and protein requirements for growth. We used the equations of the 1996 Beef NRC to compute energy and protein requirements for growth. The 1996 Beef NRC adapted the size scaling equation developed by Fox et al. (10) for all classes of beef and dairy cattle, which was refined and validated by Tylutki et al. (27) (Equation [1] below). As in the Commonwealth Scientific and Industrial Research Organization (CSIRO) (7) and Institut National de la Recherche Agronomique (INRA) (16) systems, the 1996 Beef NRC model assumes that various types of growing cattle have a similar chemical composition of growth at the same degree of maturity. Equation [2] below is used to compute the energy content of gain at various stages of growth and rates of gain for all cattle types because it was developed from a large, robust data set (12) (72 comparative slaughter studies), and it has been used with success in previous NRC publications (20, 21, 22, 23). The size scaling in the 1996 Beef NRC adjusts the BW of cattle of various mature sizes to a weight at which they are equivalent in body composition to a standard reference animal.

$$EQSBW = SBW \times (478/MSBW) \quad [1]$$

$$NE_R = 0.0635 \times EQEBW^{0.75} \times EBWG^{1.097} \quad [2]$$

Where EQEBW is 0.891 × EQSBW and EBWG is 0.956 × SBWG.

In this dairy cattle model, EQSBW is the weight of the dairy heifer equivalent to the standard reference animal at the same stage of growth. In equation [1], 478 kg is the weight at which the standard reference breeding female is assumed to reach chemical maturity (24), and MSBW is the expected mature SBW of herd replacement heifers.

Given the relationship between energy retained and the protein content of gain, protein content of SBWG is (24):

$$NP_G = SBWG \times (268 - (29.4 \times (NE_R/SBWG))). \quad [3]$$

Amino acid requirements for tissue growth are then computed as a percentage of each amino acid in the net protein accretion, based on a summary of studies (3): Arg, 6.6; His, 2.5; Ile, 2.8; Leu, 6.7; Lys, 6.4; Met, 2.0; Phe, 3.5; Thr, 3.9; and Val, 4.0. Tryptophan values were not given because of analytical difficulties. The metabolizable protein requirement is:

$$MP_R = NP_G/(0.83 - (EQSBW \times 0.00114)); \quad [4]$$

If EQSBW is > 478 kg, then EQSBW = 478 kg.

To diagnose and evaluate heifer performance and feeding programs, daily gain needed to be predicted from the diet being fed. To accomplish this, EQSBW was substituted for SBW and the NE_{GA} is substituted for NE_R in equation [5] below to predict SBWG:

$$SBWG = 13.91 \times EQSBW^{-0.6837} \times NE_{GA}^{0.9116}. \quad [5]$$

Then SBWG and NE_{GA} can be substituted in Equations [3] and [4] to evaluate adequacy of the protein intake.

Setting Target Growth Rate to Compute Energy and Protein Required for Growth

The 1996 Beef NRC equations to predict target weights were modified for predicting target weights for dairy heifers. Based on Van Amburgh et al. (29), it is assumed that target weight post first calving should be 85% of mature weight. The target postcalving weights for dairy females in their second and third lactations should be 92 and 96% of mature weight, respectively, based on the model described by Fox et al. (10) and the data of Van Amburgh et al. (29). The equations to predict target weights and rates of gain are as follows:

$$TPW_1 = MSBW \times 0.55. \quad [6]$$

$$TPA_1 = TCA_1 - 280. \quad [7]$$

$$TBPSBWG_1 = (TPW_1 - \text{current SBW}) /(TPA_1 - \text{current age}). \quad [8]$$

$$TCW_1 = MSBW \times 0.85. \quad [9]$$

$$TCW_2 = MSBW \times 0.92. \quad [10]$$

$$TCW_3 = MSBW \times 0.96. \quad [11]$$

$$TCW_4 = MSBW \times 1. \quad [12]$$

$$TAPSBWG_1 = (TCW_1 - TPW_1)/280. \quad [13]$$

$$TACSBWG_1 = (TCW_2 - TCW_1)/CI. \quad [14]$$

$$TACSBWG_2 = (TCW_3 - TCW_2)/CI. \quad [15]$$

$$TACSBWG_3 = (TCW_4 - TCW_3)/CI. \quad [16]$$

Equation [2] is used to compute the NE_G requirement for all target rates of gain, and Equations [3] and [4] are used to compute protein requirement for growth. Observed weights can be substituted for previous target weight and divided by days left to reach the next target weight, to determine SBWG required to reach the next target weight. The NE_G required to reach the target weight can then be calculated.

For pregnant animals, gain due to growth of the gravid uterus should be added to predicted daily SBWG as follows (24):

$$ADG_{preg} = CBW \times (18.28 \times (0.02 - 0.0000286 \times t) \times e^{((0.0200 \times t) - (0.0000143 \times t\kappa 2))}. \quad [17]$$

For pregnant heifers, the weight of fetal and associated uterine tissue should be deducted from SBW to compute growth requirements. The conceptus weight (CW) can be calculated as follows:

$$CW = (CBW \times (0.01828) \times e^{((0.02 \times t) - (0.0000143 \times t\kappa 2))}. \quad [18]$$

Predicting Energy Requirements for Body Reserves

We used the 1996 Beef NRC body reserves model equations to predict body composition for body condition score (BCS). These equations were developed from data on chemical body composition and BCS (1 to 9 scoring system) from 106 mature cows of diverse breed types, mature weights, and BCS. The resulting best-fit equations to describe relationships between BCS and empty body percentage of fat, protein, water, and ash were linear. A zero intercept model with individual animal data was used to describe the relationship between the percentage of empty body fat and BCS. The BCS accounted for 65, 52, and 66% of the variation in body fat, body protein, and body energy, respectively, between individual cows. The SBW was 85.1% of EBW. The mean SBW change associated with a BCS change (1 to 9 scale) was 6.85% of mean SBW.

The following equations summarize this model as modified for use with dairy cattle. Modifications included using the 1 to 5 dairy condition scoring system (31) and using the SBW change per condition score to develop a method for computing the weight change associated with any BW and BCS.

$$\text{1996 Beef NRC 1 to 9 scale BCS} = [(\text{dairy BCS} - 1) \times 2] + 1. \quad [19]$$

$$\text{EBW} = 0.851 \times \text{SBW}. \quad [20]$$

Using the database change of 6.85% of SBW change per BCS, EBW at BCS 5 was calculated:

$$\text{EBW 5} = (\text{current EBW/adjustment factor}), \quad [21]$$

where adjustment factors for BCS 1 to 9 were 0.726, 0.7945, 0.863, 0.9315, 1, 1.0685, 1.137, 1.2055, and 1.274. Then EBW is computed for each BCS, using these factors applied to EBW at BCS 5.

Body composition is computed for each BCS:

$$\text{AF} = 0.037683 \times \text{BCS}. \quad [22]$$

$$\text{AP} = 0.200886 - 0.0066762 \times \text{BCS}. \quad [23]$$

$$\text{TF} = \text{AF} \times \text{EBW}. \quad [24]$$

$$\text{TP} = \text{AP} \times \text{EBW}. \quad [25]$$

$$\text{ER} = 9.4\ \text{TF} + 5.7\ \text{TP}. \quad [26]$$

Energy reserves for the next lower and higher BCS were subtracted from the current BCS to compute energy and protein gain or loss to reach the next BCS. During mobilization, 1 Mcal of ER substitutes for 0.82 Mcal of diet NE_L; 1 Mcal of diet NE_L will provide 0.75/0.644 = 1.16 Mcal of ER. In this equation, 0.75 is the efficiency of use of metabolizable energy (ME) for reserves in lactating cows and 0.644 is the efficiency of use of ME for lactation (23).

$$\text{Days to change 1 BCS} = NE_L \text{ for 1 BCS change}/NE_L \text{ balance}. \quad [27]$$

Model Evaluation

The data set used to evaluate the equations for predicting energy and protein retained during growth was the serially slaughtered nonimplanted Holstein heifer data published by Fortin et al. (9) and Anrique et al.

TABLE 2. Relationship of stage of growth and rate of gain to body composition.[1]

Mature weight	Requirements during growth						
	BW during growth (kg)						
478 kg	200	250	300	350	400	450	500
600 kg	250	314	376	439	500	565	627
650 kg	272	340	408	476	544	612	680
	NE_g required, meal/d[2]						
Average daily gain (kg)							
0.6	1.68	1.99	2.28	2.56	2.83	30.9	3.34
0.8	2.31	2.73	3.13	3.51	3.88	4.24	4.59
1.0	2.95	3.48	4.00	4.49	4.96	5.42	5.86
	Protein in gain, %/d[3]						
0.6	20.4	19.5	18.8	18.0	17.3	16.6	16.0
0.8	18.7	17.6	16.5	15.5	14.6	13.6	12.7
1.0	17.0	15.6	14.2	13.0	11.7	10.5	9.3
	Fat in gain, %[4]4						
0.6	5.9	9.7	13.2	16.6	19.9	23.1	26.2
0.8	13.6	18.7	23.6	28.2	32.8	37.1	41.4
1.0	21.4	27.9	34.1	40.1	45.6	51.5	56.9
	Body fat, percent of SBW[5]						
0.6	11.6	10.8	10.9	11.5	12.3	13.4	14.5
0.8	11.6	12.5	13.9	15.6	17.5	19.4	21.4
1.0	11.6	14.2	17.0	19.9	22.8	25.6	28.5

[1]Adapted for dairy heifers from the 1996 Beef NRC (24). The shrunk BW within a column have the same equivalent shrunk BW.

[2]SBWG = Daily shrunk BW gain. Net energy required for growth (NE_G) is computed from the 1996 Beef NRC equation (Equation 2) which was determined from 72 comparative slaughter experiments (20).

[3,4]Computed from the equations of Garrett (21), which were determined from the Garrett (20) database; proportion of fat in the SBWG = 0.122 NE_G − 0.146, and proportion of protein = 0.248 − 0.0264 RE. The proportion of fat and protein in the gain is for the BW and SBWG the NE_G is computed for.

[5]Computed from accumulated body fat when grown at the respective SBWG.

(4). The evaluation procedures used were as described by Tylutki et al. (27). The equations to predict target growth rates were evaluated with the data of Van Amburgh et al. (28, 29).

We used the data of Otto et al. (25) to evaluate the revised energy reserves model. In this study, body composition and BCS of 56 Holstein cows selected to represent the range in dairy BCS 1 to 5 were determined. The cows were randomly selected from the pens at Taylor Packing Co. (Wyalusing, PA) (n = 44) or from the Cornell University herd (Ithaca, NY) (n = 12), body condition was scored, and the 9–10–11 rib section was removed for chemical analysis. We used the treatment mean data presented in Table 1 of Otto et al. (25) to compute observed BW changes associated with BCS changes and empty body composition from 9–10–11 rib section chemical analysis as described by Ainslie et al. (3). Evaluation procedures were as described by Tylutki et al. (27).

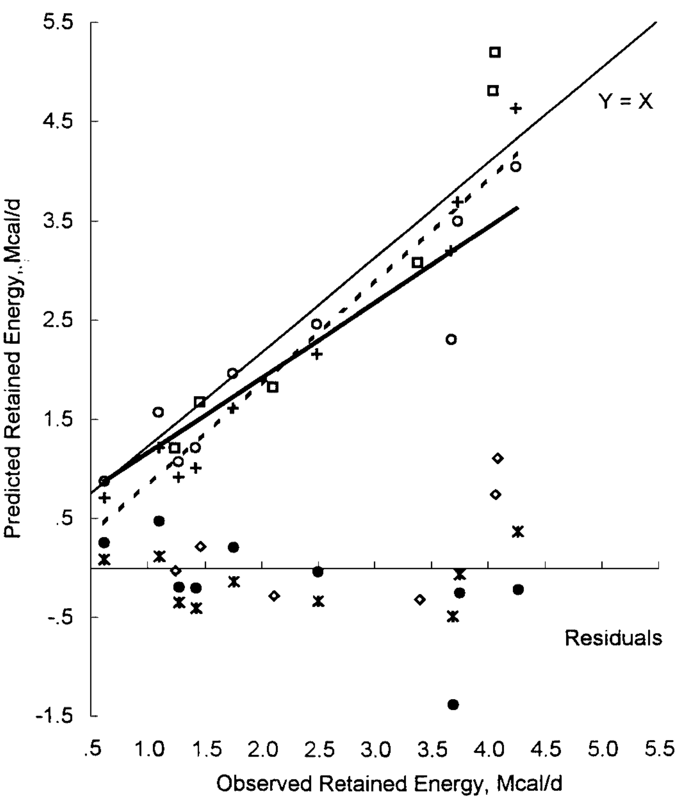

Figure 1. Evaluation of the prediction of energy retained (RE) in growing dairy heifers. The data is from serial slaughter of Angus and Holstein heifers (4, 9). The heavy solid (—) and dashed lines (– – –) are the regressions for Holstein heifers only for the 1989 Dairy NRC (23) and the 1996 Beef NRC (24), respectively. The data points are predicted vs observed for Angus [1996 NRC, (□)]; and Holstein [1989 NRC, (○); 1996 NRC, (+)] heifers. The r^2 were 0.86 and 0.96 with biases of –11 and –4% for the 1989 Dairy NRC and the 1996 Beef NRC respectively. The residuals plot includes Angus [1996 NRC, (◇)] and Holstein [1989 NRC, (●); 1996 NRC, (*)] heifers.

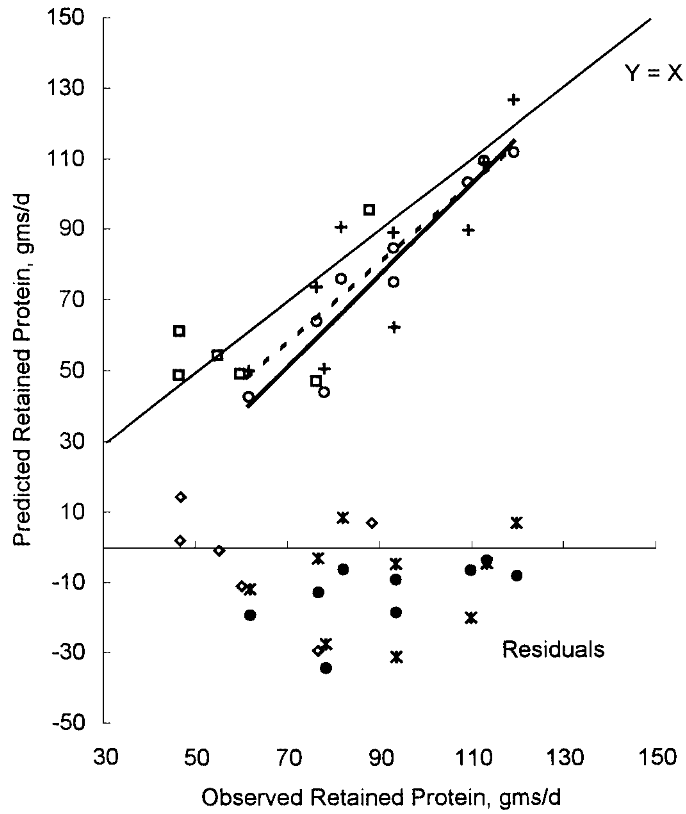

Figure 2. Evaluation of the prediction of protein retained (RP) in growing dairy heifers. The data is from serial slaughter of Angus and Holstein heifers (4, 9). The heavy solid (—) and dashed lines (– – –) are the regressions for Holstein heifers only for the 1989 Dairy NRC (23) and the 1996 Beef NRC (24), respectively. The data points are predicted vs observed for Angus [1996 NRC, (□)]; and Holstein [1989 NRC, (○); 1996 NRC, (+)] heifers. The r^2 were 0.91 and 0.71 with biases of –13% and –10% for the 1989 Dairy NRC and the 1996 Beef NRC respectively. The residuals plot includes Angus [1996 NRC, (◇)] and Holstein [1989 NRC, (●); 1996 NRC, (*)] heifers.

RESULTS AND DISCUSSION

Requirements for Dairy Heifer Growth

Table 2 shows net energy requirements computed by weights at which heifers of different mature sizes have the same EQSBW. To evaluate these results, we estimated the composition of the gain at different weights shown in Table 2 from NE_R (13); fat fraction $= (0.122 \times NE_R) - 0.146$, and protein fraction $= 0.248 - (0.0264 \times NE_R)$. Several important relationships are shown in this table. First, as BW increases, the energy content of the gain increases because more energy is deposited as fat at a given SBWG and body size. Second, the protein and fat content of the gain and expected body fat depend on the rate of gain at a particular stage of growth. Table 2 shows that even at low rates of gain and during the early stages of growth, some fat is deposited and that both protein

TABLE 3. Example application of equations to predict target weights and daily gain, using the evaluation data set.

Target	Input variables and calculations of target	
Target first pregnancy weight (TPW_1)	641 × 0.55	= 352 kg
Target first calving age, in d (TCA_1)		= 687 d
Target age at first pregnancy, d (TPA_1)	687 − 280	= 407 d
Target SBWG before conception ($TBPSBWG_1$)	(352 − 84)/(407 − 77)	= 0.87 kg/d
Target weight post first calving (TCW_1)	641 × 0.85	= 545 kg
Target SBWG after first conception, ($TAPSBWG_1$)	(545 − 352)/280	= 0.69 kg/d
Target weight post second calving (TCW_2)	641 × 0.92	= 590 kg
Calving interval (CI)		= 431 d
Target SBWG after first calving ($TACSBWG_1$)	(590 − 545)/431	= 0.104 kg/d
Target weight post third calving (TCW_3)	641 × 0.96	= 615 kg
Target SBWG after second calving ($TACSBWG_2$)	(615 − 590)/431	= 0.06 kg/d
Target SBWG after third calving ($TACSBWG_3$)	(641 − 615)/431	= 0.06 kg/d

and fat are synthesized as rate of gain increases. In part, this is because phospholipids are required for cellular membrane growth (19). In agreement with Table 2, lightweight (90 kg) Holstein calves restricted to 0.23 to 0.53 kg of ADG/d had 14.2 to 16.5% fat in the gain, respectively (1). As energy intake above maintenance increases, it is assumed that the rate of protein synthesis becomes first limiting, and excess energy is deposited as fat. The fat dilutes body content of protein, ash, and water, which are deposited at nearly constant ratios to each other at a given age (13). In agreement with Table 2, Radcliff et al. (26) reported Holstein heifers grown at 0.8 versus 1.2 kg/d to either 344 or 388 kg of SBW, had 12.1% versus 18.5% body fat in the SBW. Waldo et al. (30) indicated that Holstein heifers grown to 321 kg of SBW (the mean SBW during the trial was 249 kg) deposited 1.93 Mcal/d (2.58 Mcal/kg of SBWG) when grown at 0.75

TABLE 4. Example application of equations to predict energy and protein requirements, using evaluation data set target weights and daily gains.

Variable	Calculation of requirement
NE_G required for target SBWG during first conception growth:	
Mean target SBW	(352 + 84)/2 = 218 kg
EQSBW	(478/641) × 218 = 163 kg
EQEBW	163 × 0.891 = 145 kg
EBG	0.87 × 0.956 = 0.83 kg/d
NE_G	$0.0635 \times 145^{0.75} * 0.83^{1.097} = 2.16$ Mcal/d
NE_G required for target SBWG for heifer growth during first pregnancy:	
Mean target SBW	(352 + 545)/2 = 449 kg
EQSBW	(478/641) × 449 = 335 kg
EQEBW	335 × 0.891 = 298 kg
EBG	0.956 × 0.69 = 0.66 kg/d
NE_G	$0.0635 \times 298^{0.75} \times 0.66^{1.097} = 2.89$ Mcal/d
NE_G required for target SBWG during first lactation:	
Mean target SBW	(545 + 590)/2 = 568 kg
EQSBW	(478/641) × 568 = 424 kg
EQEBW	424 × 0.891 = 378 kg
EBWG	0.956 × 0.104 = 0.10 kg/d
NE_G	$0.0635 \times 378^{0.75} \times 0.10^{1.097} = 0.44$ Mcal/d
NE_G required for target SBWG during second lactation:	
Mean target SBW	(590 + 615)/2 = 603 kg
EQSBW	(478/641) × 603 = 450 kg
EQEBW	424 × 0.891 = 401 kg
EBWG	0.956 × 0.060 = 0.057 kg/d
NE_G	$0.0635 \times 401^{0.75} \times 0.057^{1.097} = 0.25$ Mcal/d
NE_G required for target SBWG during third lactation:	
Mean target SBW	(641 + 615)/2 = 628 kg
EQSBW	(478/641) × 628 = 468 kg
EQEBW	468 × 0.891 = 417 kg
EBWG	0.956 × 0.060 = 0.057 kg/d
NE_G	$0.0635 \times 417^{0.75} \times 0.057^{1.097} = 0.25$ Mcal/d

TABLE 5. Empty body chemical composition at different body condition scores.[1]

Dairy BCS	% in Empty body Fat	Protein	Ash	Water	SBW, % of BCS 3	Mcal/kg SBW change[2]
1.0	3.77	19.42	7.46	69.35	72.6	. . .
1.5	7.54	18.75	7.02	66.69	79.5	4.36
2.0	11.30	18.09	6.58	64.03	86.3	4.90
2.5	15.07	17.42	6.15	61.36	93.2	5.44
3.0	18.84	16.75	5.71	58.70	100.0	5.98
3.5	22.61	16.08	5.27	56.04	106.9	6.51
4.0	26.38	15.42	4.83	53.37	113.7	7.05
4.5	30.15	14.75	4.39	50.71	120.6	7.59
5.0	33.91	14.08	3.96	48.05	127.4	8.13

[1]BCS = Body condition score, SBW = shrunk BW.

[2]Weight change is the difference between the BW at the current BCS and the BW at the next lower or higher BCS. The weight loss from BCS 3 to a BCS 2 contains 8.3% protein.

kg/d compared to 2.75 Mcal/d (3.67 Mcal/kg of SBWG) when the heifers grew at 0.95 kg/d.

Evaluation of model to predict energy and protein requirements for growth of dairy heifers. Figures 1 and 2 summarize the validations for NE_R and NP_R, respectively. The Y = X and residuals lines show both Angus and Holstein heifer composition of gain data fit the same line (no breed effect using the size scaling approach). In these figures, the dashed line shows the regression describing the Holstein heifers and had the same slope and a similar intercept as the Y = X line for both breeds. For NE_R in Holstein heifers, the r^2 was 0.86 for the 1989 NRC and 0.96 for the 1996 Beef NRC, with biases of –11% and –4%, respectively. For NP_R in Holstein heifers, the R^2 was 0.91 for the 1989 NRC and 0.71 for the 1996 NRC, with biases of –13% and –10%, respectively. The bias for the 1989 NRC was nonuniform, with under prediction of NP_R at lower BW. These results indicate the 1996 Beef NRC can be used to predict NE_R and NP_R for both beef and dairy cattle. We suggest, however, that more research is needed to account for factors influencing NP_R, as indicated by the lower R^2 and higher bias in predicting NP_R compared to NE_R.

The data of Waldo et al. (30), which included information from 32 Holstein heifers fed alfalfa or corn silage diets for two rates of ADG (0.78 and 0.99 kg/d) from 181 to 334 kg of FBW, were evaluated with Equation [2]. Because the expected MSBW was not published, MSBW was changed in Equation [2] until predicted and observed NE_R agreed in the low (0.643 kg of EBWG/d) and high (0.844 kg of EBWG/d) gain groups. The SBW was computed as 0.96 × FBW. Mature BW required for predicted NE_R to equal the measured NE_R was 580 and 540 kg, respectively, for the low and high gain groups. The EBW averaged 89% of SBW compared to 89.1% in Equation [2]. The EBWG averaged 87.4% of SBWG, compared to the 95.6% used in Equation [2]. At the same stage of growth, EBW was 89% of SBW, and EBWG averaged 95.7% of SBWG in Holstein steers that weighed less than 400 kg that were fed corn silage-based diets (1). These values are nearly identical to those in Equation [2].

Application of the growth model for dairy heifers. Data from the study published by Van Amburgh et al. (28, 29) is used to demonstrate how the growth model can be applied to calculate NE_G required for growth of replacement dairy heifers. This study in-

TABLE 6. Energy reserves for dairy cows with different body sizes and body condition scores (BCS).

Dairy BCS	Shrunk body weight, kg: 400	450	500	550	660	650	700	750
	Mcal NE_L required or provided for each half BCS[1]							
1.5	120	135	150	165	180	195	210	225
2.0	134	151	168	184	201	218	235	251
2.5	149	168	186	205	224	242	261	280
3.0	164	184	205	225	246	266	287	307
3.5	179	201	223	246	268	290	312	335
4.0	193	217	242	266	290	314	338	362
4.5	209	235	261	287	313	339	365	391
5.0	222	250	278	305	333	361	389	417

[1]Represents the energy mobilized in moving to the next lower score, or required to move from the next lower score to this one.

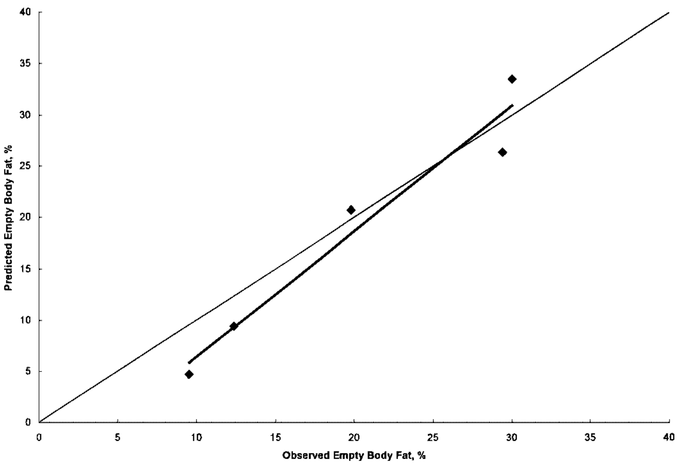

Figure 3. Evaluation of the prediction of empty body fat in Holstein cows. The data (—■—) is from slaughter of Holstein cows across the range of dairy body condition scores (25). The revised 1996 Beef NRC (24) model accounted for 96% of the variation in body fat with a bias of 1.6%.

volved 273 Holstein heifers fed from an average of 77 d of age through the first lactation. The mean MSBW of the herd was 641 kg. The average postweaning and transition weight of calves was 84 kg. The mean age at first calving was 687 d, and the calving interval was 431 d. Targets computed with the model presented are shown in Table 3. Mean BW and SBWG observed in this experiment compared well with model predicted values. The SBWG before first calving averaged 0.82 kg/d versus a target of 0.87 kg/d; weight at first pregnancy was 370 kg versus a target of 352 kg; the SBWG during first pregnancy averaged 0.63 kg/d versus a target of 0.69 kg/d; weight post first calving averaged 533 kg versus a target of 545 kg; first lactation SBWG averaged 0.136 kg/d versus a target of 0.104; and second post calving weight was 592 kg (projected from 40 wk of lactation SBW and SBWG) versus a target of 590 kg.

Equation [2] is used to compute NE_R for each target SBWG and Equations [3] and [4] were used to compute net and absorbed protein requirements for the computed target SBW and SBWG values, as shown in Table 4.

The model presented was designed to avoid an inadequate body size at first calving, which may limit milk production and impair reproductive performance during the first lactation (15). These targets were also designed to avoid excess energy intake, which leads to overconditioning from 2 to 3 mo of age until conception (which can reduce first lactation milk production) (29).

Requirements for Body Reserves

Table 5 shows the percent composition and SBW change associated with each BCS computed with this model. This model predicts energy reserves to be 5.98 Mcal/kg of live weight loss at a BCS of 3.0 compared to the INRA (16) and the 1989 Dairy NRC (23) value of 6 Mcal/kg. Predicted energy content of weight loss ranges from 4.36 Mcal/kg at BCS 1.5 to 7.59 Mcal/kg at BCS 4.5 compared to CSIRO (7) values of 3.0 and 7.1, respectively. Protein in the weight loss from a BCS 3 to a BCS 2 is predicted to be 83 g/kg, compared to 117, 135, 138, and 160 g/kg weight loss for the Buskirk et al. (5), CSIRO (7), Agricultural and Food Research Council (2), and NRC Dairy 1989 systems (23).

These results (Tables 2 and 5) agreed with available data that indicates composition of live weight loss at maturity is approximately equal to the composition of live weight gain in animals (2, 7, 24). Data in Table 2 show that 1 kg of SBWG contains 5.86 Mcal and 93 g of protein after a heifer reaches mature weight, compared to the Table 5 value of 5.98 Mcal and 83 g of protein/kg at BCS 3. The 160-g protein in weight loss proposed by the 1989 Dairy NRC seems high; Table 2 shows this is the protein content of 1 kg of gain at approximately 50% of mature weight.

Table 6 gives megacalories mobilized in moving cows to the next lower score or required to move cows from the next lower score to the one being considered for cows with different mature sizes. Diet NE_L replaced by mobilized reserves, or required to replenish reserves, was computed by assuming 1 Mcal of mobilized

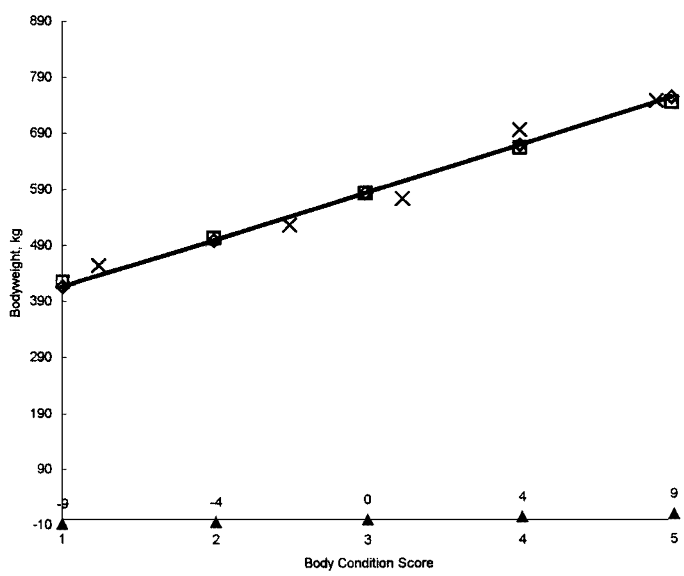

Figure 4. The relationship between body weight and condition score in Holstein cows computed from the data of Otto et al. (25) or the model presented in this paper. The relationship between observed BW and observed body condition score is; y = 84.6 + 330; r^2 = 0.96. The data points (X) are actual published treatment means. For each body condition score, BW is computed from this regression equation (◇) or predicted by the model presented in this paper (□).

tissue would replace 0.82 Mcal of diet NE_L, and 1 Mcal of diet ME would provide 0.75 Mcal of tissue net energy if the cow is lactating or 0.60 Mcal if it is dry, based on Moe (17, 18) and 1989 Dairy NRC (23). For example, a 600-kg cow at BCS 3 will mobilize 246 Mcal of net energy in declining to a score of 2.5. If NE_L intake is deficient 3 Mcal/d, this cow will lose 1 BCS in $(246 \times 0.82)/3 = 67$ d. If the cow is consuming 3 Mcal of NE_L above daily requirements, this cow will move back to a BCS 3 in $246/((3/0.644) \times 0.75) = 70$ d.

Evaluation of model for predicting energy reserves in dairy cows. Data in Figure 3 show that body fat at a particular condition score in Holstein cows was predicted with an r^2 of 0.95 and a bias of –1.6%. Figure 4 shows the relationship between BW change and BCS in Holstein cows was 84.6 kg/BCS (r^2 = 0.96), which compared to 80 kg predicted by the model. The intent of this evaluation was to test the model data containing both chemical composition of cows and BCS representing the range in dairy BCS, with the BCS obtained consistently with the way they are applied on dairy farms. Although the evaluation strongly supports the use of this model, further validation with other data sets should be conducted.

CONCLUSIONS

The evaluations presented indicate the 1996 Beef NRC model modified as presented can be used to predict net energy and protein requirements for growth and body reserves of dairy cattle. However, the model has not been evaluated for use with calves less than 100 kg of BW. This model allows the user to predict requirements for any mature size of dairy cattle. We found this model to be a useful tool for evaluating and improving diets to minimize herd replacement costs while maximizing lifetime milk production under widely varying conditions. Evaluations indicate the model presented can be used to predict energy reserves in dairy cattle. We have found this model to be a useful tool for predicting BCS changes from ration energy balance. Although protein content of weight loss can be predicted, our model does not attempt to predict whether this protein will be available for meeting protein versus energy requirements.

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