11 Growth

ENERGY AND PROTEIN REQUIREMENTS FOR GROWING DAIRY HEIFERS

Since the publication of the last National Research Council review of nutrient requirements of dairy cattle (National Research Council, 1989), several articles on use of accelerated growth programs for heifers and their effects on milk production have been published (Lammers et al., 1999; Radcliff et al., 1997; Van Amburgh et al., 1998a, 1998b). In addition, there have been several reports of studies on protein requirements of heifers (Pirlo et al., 1997; Tomlinson et al., 1997). This renewed interest in rearing heifers is largely due to the costs of raising replacement animals and the impact of the growing period on lifetime milk production. These economic imperatives underscore the importance of accurate prediction of heifer nutrient requirements. Energy and protein requirements for growth are estimated from the energy and protein content of the tissue deposited during growth (National Research Council, 1996). The amount of energy required for growth is calculated from the net energy deposited. The amount of protein that must be consumed daily to achieve the target growth rate is the sum of 1) rumen degradable protein (RDP) required for microbial growth that can be achieved given the level of ruminally available carbohydrates, and 2) rumen undegradable protein (RUP) required to supplement the microbial protein produced to support the energy allowable average daily gain (ADG). Preston (1982) indicated that protein requirements for growth could be expressed as a ratio of dietary crude protein (CP) to dietary total digestible nutrients (TDN). However, this approach does not account for differences in RDP and RUP requirements, and in mature body size.

Tomlinson et al. (1997) reported a growth response when RUP was added to heifer diets. A growth response also was evident when RUP was added to low energy, but not high energy, diets fed to heifers less than 385 days old (Bethard et al., 1997). Heifers responded to both supplemental TDN and CP when the basal diet contained 90 percent of National Research Council-predicted requirements (Pirlo et al., 1997). Accurate estimation of dietary requirements for protein should be based on ruminal and tissue requirements in varied production environments (National Research Council, 1996; Van Amburgh et al., 1998a).

Terminology

In this section on growth, several terms are used which are less familiar to those in the dairy industry than to those who work primarily with growing animals. In the 1989 publication on requirements of dairy cattle (National Research Council, 1989), all calculations were done on a full body weight (BW or FBW) basis. In this publication, the terms shrunk body weight (SBW) and empty body weight (EBW) also are used. These terms permit better description of biologic functions than reliance on live weight alone. For example, SBW, which is defined as 96 percent of FBW, is equivalent to an animal's weight after an overnight fast without feed or water. It is used to compute NE_M requirements, which are measured as fasting heat production (National Research Council, 1984). Shrunk body weight also is used in calculations to determine the amount of net energy available for growth in the diet (NEFG) and target shrunk weight gain (SWG). Empty body weight (weight without ingesta), which is 89.1 percent of SBW or 85.5 percent of BW, was used to develop the equation to predict the energy required for SWG because net energy requirements are a function of the proportion of fat and protein in the empty body tissue gain (EBG) (Garrett et al., 1959). Empty body gain is 96 percent of SWG.

Growth Requirements and Composition of Gain

The strong relationship between weight and height (Heinrichs and Losinger, 1998) makes it possible to use linear measurements to describe dimensional changes as an animal matures (Hoffman, 1997; Kertz et al., 1998; Lammers et al., 1999). Although these measurements have several useful field applications, skeletal growth cannot be directly used to compute energy and protein requirements for growth for two reasons: 1) net energy for gain (NE_G) is defined as the energy content of the tissue deposited during growth, and 2) most of the data relating stature and weight are from Holsteins so that the system would be unworkable for other breeds. It is a function of the proportion of fat and protein in EBG (Garrett et al., 1959). Simpfendorfer (1974) summarized data on the body composition of growing cattle from birth to maturity and found that 95.6–98.9 percent of the variation in chemical composition was associated with differences in the weights of cattle of similar mature sizes. If an animal is fed a diet containing adequate energy, the percentage of protein diminishes and the percentage of fat increases in the empty body as the animal matures (National Research Council, 1996). Chemical maturity is achieved when weight gain contains little additional protein (National Research Council, 1996). Previous subcommittees on beef and dairy nutrition (National Research Council, 1984, 1989, 1996) adopted the equation developed by Garrett (1980) to predict the energy content of weight gain. Garrett's data set included 72 comparative slaughter experiments conducted at the University of California between 1960 and 1980 with approximately 3,500 cattle (predominantly British breed beef steers) fed a variety of diets. The Garrett equation describes the relationship between retained energy (RE) and EBG for a given EBW. The same data were used to derive the relationships between FBW, SBW, and EBW and to describe the composition of ingesta-free BW gain at a particular stage of growth of cattle (National Research Council, 1996).

Because the weight at which cattle reach a given chemical composition varies depending on mature size and gender, body composition may differ among animals of similar weights (National Research Council, 1996). Following the approach adopted in the 1984 *Nutrient Requirements of Beef Cattle* (National Research Council, 1984) and in the 1989 *Nutrient Requirements of Dairy Cattle* (National Research Council, 1989), recently developed systems to predict animal requirements have used a size scaling approach to account for these effects (National Research Council, 1996). The size-scaling approach adopted in the Australian system (Commonwealth Scientific and Industrial Research Organization [CSIRO], 1990) involves calculation of the relationship between an animal's current weight and a standard reference weight. The standard reference weight is defined as the weight at which skeletal development is complete and the empty body contains 25 percent fat corresponding to a body condition score (BCS) of 3 on a 0 to 5 scale. To facilitate ration balancing, standard reference weights for different breeds are provided in a table in the CSIRO system (1990).

Oltjen et al. (1986) developed a simulation model of growth and body composition based on differential equations describing whole body DNA accretion and protein synthesis and degradation. He assumed that the difference between net energy available for gain and that required for protein synthesis deposited as fat. By using the ratio between the animal's current weight and its mature weight, it was possible to adjust for differences in mature size.

In the model developed by the Institut National de la Recherche Agronomique (INRA) system (Institut National de la Recherche Agronomique, 1989), the amounts of protein and lipid retained daily are predicted considering the type, live weight, and daily live weight gain of the animal. The INRA approach to prediction of energy and protein requirements involves use of allometric relationships between EBW and live weight, between lipid content (kg) and EBW, and between protein content and fat-free body mass. The coefficients in the INRA equations are the parameters obtained by fitting data on live weight and age to the Gompertz equation (Taylor, 1968). The French system includes initial and final weights and growth curve coefficients for six classes of bulls, two classes of steers, and two classes of heifers for finishing cattle, and two classes each for male and female growing cattle. The amount of lipid deposited daily is proportional to the daily live weight gain raised to the power 1.8 ($BW^{1.8}$). Daily protein accretion is calculated from the gain in the fat-free body mass because protein content of fat-free gain varies little with type of animal, growth rate, or feeding level (Garrett, 1987).

The mature weights of dairy cattle vary from 400 kg for small breeds to more than 680 kg for large breeds. Because of the considerable variation in mature size within and among breeds, this committee decided that it was necessary to consider mature size in estimating growth requirements. In the previous publication on the nutrient requirements of dairy cattle (National Research Council, 1989), size effects were taken into account by including requirements for small, medium, and large breeds in the nutrient requirement tables. However, the equations used to compute the net energy and protein content of gain were not adjusted to account for the effect of mature weight.

The National Research Council *Nutrient Requirements of Beef Cattle* (1996) adopted the size scaling system developed by Fox et al. (1992) with refinements published by Tylutki et al. (1994). This system is used to account for differences in mature size of cattle (Equations 11-1 and 11-2) with further modifications made to adapt it for use with dairy heifers (except for pre-ruminant calves) (Fox et al., 1999). As in the CSIRO (1990) and INRA (1989) systems, it is assumed in this model that the chemical composition of gain is similar among animals at the same proportion of mature BW. The size scaling equation in the beef growth model (National Research Council, 1996) is similar to the approach adopted by CSIRO (1990).

The equations of Garrett (1980), with the adjustments for mature size shown in Equations 11-2 and 11-5, are used to compute the energy content of gain at various stages of growth and rates of gain. These equations were chosen because: a) they were developed from a large, robust data set (Garrett, 1980), b) they have been used with success in previous National Research Council publications (National Research Council, 1984, 1989, 1996), and c) they accurately described the net energy and protein content of Holstein heifers (Fox et al., 1999) using the adjustments for mature body size in Equations 11-2 and 11-5.

$$\text{EQSBW} = \text{SBW} \times (478/\text{MSBW}) \qquad (11\text{-}1)$$

$$\text{RE, Mcal} = 0.0635 \times \text{EQEBW}^{0.75} \times \text{EQEBG}^{1.097} \qquad (11\text{-}2)$$

where EQEBW is 0.891 × EQSBW and EQEBG is 0.956 × SWG.

In this growth model, EQSBW is the weight at which the standard reference animal has the same energy content of gain as the dairy heifer being evaluated. An analysis of the California data set indicated that the mature SBW for the animals in the serial slaughter studies averaged 478 kg. Equation 11-2, which describes the energy content of gain at a particular weight for the California data base (National Research Council, 1996), is used in the current model to describe the growth curve of dairy heifers. As a result, the standard reference animal is assumed to have a mature weight of 478 kg (National Research Council, 1996). In Equation 11-2, energy content of gain increases with weight and rate of growth. If we assume that the average Holstein has a full BW (FBW) of 677 kg or SBW of 650 kg, the relationship between this animal and the standard reference animal can be determined using Equation 11-1. The ratio of the reference SBW to the mature SBW (478/650) is used to determine that the standard reference animal weighs 73.5 percent as much as the Holstein at chemical maturity. Assuming an average SBW of 650 kg, Equation 11-1 indicates the standard reference animal weighs 478/650 = 73.5 percent as much at maturity, and therefore weighs 73.5 percent as much as this Holstein at the same stage of chemical maturity. For example, the "size-scaled" weight of a Holstein heifer with an SBW of 300 kg (313 FBW) and a mature SBW of 650 kg (677 FBW) is 300 × (478/650) = 221 kg. This value is then adjusted to an empty body basis (221 × 0.891 = 197 kg) and used in Equation 11-2 to compute her net energy requirement. For a 300 kg SBW Holstein heifer with a mature weight of 800 kg, the size-scaled weight is 300 × (478/800) = 179 kg, with an EBW of 159 kg. The size-scaled weight of a Jersey heifer weighing 300 kg SBW with a mature weight of 400 kg is 300 × 478/400 = 359 kg with an EBW of 320 kg, which is used in Equation 11-2 to compute her net energy requirement. Although these three heifers weigh the same amount (300 kg SBW), the Jersey heifer is at 75 percent of her mature weight, while the average and large Holstein heifers are at 46 percent and 38 percent of their respective mature weights. When these size-scaled weights are used in Equation 11-2 with a rate of gain of 0.7 kg (EBG = 0.7 × 0.956 = 0.669), the Jersey heifer will have the highest net energy content of gain, followed by the average and large mature size Holstein heifers (3.09, 2.15, and 1.83 Mcal, respectively). The validation by Fox et al. (1999) showed that this size scaling approach can be used for dairy heifers.

Given the relationship between energy retained and protein content of gain, protein content of SWG (net protein for gain, NP_g) is computed from the following equation (National Research Council, 1984, 1996):

$$NP_g\text{, g/d} = \text{SWG} \times (268 - (29.4 \times (\text{RE/SWG}))) \qquad (11\text{-}3)$$

The retained protein predicted in Equation 11-3 is adjusted for mature size because the RE used in that equation is based on EQEBW. The absorbed protein requirement is:

$$\text{MPGrowth} = NP_g / (0.834 - (\text{EQSBW} \times 0.00114))$$
$$\text{If EQSBW is} > 478 \text{ kg, then EQSBW} = 478 \text{ kg.} \qquad (11\text{-}4)$$

To develop feeding programs and evaluate heifer performance, daily gain must be predicted from the diet being fed. This is accomplished by substituting EQSBW for SBW and the net energy available for growth (NEFG) for RE in the Garrett (1980) equation (Equation 11-5) to predict SWG:

$$\text{SWG} = 13.91 \times \text{NEGrowthDiet}^{0.9116} \times \text{EQSBW}^{-0.6837} \qquad (11\text{-}5)$$

Actual SWG and NEGrowthDiet can be substituted into Equation 11-3 to compute the protein required for the observed SWG and NEFG. Equation 11-4 can then be used to compute the MP required for the observed SWG to evaluate whether protein requirements have been met.

Evaluation of Model Predictions of Energy and Protein Requirements for Growth of Dairy Heifers

Table 11-1 shows the net energy requirements of heifers of different mature sizes (650, 800, and 400 kg) growing at different rates (0.6, 0.8, and 1.0 kg/day). Several important relationships are shown in this table. First, as BW increases, the energy content of the gain increases and protein content of the gain decreases, because more energy is deposited as fat. Second, as SWG increases, energy content of the gain increases and protein content of the gain decreases because the gain contains a higher proportion of fat as

TABLE 11-1 Relationship Between Mature Size and Growth Requirements[a]

Mature weight	Live Body Weight During Growth (kg)						
650 kg Holstein	200	250	300	350	400	450	500
800 kg Holstein	246	308	369	431	493	554	616
400 kg Jersey	139	173	208	242	277	312	346
SWG (kg/day)	NE_G required, Mcal/d[b]						
0.6	1.34	1.58	1.81	2.03	2.25	2.46	2.66
0.8	1.83	2.17	2.48	2.79	3.08	3.37	3.64
1.0	2.34	2.77	3.17	3.56	3.94	4.30	4.65
	Net protein required for growth, g/d[c]						
0.6	122	114	108	101	95	89	83
0.8	161	151	141	132	124	115	107
1.0	199	187	175	163	152	142	131
	Metabolizable protein required for growth, g/d[d]						
0.6	182	183	185	187	190	194	199
0.8	241	241	243	245	248	253	259
1.0	299	299	300	302	305	310	316

[a] The body weights are full, not shrunk, body weights. The weights within the same column are at the same stage of growth.

[b] NE_G requirement is computed from Equation 11-2: Retained energy (RE), Mcal $= 0.0635\ EQEBW^{0.75}\ EQEBG^{1.097}$, where EQEBW is equivalent empty body weight and EQEBG is $0.956 \times$ SWG.

[c] Net protein in the gain is computed from Equation 11-3: NP_g (g/d) $=$ SWG $\times$ (268 $-$ (29.4 $\times$ (RE/SWG)))

[d] Metabolizable protein required is computed from Equation 11-4: MPGrowth $= NP_g$ / (0.834 $-$ (EQSBW $\times$ 0.00114)); If EQSBW is $>$ 478 kg, then EQSBW $=$ 478 kg.

growth rate increases. Third, as animals increase in weight, metabolizable protein required does not decrease as rapidly as net protein required, because the efficiency of protein absorption declines. As energy intake above maintenance increases, it is assumed that the rate of protein deposition becomes limiting, and excess energy is deposited as fat. The fat dilutes the body content of protein, ash, and water, which are deposited at nearly constant ratios to each other at a given age (Garrett, 1987). The carcasses of Holstein heifers growing from 344 to 388 kg SBW that gained either 0.8 or 1.2 kg/d contained 12.1 or 18.5 percent body fat in the SBW (Radcliff et al., 1997). Holstein heifers grown to 321 kg SBW (334 kg FBW) deposited 1.93 Mcal/d (2.58 Mcal/kg SBG) when grown at 0.75 kg/d compared to 2.75 Mcal/d (3.67 Mcal/kg SBG) when the heifers grew at 0.95 kg/d (Waldo et al., 1997).

The equations used to predict energy and protein retained during growth were validated using data from experiments with Holstein heifers that were serially slaughtered (Fortin et al., 1980; Anrique et al., 1990, as described by Fox et al., 1999). Although these animals were fed diets that were pelleted and contained less fiber than usually is fed to growing animals, the energy retained for the observed daily gain can be used to validate this model. Plots of observed and predicted values and plots of residuals of data on composition of gain of Angus and Holstein heifers showed that the composition of gain for beef and dairy breeds was similar when the size scaling approach was used. The slope and intercept of the regression describing the composition of gain of the Holstein heifers was similar to the regression for the combined data set. The r^2 was 0.86 when observed and predicted data on RE of Holstein heifers were regressed using the equations from *Nutrient Requirements of Dairy Cattle* (National Research Council, 1989) with a bias of -11 percent. The r^2 was 0.96 for the model presented here, with a bias of -4 percent. When similar regressions were performed to evaluate prediction of RP in Holstein heifers, the r^2 was 0.91 for the 1989 equations and 0.71 for the model presented here, with biases of -13 and -10 percent, respectively. The bias for the 1989 National Research Council equations was nonuniform, with under prediction of RP at lower BW. These results indicate the present model can be used to predict RE and RP for dairy heifers. We suggest, however that more research is needed to account for factors influencing RP, as indicated by the lower r^2 and higher bias in predicting RP compared to RE.

Information from 32 Holstein heifers fed alfalfa or corn silage diets at two rates of ADG (0.78 and 0.99 kg/d) from 181 to 334 kg of FBW (Waldo et al., 1997) was used to evaluate the prediction of EBW and EBG. The EBW averaged 89 percent of SBW compared to 89.1 percent in the Garrett (1980) data-base, which was used to develop this model. The EBG averaged 87.4 percent of SWG compared to 95.6 percent in the Garrett (1980) data-base. In Holstein steers at the same stage of growth as the heifers in the trials conducted by Waldo et al. (1997) ($<$ 400 kg SBW), EBW was 89 percent of SBW and EBG averaged 95.7 percent of SWG (Abdalla et al., 1988). These values are nearly identical to those used in this model.

Based on these evaluations of the model, errors in predicting net energy and protein requirements and SWG may occur due to one or more of the following factors:

- Using an incorrect MSBW.
- Short-term, transitory effects of previous nutrition.
- Variation in the NE_M requirement.
- Variation in the ME value assigned to the feed because of variations in feed composition and extent of ruminal or intestinal digestion.
- Variation in NE_M and NE_G derived from the ME because of variation in end products of digestion and their metabolizability.
- Variations in gut fill.

Although ionophores are commonly fed to replacement heifers, the computer model accompanying this publication includes no adjustments for ionophores for several reasons. The relative importance of the various effects of ionophores such as changes in intake, protein sparing, influence on ruminal pH, increased energetic efficiency of the ruminal microbes and reduced problems with protozoal pathogens has not been fully elucidated. The effects of ionophores vary with diet, animal condition, environmental conditions, and the types of ionophore used. The model may not predict accurately when ionophores are fed unless the user adjusts either intake or the digestibility of nutrients in the ration.

SETTING TARGET GROWTH RATES

Growth rates of replacement heifers affect economic returns on dairy farms (Cady and Smith, 1996). Inadequate size at first parturition may limit milk production and conception rate during first lactation (Hoffman et al., 1996). Excess energy intake, however, can have negative effects on mammary development by affecting the mammary parenchyma (ductular epithelial tissue) (Harrison et al., 1983; Foldager and Serjsen, 1987). There was an interaction between protein and energy because, when adequate amounts of metabolizable protein were supplied to animals receiving high-energy diets, fewer effects on mammary development were evident (Radcliff et al., 1997). Follow-up research showed that heifers fed diets high in energy and protein decreased age at first parturition and milk production at first lactation (Radcliff et al., 2000) but milk production was not reduced in the first lactation in other heifers raised on an accelerated (0.9 kg ADG/day) growth program (Abeni et al., 2000). Because puberty is associated with BW and weight is not linearly related to growth, parenchyma tissue growth may be truncated before full ductal development occurs if excess energy is consumed before puberty (Van Amburgh et al., 1991). Excessive energy intake, indicated by over-conditioning from 2 to 3 months of age until after conception, can reduce first lactation milk production (Van Amburgh et al., 1998b). Numerous data are available to support the concept of a genetically determined threshold age and weight at which heifers attain puberty (National Research Council, 1996). Joubert (1963) proposed that heifers would not attain puberty until they reached a given degree of physiologic maturity, which is similar to the ‘‘target weight’’ concept proposed by Lamond (1970). Simply stated, the concept is to feed heifers to attain a pre-selected or target weight at a given age to achieve optimum first lactation performance while controlling the costs of rearing replacements. Heifers of beef breeds usually attain puberty at about 60 percent of mature weight, while dual purpose and dairy heifers reach puberty at a younger age at about 55 percent of mature weight (National Research Council, 1996).

Optimum growth rates for heifers to minimize replacement costs while maximizing first lactation milk production have been described recently (Ferguson and Otto, 1989; Hoffman, 1997; Van Amburgh et al., 1998b). The *Nutrient Requirements of Beef Cattle* (National Research Council, 1996) equations to predict target weights, modified and evaluated by Fox et al. (1999), are used to predict target weights for dairy heifers. Further modifications included in this version of *Nutrient Requirements of Dairy Cattle*, compared to those outlined by Fox et al. (1999), are that the target weights after first and third calving were set to 82 and 100 percent of mature weight respectively, instead of 85 percent and 96 percent.In the following equations, calving weights are weights after parturition. The equations to predict target weights and rates of gain are as follows:

$$\text{Target weight first bred} = \text{Mature SBW} \times 0.55 \quad (11\text{-}6)$$

$$\text{Target age for 1st pregnancy} = \text{Target first calving age} - 280 \quad (11\text{-}7)$$

$$\text{Target SWG before 1st pregnancy} = (\text{Target weight first bred} - \text{current SBW}) / (\text{Target age for 1st pregnancy} - \text{current age}) \quad (11\text{-}8)$$

$$\text{Target 1st calving weight} = \text{Mature SBW} \times 0.82 \quad (11\text{-}9)$$

$$\text{Target 2nd calving weight} = \text{Mature SBW} \times 0.92 \quad (11\text{-}10)$$

$$\text{Target 3rd calving weight} = \text{Mature SBW} \times 1.00 \quad (11\text{-}11)$$

$$\text{First pregnant SWG} = (\text{Target 1st calving weight} - \text{Target weight first bred})/280 \quad (11\text{-}12)$$

$$\text{1st lactation SWG} = (\text{Target 2nd calving weight} - \text{Target 1st calving weight}) / \text{Calving interval} \quad (11\text{-}13)$$

$$\text{2nd lactation SWG} = (\text{Target 3rd calving weight} - \text{Target 2nd calving weight}) / \text{Calving interval} \quad (11\text{-}14)$$

Where calving interval (CI) is in days.

For all target rates of gain, Equation 11-2 is used to compute the NE_G requirement and Equations 11-3 and 11-4 are used to compute the protein requirement for growth. Observed weights can be substituted for the previous target weight and divided by days left to reach the next target weight to determine SWG required to achieve the next target weight. The NE_G required to reach the target weight can then be calculated. The target ADG will be small when the actual weight is close to the target weight. For pregnant animals, weight gain due to growth of the gravid uterus should be added to predicted daily shrunk weight gain (SWG) as follows:

$$ADG_{preg} = 665 \times (CBW/45) \text{ if DaysPreg} > 190 \quad (11\text{-}15)$$

Where CBW = expected calf birth weight (kg).

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

$$CW = (18 + ((DaysPreg - 190) \times 0.665)) \times (CBW/45) \quad (11\text{-}16)$$

When evaluating requirements and rations with the accompanying computer model, the user must choose whether to use the target gains predicted by the model using the system described above or to enter desired rates of gain (for example, 500g/day) to determine nutrient requirements. The only difference between these two systems is the rate of gain used to calculate the requirements; all the other computations are similar.

Evaluation of Target Weight Equations

The NE_G required for growth of replacement heifers can be calculated from published data (Van Amburgh et al., 1998a). This study involved 273 Holstein heifers fed from an average of 77 d of age through the first lactation. Average mature weight of the herd determined at all stages of lactation was 641 kg. The weight after weaning (calves were weaned at 6–8 wk and there was a 3-wk transition period) was 84 kg, average age at first calving was 687 d, and calving interval was 431 d. Targets computed with the model presented are shown in Table 11-2. Average BW and SWG observed in this experiment compared well with model predicted values. The SWG before first calving averaged 0.82 kg/d compared to a target of 0.87 kg/d; weight at first pregnancy was 370 kg vs. the target of 352 kg; the SWG during first pregnancy averaged 0.63 kg/d vs. a target of 0.62 kg/d; weight post first calving averaged 533 kg vs. a target of 526 kg; first lactation SWG averaged 0.136 kg/d vs. a target of 0.148 kg/d; and the weight after the second calving was 592 kg (projected from 40 wk of lactation SBW and SWG) compared to a target of 590 kg.

TABLE 11-2 Calculation of Target Weights and Daily Gain Using the Data Set of Van Amburgh et al. (1998a)

Target	Input variables and calculations of target
Target first pregnant weight, kg	641 × 0.55 = 352 kg
Target first calving age, days	= 687 d
Target age at first pregnancy, days	687 − 280 = 407 d
Target SWG before conception, kg	(352 − 84) / (407 − 77) = 0.87 kg/d
Target weight post-first calving, kg	641 × 0.82 = 526 kg
Target SWG after first conception, kg	(526 − 352) / 280 = 0.62 kg/d
Target weight post-second calving, kg	641 × 0.92 = 590 kg
Calving interval, days	= 431 d
Target SWG after first calving, kg	(590 − 526) / 431 = 0.148 kg/d
Target weight post-third calving, kg	641 × 1 = 641 kg
Target SWG after second calving, kg	(641 − 590) / 431 = 0.118 kg/d

Using the data from Table 11-2, the target growth rates and energy and protein requirements are calculated using the data from Van Amburgh et al. (1998a). This example outlines the calculations performed by the model.

Recent studies have provided target weights and growth rates for Holstein heifers (Hoffman, 1997; Kertz et al., 1998). The target postpartum weight for the Van Amburgh study (1998a) (526 kg) agrees with the actual weight of 533 kg, and both of these weights are within the ranges suggested by Hoffman (1997) (515–558 kg). The data of Kertz et al. (1997, 1998) indicated that postpartum weight of replacement heifers should be 77 percent of mature BW, compared to 83 percent in the study of Van Amburgh et al. (1998a) and the target of 82 percent in this model. The target weight at conception of 352 kg is within the range proposed by Hoffman (1997). The target daily gain before conception in this study (0.87 kg/d), which was set for animals calving at 22.5 months of age, agrees with the upper range of 0.84 kg/d suggested by Hoffman (1997) for animals calving at 24 months of age. The target ADG in the study by Van Amburgh et al. (1998a) (0.87 kg/d) was between the standard and accelerated ADG reported by Lammers et al. (1999) (0.70 and 1.01 kg/d, respectively), and is within the range suggested by Kertz et al. (1998) (0.82–0.93 kg/d). Thus, this model appears to give target weights and growth rates within the ranges suggested by recent research with Holstein cattle (Table 11-3).

MAINTENANCE REQUIREMENT EFFECTS ON GROWTH

The growth rate of heifers depends on the net energy available after maintenance requirements have been met. Data collected on growth of dairy heifers on farms in Wisconsin indicated that environment had a substantial effect on heifer growth (Hoffman et al., 1994). The National Research Council (1996) provided a summary of the effects of environment on maintenance requirements of cattle. The maintenance model published by the National Research Council (1996) was adapted by this committee, with modifications for dairy heifers based on Fox and Tylutki (1998).

The maintenance requirement for energy was defined in *Nutrient Requirements of Beef Cattle* (National Research Council, 1996) as the intake of feed energy that results in no net loss or gain of energy from the tissues of the animal's body. This energy is required for essential metabolic processes, body temperature regulation and physical activity. To predict the amount of feed intake required for these purposes in diverse situations, the maintenance require-

TABLE 11-3 Application of Equations to Predict Energy and Protein Requirements, Using Target Weights and Daily Gains from Table 11-2 (Van Amburgh et al., 1998a)

Variable	Calculation of requirement
NE_G required for target SWG for growth before first conception:	
Mean target SBW	(352 + 84) / 2 = 218 kg
EQSBW	(478/641) × 218 = 163 kg
EQEBW	163 × 0.891 = 145 kg
EQEBG	0.87 × 0.956 = 0.83 kg/d
NE_G required	$0.0635 \times 145^{0.75} \times 0.83^{1.097} = 2.16$ Mcal/d
NE_G required for target SWG for heifer growth during first pregnancy:	
Mean target SBW	(352 + 526) / 2 = 439 kg
EQSBW	(478/641) × 439 = 327 kg
EQEBW	327 × 0.891 = 292 kg
EQEBG	0.956 × 0.62 = 0.59 kg/d
RE (or NE_G required) during pregnancy	$0.0635 \times 292^{0.75} \times 0.59^{1.097} = 2.51$ Mcal/d
NE_G required for target SWG during first lactation:	
Mean target SBW	(526 + 590) / 2 = 558 kg
EQSBW	(478/641) × 558 = 416 kg
EQEBW	416 × 0.891 = 371 kg
EQEBG	0.956 × 0.148 = 0.141 kg/d
NE_G required	$0.0635 \times 371^{0.75} \times 0.141^{1.097} = 0.63$ Mcal/d
NE_G required for target SWG during second lactation:	
Mean target SBW	(590 + 641) / 2 = 616 kg
EQSBW	(478/641) × 616 = 459 kg
EQEBW	459 × 0.891 = 409 kg
EQEBG	0.956 × 0.118 = 0.113 kg/d
NE_G required	$0.0635 \times 409^{0.75} \times 0.113^{1.097} = 0.53$ Mcal/d

ment must be partitioned into the energy required for basal metabolism, physical activity, and temperature regulation.

Basal Maintenance Requirement

Fox and Tylutki (1998) defined the maintenance requirement for dairy heifers in a thermoneutral environment with minimal activity as follows:

$$NE_M = (0.086 \times SBW^{0.75} \times COMP) + a2 \quad (11\text{-}17)$$

Where COMP = compensatory effect for previous plane of nutrition, and a2 = maintenance adjustment for previous temperature effect (Mcal/d/kg $SBW^{0.75}$).

The coefficient of 0.086 for dairy heifers is based on calorimetric data (Haaland et al., 1980; 1981) and comparative slaughter studies (Fox and Black, 1984). Approximately 10 percent of this requirement is for activity (Fox and Tylutki, 1998). Fox and Tyltuki (1998) presented a more complicated model to account for variation in heat stress.

Adjustment for Previous Temperature

The a2 value is used to adjust for the effect of the previous temperature on metabolic rate. The National Research Council (1981) concluded that the temperature to which the animal had been exposed previously (PrevTemp) has an effect on the animal's current basal metabolic rate. A temperature of 20°C is thermoneutral because it has no effect on basal metabolic rate. The studies of Young (1975a,b) were used to describe how the NE_M requirement of cattle adapted to a given thermal environment is related to the previous ambient air temperature.

$$a2 = 0.0007 \times (20 - \text{PrevTemp}) \quad (11\text{-}18)$$

The current temperature (Temp) affects how much energy is required to respond to the current effects of cold or heat stress. On average, temperatures move slowly from one season to the next, but can fluctuate widely from day to day. To avoid a model that is too sensitive to temperature effects, we recommend using the average mean daily temperature over the previous month to which the animals have been exposed as the value for PrevTemp. The recommended input for current temperature is the average daily temperature for the previous week. To account for local environmental effects, it is best to measure these temperatures in the animal's environment (barn, outside lot, etc.).

Adjustment for Previous Plane of Nutrition

Recent summaries of the literature (CSIRO, 1990; National Research Council, 1996) documented the effect of restricted feeding on fasting heat production. Sheep and cattle kept in drought conditions averaged 16 percent lower fasting metabolism than those with access to adequate feed supplies (CSIRO, 1990). These changes in basal metabolic requirement are due to changes in the activity of ionic pumps, metabolite cycling, and, most importantly, alterations in the size and metabolic activity of visceral organs (National Research Council, 1996). The National Research Council (1996) concluded that the requirement for metabolism of fasted animals was reduced by an average of 20 percent in published studies. Clearly, the extent and duration of undernutrition, as well as the plane of nutrition during the period of repletion, affect this average. An assumption made in the current model is that the BCS reflects the previous plane of nutrition. A change of 10 percent in the energy requirement for fasting metabolism is predicted for each increase or decrease in condition score from the average of 3. For example, animals with a BCS of 2 and 4 would have a basal metabolic requirements equal to 90 and 110 percent of the requirements of an animal with a BCS of 3.

$$COMP = 0.8 + ((BCS - 1) \times 0.05) \qquad (11\text{-}19)$$

Adjustment for the Direct Effects of Cold Stress

The following series of equations are used to compute the energy required to maintain a normal body temperature during cold stress.

$$SA = 0.09 \times SBW^{0.67} \qquad (11\text{-}20)$$

$$HP = (MEI - NEFP) / SA \qquad (11\text{-}21)$$

$$EI = ((7.36 - (0.296 \times WINDSPEED) + (2.55 \times HAIRDEPTH)) \times COAT) \times 0.8 \qquad (11\text{-}22)$$

Where SA = surface area (m^2), HP = heat production (Mcal/m^2/d), MEI = metabolizable energy intake (Mcal/d), NEFP = net energy available for production, Mcal/d, EI = external insulation value (°C/Mcal/m^2/d), WINDSPEED = wind speed (kph), HAIRDEPTH = hair depth (cm), and COAT = adjustment factor for external insulation. COAT is a discrete variable that is used to describe the insulation value of the coat with a choice of 4 codes; 1 = clean and dry, 2 = some mud on lower body, 3 = wet and matted, and 4 = covered with wet snow or mud. When the COAT variable equals 1, no change is made in the effectiveness of the insulation provided by the coat, but, when the COAT variable is equal to 2, 3, or 4, the coat insulation is 0.8, 0.5 or 0.2 times that of the clean, dry coat.

$$INS = TI + EI \qquad (11\text{-}23)$$

Where I = insulation value (°C/Mcal/m^2/d), and TI = tissue (internal) insulation value (°C/Mcal/m^2/d) and is

2.5 for newborn calf,
6.5 for 1-mo old calf,
5.1875 + (0.3125 × BCS) for yearlings, and
5.25 + (0.75 × BCS) for adult cattle.

$$LCT = 39 - (INS \times HP \times 0.85) \qquad (11\text{-}24)$$

$$ME_{cs} = SA \times (LCT - Tc) / INS \qquad (11\text{-}25)$$

$$NE_{Mcs} = k_m \times ME_{cs} \qquad (11\text{-}26)$$

$$\text{DMI for maintenance} = NE_M / NE_{Ma} \qquad (11\text{-}27)$$

Where LCT = animal's lower critical temperature (°C), ME_{cs} = metabolizable energy required for cold stress (Mcal/d), NE_{Mcs} = net energy required for cold stress (Mcal/d), k_m = diet NE_M/diet ME, NE_M = net energy required for maintenance adjusted for acclimatization and cold stress, and NE_{Ma} = net energy value of diet for maintenance (Mcal/kg).

Adjustment for the Direct Effects of Heat Stress

The NE_M requirement increases when temperature increases above thermoneutral because of the energy cost of dissipating excess heat (National Research Council, 1996). Because of the difficulty in accounting for the complex interactions involved in predicting the upper critical temperature, a panting index (NE_M multiplier of 1.07 if an animal has rapid, shallow breathing or 1.18 if open mouth panting is evident) is used to adjust for the energy cost to dissipate excess heat. A more complex model was developed Fox and Tylutki (1998) to account for the effects of humidity and temperatures above thermoneutral on the maintenance requirement.

Model Evaluation

The effects of temperature, relative humidity, wind, and hair coat condition on maintenance energy requirements are shown in Table 11-4. The effects of acclimatization are

TABLE 11-4 Multipliers Used to Adjust the Maintenance Energy Requirement to Reflect Various Environmental Conditions[a,b]

	−1.1°C		−12°C		−23°C	
Hair Coat Code	1[c]	3[c]	1[c]	3[c]	1[c]	3[c]
Wind velocity (kph)						
1.6	1.17	1.41	1.37	1.90	1.74	2.39
16	1.33	1.70	1.80	2.27	2.26	2.84

[a]Temperature values reflect current temperature (Temp).
[b]Values given are net energy maintenance requirement (NE_M) required for these conditions divided by the maintenance requirement without stress.
[c]Hair coat code: 1 = dry and clean, 2 = mud on lower body (values not shown), and 3 = wet and matted.

accounted for by using the average temperature for the previous month for PrevTemp. Current environmental effects on energy requirements are computed by determining heat loss relative to heat production, based on current temperature, internal and external insulation, wind, and hair coat depth and condition. This calculation becomes important when the animal is in an environment below the model's lower critical temperature. No effect is evident at 20°C, but when the hide is dirty and it is −12°C with a 16 kph wind, the maintenance requirement is nearly three times as high as the requirement of a clean animal in a thermoneutral environment without wind. The maintenance requirement multiplier of 1.17 at −1.1°C with a clean and dry hair coat reflects the adjustment for acclimatization, because in this environment the animals are above their lower critical temperature. Energy intake also affects cold stress because increased ME intake results in a larger heat increment that can be used to alleviate cold stress.

Table 11-5 shows the predicted impact of the environment on the performance of heifers from 8 weeks to calving (Fox and Tylutki, 1998). At a thermoneutral temperature (20°C), the revised model yields the same maintenance requirement as the National Research Council (1989) requirements. In Table 11-5, the "northern" environment category has mean monthly temperatures similar to the those in the north central and northeastern United States, while "southwest" reflects mean monthly temperatures found in the southwestern United States. In situation 1, the animal's coat is clean and dry, while in situation 2 the coat is moderately matted. In situation 3, the hair coat is moderately matted from April through November and the animal is housed in a lot with 10 cm of mud from November through March. Situation 4 is the same as situation 1 except that there is a 16 kph wind. The specific effects of temperature and hair coat insulation are shown in Table 11-4. The energy available for growth depended on interactions among DMI, heat increment, and animal insulation, variables that were influenced by environmental temperature, wind, and animal heat production and loss. When environmental stress delayed puberty, age at first calving was increased. Weight at first calving was decreased if environmental stress occurred after conception.

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TABLE 11-5 Predicted Effects of Four Environments on Heifer Performance (Fox and Tylutki, 1998)

	Neutral[a]	Northern[b]				Southwest[c]			
	1	1	2	3	4	1	2	3	4
ADG[d], kg/d	0.94	0.88	0.60	0.53	0.68	0.88	0.88	0.78	0.88
Calving age, mo	20.3	21.1	28.5	28.5	25.9	20.7	20.7	22.4	20.7
Calving BW, kg	603	588	560	501	574	580	580	561	580

[a]Same maintenance requirement as the National Research Council (1989).

[b]Mean monthly temperatures similar to the northcentral and northeastern United States. Situation 1 = clean and dry, situation 2 = moderately matted hair coat, situation 3 = situation 2 plus 10 cm mud from November through March, and situation 4 = situation 1 plus 16 kph wind velocity.

[c]Mean monthly temperatures similar to the southwestern region of the United States.

[d]Average daily gain.

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