

2 Energy

ENERGY REQUIREMENTS OF LACTATING AND PREGNANT COWS

Energy Units

Energy requirements for maintenance and milk production are expressed in net energy for lactation (NE_L) units. The net energy for lactation system (Moe and Tyrrell, 1972) uses a single energy unit (NE_L) for both maintenance and milk production because metabolizable energy (ME) was used with similar efficiencies for maintenance (0.62) and milk production (0.64) (Moe and Tyrrell, 1972) when compared with directly measured fasting heat production (Flatt et al., 1965). The energy values of feed are also expressed in NE_L units. Thus in the tables in Chapter 14 and in the computer model, one feed value (NE_L) is used to express the requirements for maintenance, pregnancy, milk production, and changes in body reserves (not growth) of adult cows.

ENERGY VALUES OF FEEDS

The method used to obtain and express feed energy values in this edition is substantially different from that used in previous versions. In the 6th revised edition of the *Nutrient Requirements of Dairy Cattle* (National Research Council, 1989), feedstuffs were assigned total digestible nutrient (TDN) values that had been determined experimentally using similar feeds. The concentrations of digestible energy (DE), ME, and NE_L for each feedstuff were then calculated from the TDN value using Equations 2-1, 2-2, and 2-3. Equations 2-1 and 2-2 assume intake is the same for the independent and dependent variables (e.g., both at one times maintenance or 1X). Equation 2-2 was derived with cows fed at 3 times maintenance (3X), and questions have been raised (Vermorel and Coulon, 1998) about its accuracy when used to convert DE_{1X} to ME_{1X} . Equation 2-3 converts TDN_{1X} to NE_{L3X} assuming an 8 percent reduction in digestibility at 3X maintenance.

$$DE \text{ (Mcal/kg)} = 0.04409 \times TDN(\%) \quad (2-1)$$

$$ME \text{ (Mcal/kg)} = 1.01 \times DE \text{ (Mcal/kg)} - 0.45 \quad (2-2)$$

$$NE_L \text{ (Mcal/kg)} = 0.0245 \times TDN(\%) - 0.12 \quad (2-3)$$

The problems with this approach are:

- Most of the experimentally determined TDN values currently available in feed composition tables are from experiments conducted many years ago; however, other composition data have been updated. The TDN values in the table may not correspond to the feed with the nutrient composition given in Table 15-1.
- A published TDN value is only appropriate when the nutrient composition of the feed is essentially the same as that for the feed used in the digestibility trial.
- For many feeds, TDN cannot be measured directly because the feed cannot comprise a major portion of the diet. Calculating TDN using the difference method can lead to inaccurate (because of associative effects) and imprecise estimates of TDN.
- Very few ME and NE_L values of individual feedstuffs are available; rather ME and NE_L values of mixed diets are measured. The equations used to convert TDN to ME and NE_L were derived for complete diets, and the TDN for many feedstuffs are outside of the range for TDN values of the diets used to generate the equations, and the equations may not be linear over a wide range of TDN.
- A constant discount of 8 percent as calculated in Equation 2-3 assumes all cows are consuming at 3X maintenance. Based on the normal distribution of milk production among herds, the mean energy intake for a herd may range from 2 to more than 4X maintenance.

Because of these problems, the TDN values at 1X maintenance (TDX_{1X}) in Table 15-1 and in the software dictionary were calculated from composition data rather than being experimentally determined. In addition, NE_L values are calculated based on actual intake and the digestibility of the entire diet. In Table 15-1, NE_L values for individual

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feeds are shown assuming intake at 3 and 4X maintenance and a total diet TDN_{IX} of 74 percent. The NE_L of diets formulated using the NE_L values in Table 15-1 may be different than the NE_L of diets formulated by the computer model because intake and digestibility discount (estimated from total diet TDX_{IX}) may be different from those assumed in Table 15-1.

Estimating TDN of Feeds at Maintenance

A summative approach was used to derive the TDN_{IX} values in Table 15-1. In this approach, the concentrations (percent of dry matter) of truly digestible nonfiber carbohydrate (NFC), CP, ether extract (EE), and NDF for each feed are estimated (Weiss et al., 1992) using Equations 2-4a, 2-4b, 2-4c, 2-4d, 2-4e. Ether extract does not represent a nutritionally uniform fraction and therefore does not have a constant digestibility across feedstuffs. Fatty acids (FA) are a uniform fraction with a true digestibility of 95 to 100 percent when diets contain 3 percent or less EE (Palmquist, 1991). A value of 100 percent digestibility was chosen. FA content of feed can be estimated as FA = EE - 1 (Allen, 2000). A more accurate approach would be to measure FA directly; however, limited data prevented the inclusion of FA data in Table 15-1. In all equations listed below, measured FA or EE - 1 can be used to represent the FA fraction.

$$\begin{aligned} \text{Truly digestible NFC (tdNFC)} \\ = 0.98 (100 - [(NDF - NDICP) \\ + CP + EE + \text{Ash}]) \times \text{PAF} \end{aligned} \quad (2-4a)$$

$$\begin{aligned} \text{Truly digestible CP for forages (tdCPf)} \\ = CP \times \exp[-1.2 \times (ADICP/CP)] \end{aligned} \quad (2-4b)$$

$$\begin{aligned} \text{Truly digestible CP for concentrates (tdCPc)} \\ = [1 - (0.4 \times (ADICP/CP))] \times CP \end{aligned} \quad (2-4c)$$

$$\begin{aligned} \text{Truly digestible FA (tdFA)} \\ = \text{FA} \quad \text{Note: If EE} < 1, \text{ then FA} = 0 \end{aligned} \quad (2-4d)$$

$$\begin{aligned} \text{Truly digestible NDF (tdNDF)} \\ = 0.75 \times (NDFn - L) \\ \times [1 - (L/NDFn)^{0.667}] \end{aligned} \quad (2-4e)$$

In Equations 2-4a, 2-4b, 2-4c, 2-4d, 2-4e, NDICP = neutral detergent insoluble N $\times$ 6.25, PAF = processing adjustment factor (see below), ADICP = acid detergent insoluble N $\times$ 6.25, FA = fatty acids (i.e., EE - 1), L = acid detergent lignin, and NDFn = NDF - NDICP. All values are expressed as a percent of dry matter (DM).

Note: Digestible NDF can be obtained using a 48-hour rumen in vitro assay. The in vitro NDF digestibility is entered into the model when the software is used and that value is used to calculate digestible NDF at maintenance.

Equations 2-4a, 2-4b, 2-4c, 2-4d, and 2-4e are based on true digestibility, but TDN is based on apparent digestibility; therefore, metabolic fecal TDN must be subtracted from the sum of the digestible fractions. Weiss et al. (1992) determined that, on average, metabolic fecal TDN equalled 7. The TDN_{IX} is then calculated using Equation 2-5.

$$\begin{aligned} \text{TDN}_{IX} (\%) = \text{tdNFC} + \text{tdCP} \\ + (\text{tdFA} \times 2.25) + \text{tdNDF} - 7 \end{aligned} \quad (2-5)$$

Equations 2-4 and 2-5 were used to calculate TDN_{IX} for most, but not all, feedstuffs in Table 15-1. Different equations are used to estimate TDN for animal protein meals and fat supplements (see below).

EFFECT OF PROCESSING ON NFC DIGESTIBILITY

Physical processing, and heat and steam treatment of feeds usually does not greatly change their composition as measured by conventional feed testing assays but often increases the digestibility of starch (see Chapter 13). To account for the effect of processing and some other non-chemical factors on starch digestibility, an empirical approach was used. Based on in vivo digestibility data (see Chapter 13), a processing adjustment factor (PAF) was developed (Table 2-1). Expected true digestibility of NFC at 1X maintenance is about 0.98 and 0.90 at 3X maintenance (approximately the feeding level used in the digestibility studies) (Tyrrell and Moe, 1975; Van Soest, 1982).

TABLE 2-1 Processing Adjustment Factors (PAF) for NFC^a

Feedstuff	PAF
Bakery waste	1.04
Barley grain, rolled	1.04
Bread	1.04
Cereal meal	1.04
Chocolate meal	1.04
Cookie meal	1.04
Corn grain, cracked dry ^b	0.95
Corn grain, ground ^b	1.00
Corn grain, ground high moisture ^b	1.04
Corn and cob meal, ground high moisture ^b	1.04
Corn grain, steam flaked ^c	1.04
Corn silage, normal	0.94
Corn silage, mature	0.87
Molasses (beet and cane)	1.04
Oats grain	1.04
Sorghum grain, dry rolled	0.92
Sorghum grain, steam-flaked ^d	1.04
Wheat grain, rolled	1.04
All other feeds	1.00

^aSee Chapter 13 for details on how values were calculated. For feeds not shown, PAF = 1.0.

^bMean of several experiments, actual PAF depends on particle size. Finer grinding will increase PAF.

^cMean density of 0.36 kg/L; PAF should be negatively correlated with density.

^dMean density of 0.36 kg/L; PAF should be negatively correlated with density.

The PAF was calculated by dividing in vivo starch digestibility of different feeds by 0.90. The PAF is used only for NFC. The PAF adjustment will result in overestimation of energy values in some feeds when fed at maintenance, but NE_L values when fed at 3 times maintenance should be correct.

ANIMAL PROTEIN MEALS

Animal products contain no structural carbohydrates; however, certain animal products contain substantial amounts of neutral detergent insoluble residue. Because this material is not cellulose, hemicellulose, or lignin, the above equations cannot be used. For those feeds, TDN_{IX} was estimated using Equation 2-6.

$$TDN_{IX} (\%) = CP_{digest} \times CP + FA \times 2.25 + 0.98(100 - CP - Ash - EE) - 7 \quad (2-6)$$

Where CP_{digest} = estimated true digestibility of CP (Table 2-2) and $FA = EE - 1$. The CP_{digest} values are from Table 15-2 assuming an intake of 2 percent of body weight (BW). The method used to obtain those values is explained in Chapter 5.

TABLE 2-2 True Digestibility Coefficients of CP Used to Estimate TDN_{IX} Values of Animal-Based Feedstuffs

Feedstuff	True Digestibility
Blood meal, batch dried	0.75
Blood meal, ring dried	0.86
Hydrolyzed feather meal	0.78
Hydrolyzed feather meal with viscera	0.81
Fish meal (Menhaden)	0.94
Fish meal (Anchovy)	0.95
Meat and bone meal	0.80
Meat meal	0.92
Whey	1.00

FAT SUPPLEMENTS

The TDN_{IX} values of different fat supplements were calculated from measured fatty acid digestibility. Partial digestion coefficients (Table 2-3) of fatty acids from supple-

TABLE 2-3 True Digestibilities at Maintenance (assumed 8 percent increase in digestibility compared with 3X maintenance) of Fatty Acids from Various Fat Sources

Fat	Fat type	Mean %	SD	N
Calcium salts of fatty acids	Fatty acids	0.86	0.11	15
Hydrolyzed tallow fatty acids	Fatty acids	0.79	0.08	9
Partially hydrogenated tallow	Fat plus glycerol	0.43	0.13	9
Tallow	Fat plus glycerol	0.68	0.13	10
Vegetable oil	Fat plus glycerol	0.86	—	—

mental fat sources were determined indirectly by difference [(additional fatty acid intake during fat supplementation minus additional fecal fatty acid output during fat supplementation)/(additional fatty acid intake during fat supplementation); Grummer, 1988]. Assumptions associated with this method are that endogenous lipid remains constant, and digestibility of fatty acids in the basal diet does not change when supplemental fat is fed. For fat sources containing triglycerides (tallow, partially hydrogenated tallow, and vegetable oil), ether extract was assumed to contain 90 percent fatty acids and 10 percent glycerol, and the glycerol was assumed to be 100 percent digestible at 1X. In the experiments used to determine fat digestibility, cows were fed at approximately 3X maintenance. Therefore, the original values were divided by 0.92 to adjust values to TDN_{IX} . After adjusting digestibility for intake (Table 2-3), digestible fat was multiplied by 2.25 to convert to TDN_{IX} (Equations 2-7a and 2-7b).

For fat sources that contain glycerol:

$$TDN_{IX} (\%) = (EE \times 0.1) + [FAdigest \times (EE \times 0.9) \times 2.25] \quad (2-7a)$$

For fat sources that do not contain glycerol:

$$TDN_{IX} (\%) = (EE \times FAdigest) \times 2.25 \quad (2-7b)$$

where $FAdigest$ = digestibility coefficients for fatty acids (Table 2-3).

Estimating DE of Feeds

Crampton et al. (1957) and Swift (1957) computed that the gross energy of TDN is 4.409 Mcal/kg. Because nutrients have different heats of combustion (e.g., 4.2 Mcal/kg for carbohydrates, 5.6 Mcal/kg for protein, 9.4 Mcal/kg for long chain fatty acids, and 4.3 Mcal/kg for glycerol; Maynard et al., 1979), the gross energy value of TDN is not constant among feeds. The gross energy of TDN of a feed that has a high proportion of its TDN provided by protein will be greater than 4.409. Conversely the gross energy of TDN of a feed with a high proportion of its TDN provided by carbohydrate or fat will be less than 4.409. Therefore, the calculation of DE as $0.04409 \times TDN$ (percent) as in the previous edition (National Research Council, 1989) was abandoned. Digestible energy was calculated by multiplying the estimated digestible nutrient concentrations (Equations 2-4a through 2-4e) by their heats of combustion, as shown in Equations 2-8a, 2-8b, 2-8c, and 2-8d. Since DE is based on apparent digestibility and Equations 2-4a through 2-4e are based on true digestibility, a correction for metabolic fecal energy is needed. The heat of combustion of metabolic fecal TDN was assumed to be 4.4 Mcal/kg; metabolic fecal $DE = 7 \times 0.044 = 0.3$ Mcal/kg.

For most feeds:

$$\begin{aligned} \text{DE}_{\text{IX}} (\text{Mcal/kg}) &= (\text{tdNFC}/100) \\ &\times 4.2 + (\text{tdNDF}/100) \times 4.2 + (\text{tdCP}/100) \\ &\times 5.6 + (\text{FA}/100) \times 9.4 - 0.3 \end{aligned} \quad (2-8a)$$

For animal protein meals:

$$\begin{aligned} \text{DE}_{\text{IX}} (\text{Mcal/kg}) &= (\text{tdNFC}/100) \times 4.2 \\ &+ (\text{tdCP}/100) \times 5.6 + (\text{FA}/100) \\ &\times 9.4 - 0.3 \end{aligned} \quad (2-8b)$$

For fat supplements with glycerol:

$$\begin{aligned} \text{DE}_{\text{IX}} (\text{Mcal/kg}) &= 9.4 \times (\text{FAdigest} \times 0.9 \\ &\times (\text{EE}/100)) + (4.3 \times 0.1 \times (\text{EE}/100)) \end{aligned} \quad (2-8c)$$

For fat supplements without glycerol:

$$\begin{aligned} \text{DE}_{\text{IX}} (\text{Mcal/kg}) &= 9.4 \times \text{FAdigest} \\ &\times (\text{EE}/100) \end{aligned} \quad (2-8d)$$

In the above Equations, 2-8a through 2-8d, tdNFC, tdNDF, tdCP, and FA are expressed as percent of DM.

In Equation 2-8b protein digestibilities are from Table 2-2. For Equations 2-8c and 2-8d, fatty acid digestibilities (FAdigest) are from Table 2-3. Because the method used to estimate those values already accounts for the difference between apparent and true digestibility, the 0.3 adjustment is not needed in Equations 2-8c and 2-8d.

Estimating DE at Actual Intake

The digestibility of diets fed to dairy cows is reduced with increasing feed intake (Tyrrell and Moe, 1975). This reduces the energy value of any given diet as feed intake increases. This is particularly important in today's high producing dairy cows where it is not uncommon for feed intake to exceed 4 times maintenance level of intake. The rate of decline in digestibility with level of feeding has been shown to be related to digestibility of the diet at maintenance (Wagner and Loosli, 1967). Diets with high digestibility at maintenance exhibit a greater rate of depression in digestibility with level of feeding than diets with low digestibility fed at maintenance. Previous National Research Council reports (National Research Council, 1978, 1989) used a constant depression of 4 percent per multiple of maintenance to adjust maintenance energy values to 3X maintenance energy values. Using this method of discounting, the percentage unit decline in TDN for a diet containing 75 percent TDN_{IX} would be 3 percentage units per multiple of maintenance, while the depression for a diet containing 60 percent TDN_{IX} would be 2.4 units. The differences in rate of depression in digestibility are generally negligible for diets having maintenance TDN values of 60 percent or less.

Figure 2-1 shows the relationship between digestibility at maintenance and the percentage unit decline in digestibility per multiple of maintenance feeding from literature reports (Brown, 1966; Colucci, et al., 1982; Moe et al.,

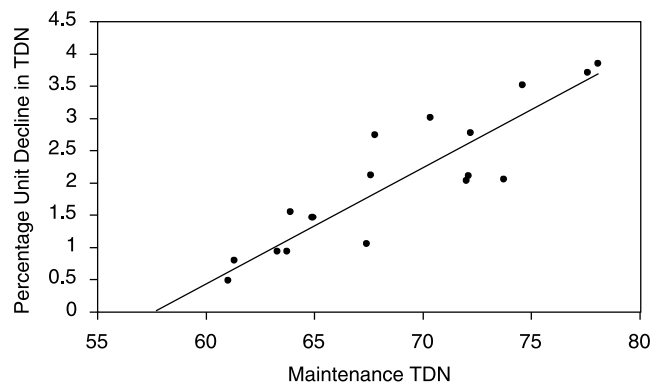


FIGURE 2-1 The relationship between feeding level expressed as multiples of maintenance and the unit decline in diet TDN per multiple of maintenance where TDN percentage unit decline = $0.18 \times \text{TDN}_{\text{IX}} - 10.3$, $r^2 = 0.85$.

1965; Tyrrell and Moe, 1972; 1974; 1975; Wagner and Loosli, 1967). It was apparent that the rate of decline in digestibility with level of feeding was a function of the maintenance digestibility of the diets fed: TDN percentage unit decline = $0.18 \times \text{TDN}_{\text{IX}} - 10.3$ ($r^2 = 0.85$). Because DE, not TDN, is used to calculate ME and NE_L, this equation was converted so that a percent discount, not a TDN percentage unit discount, was calculated:

$$\begin{aligned} \text{Discount} &= [(\text{TDN}_{\text{IX}} - [(0.18 \times \text{TDN}_{\text{IX}}) \\ &- 10.3]) \times \text{Intake}] / \text{TDN}_{\text{IX}} \end{aligned} \quad (2-9)$$

where TDN_{IX} is as a percent of dry matter and is for the entire diet, not the individual feed, and intake is expressed as incremental intake above maintenance (e.g., for a cow consuming 3X maintenance, intake above maintenance = 2). For example, for a cow consuming a diet that contains 74 percent TDN_{IX} at 3X intake, digestibility would be expected to be 0.918 times the value obtained at maintenance.

Based on Equation 2-9, a diet with a TDN_{IX} of 57.2 would exhibit no depression in digestibility with level of intake. Based on Figure 2-1, the discount for diets with 60 percent or less TDN_{IX} is negligible; therefore, for diets with 60 percent or less TDN_{IX} the discount was set to 1.0 (i.e., no discount was applied). Furthermore, a maximum discount was set so that discounted diet TDN could not be less than 60 percent. Data on effects of intake much greater than 4X maintenance are lacking. Vandehaar (1998) suggested that the effect of intake on digestibility is not linear, but rather the digestibility discount increases at a decreasing rate as feed intake increases. The possibility of a nonlinear response was one reason the minimum discounted TDN was set at 60 percent. Data are needed on the effects of very high intake on digestibility. The data in Figure 2-1 were generated with diets not containing supplemental fat. It was assumed that increasing TDN_{IX} by increasing dietary fat above 3 percent would not affect

the digestibility discount. Therefore the TDN_{IX} value, used only for the discount calculation, does not include TDN provided by dietary fat in excess of 3 percent. Diets with TDN_{IX} of 62, 67, 72, and 77 percent would exhibit a 0.9, 1.8, 2.7, and 3.6 percentage unit decline in TDN, respectively, per multiple of maintenance feeding. The percent decline in digestibility in the respective diets would be 1.5, 1.8, 3.8, and 4.7 percent. This adjustment is used continuously across all levels of feeding as contrasted to constant adjustment to 3X level of feeding used in the 1989 National Research Council report. The DE_{IX} for each feed was determined and then multiplied by the discount factor obtained using Equation 2-9 to calculate DE at productive levels of intake (DE_p).

Estimating ME at Actual Intake

Equation 2-2 was derived to convert DE into ME when cows were fed at production levels of intake. Therefore ME at production levels of intake (ME_p) should be calculated from DE_p. Equation 2-2 was developed with diets containing about 3 percent ether extract, but because the efficiency of converting DE from fat into ME is approximately 100 percent (Andrew et al., 1991; Romo et al., 1996), Equation 2-2 underestimates ME of high fat diets. A theoretical approach was used to adjust ME values of feeds with more than 3 percent EE. Assuming a feed with 100 percent EE has ME = DE and subtracting that equation from Equation 2-2 ($1.01 \times DE - 0.45$) and dividing by the change in EE concentration ($100 - 3$) yields the expression: $0.000103 \times DE + 0.00464$ change in ME per increase in EE content (percentage unit). The DE term was assumed to be negligible; therefore, ME_p values of feeds with more than 3 percent EE were increased by 0.0046 per percentage unit increase in EE content above 3 percent (Equation 2-10). For feeds with less than 3 percent EE, Equation 2-2 is used to calculate ME_p.

$$ME_p \text{ (Mcal/kg)} = [1.01 \times (DE_p) - 0.45] + 0.0046 \times (EE - 3) \quad (2-10)$$

where DE_p is Mcal/kg and EE is percent of DM.

For fat supplements, ME_p (Mcal/kg) = DE_p (Mcal/kg).

Estimating NE_L at Actual Intake

The use of Equation 2-3 to estimate NE_L has been criticized because it results in essentially equal efficiencies of converting DE to NE_L for all feeds (Vermorel and Coulon, 1998). Using Equation 2-3, a feed with 40 percent TDN (DE = 1.76 Mcal/kg) has an efficiency of converting DE to NE_{LIX} of 0.49 and for a feed with a TDN of 90 percent (DE = 3.97 Mcal/kg), the efficiency is 0.53. That

range in efficiencies is less than would be expected among feeds when DE is converted to NE_L. To overcome this problem, an equation derived by Moe and Tyrrell (1972) to convert ME_p to NE_L at production levels of intake (NE_{Lp}) was chosen to replace the previous TDN-based NE_L equation.

$$NE_{Lp} \text{ (Mcal/kg)} = [0.703 \times ME_p \text{ (Mcal/kg)}] - 0.19 \quad (2-11)$$

A modification was made to adjust for improved metabolic efficiency of fat. The average efficiency of converting ME from fat to NE_L is 0.80 [sd = 0.05; N = 3; (Andrew et al., 1991; Romo et al., 1996)]. The same approach as discussed above to adjust ME_p for fat content was used to account for increased efficiency of converting ME from fat to NE_L. The resulting term was: $(0.097 \times ME_p + 0.19)/97$ increase in NE_L per percentage unit increase in feed EE content above 3 percent (Equation 2-12). For feeds with less than 3 percent EE, Equation 2-11 is used to calculate NE_{Lp}.

$$NE_{Lp} \text{ (Mcal/kg)} = 0.703 \times ME_p - 0.19 + [(0.097 \times ME_p + 0.19)/97] \times [EE - 3] \quad (2-12)$$

where ME_p is Mcal/kg and EE is percent of DM.

For fat supplements, NE_{Lp} (Mcal/kg) = $0.8 \times ME_p$ (Mcal/kg).

Estimating Net Energy of Feeds for Maintenance and Gain

The equations used to estimate the net energy for maintenance (NE_M) and net energy for gain (NE_G) used for beef cattle (National Research Council, 1996) were retained. The NE_M and NE_G content of feeds assumed dry matter intake at 3 times maintenance and are calculated by multiplying DE_{IX} (described above) by 0.82 to obtain ME (National Research Council, 1996). That ME value is then converted to NE_M and NE_G using the following relationships (Garrett, 1980):

$$NE_M = 1.37 ME - 0.138 ME^2 + 0.0105 ME^3 - 1.12 \quad (2-13)$$

$$NE_G = 1.42 ME - 0.174 ME^2 + 0.0122 ME^3 - 1.65 \quad (2-14)$$

where ME, NE_M, and NE_G are expressed in Mcal/kg.

Those equations are not appropriate for fat supplements. For those feeds, ME_p = DE_p, and the same efficiency (0.80) of converting ME to NE_L was used to convert ME to NE_M. The efficiency of converting ME to NE_G was set at 0.55 for fat supplements. The method used to calculate feed energy values for calves weighing less than 100 kg is described in Chapter 10.

Comparison of New NE_L Values with Values from 1989 Edition

For feedstuffs in Table 15-1, NE_L values were calculated using the approach outlined above for cows fed at 3X maintenance and compared with values in Table 7-1 in the previous edition of the *Nutrient Requirements of Dairy Cattle* (National Research Council, 1989). The mean NE_L value for all feeds listed in Table 15-1 is 2 percent lower than the mean NE_L value for the same feeds in the 6th revised edition of *Nutrient Requirements of Dairy Cattle* (National Research Council, 1989). Although on average the values are similar, some marked differences exist. In general, forages, especially lower quality forages, have lower NE_L values, high protein feeds have higher NE_L values, and starchy concentrates have values similar to those in the previous edition (National Research Council, 1989). The NE_L for cottonseeds is about 16 percent lower and the value for roasted soybeans is about 25 percent higher than in the previous edition. In the previous edition, cottonseeds had more NE_L than roasted soybeans; however, cottonseed has much more NDF (50 vs. 22 percent), more lignin (13 vs. 3 percent), and less CP (23 vs. 43 percent). The NDF in cottonseed hulls, which provide most of the NDF in whole cottonseeds, has a low digestibility. These differences in composition and fiber digestibility imply that soybeans should provide more energy than cottonseeds. Because of differences in the ability of soybeans and cottonseeds to stimulate chewing and rumination, in low fiber diets, cottonseed may reduce negative associative effects and appear to have more energy than soybeans. Diets including whole cottonseeds and roasted soybeans were included in the evaluation of the software model (Chapter 16). Although data are very limited, estimated NE_L provided by those diets did not deviate greatly from estimated NE_L expenditures.

Using two different methods, the NE_L values for feeds in the 6th revised edition of the *Nutrient Requirements of Dairy Cattle* (National Research Council, 1989) were found to be about 5 percent (Weiss, 1998) and 5 to 7 percent (Vermorel and Coulon, 1998) too high. When NE_L values were calculated as described above and applied to the data set of Weiss (1998), the overestimation of feed energy was reduced from 5 percent to 1.2 percent. Dhiman et al. (1995) conducted an experiment with cows fed different ratios of alfalfa silage and concentrate (ground high moisture ear corn and soybean meal) for the entire lactation. Based on the nutrient composition of their feeds and calculated energy balance, NE_L values for the diets calculated using Equation 2-12 ranged from +5.6 percent to -7.3 percent with a mean bias of 0 percent. For the four diets used by Tyrrell and Varga (1987), the calculated NE_L values (Equation 2-11) ranged from 1.3 to 5.1 percent higher than measured values (mean bias was 2.8 percent).

For the four diets used by Wilkerson and Glenn (1997), the calculated values ranged from 7 percent lower to 1.2 percent higher than measured values (mean bias was 3.5 percent).

Precautions

The energy values for feeds and diets are based mostly on chemical characteristics of the feed and assume that feed characteristics limit energy availability. Composition of the total diet and dry matter intake have marked effects on digestibility and subsequent energy values. Diets that do not promote optimal ruminal fermentation will result in an overestimation of energy values. For example, if digestibility of diets is constrained by a lack of ruminally available protein or by low pH caused by feeding diets with insufficient fiber (or excess NFC), calculated energy values will be overestimated. Positive associative effects are not considered. In a situation where a fibrous feed is added to a diet with insufficient fiber, the energy value of that feed may appear to be higher than values calculated with Equation 2-12 because of overall improved ruminal digestion.

ENERGY REQUIREMENTS*Maintenance Requirements*

Measured fasting heat production (Flatt et al., 1965) in dry non-pregnant dairy cows averaged 0.073 Mcal/kg BW^{0.75}, and estimated fasting heat production using regression analysis suggested an identical value. Because these measurements were made with cows housed in tie stalls in metabolic chambers, a 10 percent activity allowance was added to account for normal voluntary activity of cows that would be housed in drylot or free stall systems, such that the maintenance requirement for NE_L is set at 0.080 Mcal/kg BW^{0.75} for mature dairy cows.

Cows of similar size and breed may vary in their maintenance requirements, even under controlled activity conditions, by as much as 8 to 10 percent (Van Es, 1961). The National Research Council (1996) used a net energy maintenance value of 0.077 Mcal/kg^{0.75} empty body weight (EBW) for British beef cattle breeds with adjustments to maintenance requirements based on breed and/or genotype. Assuming an empty body mass of 85 percent of live weight, the implied maintenance requirement on a live weight basis would be 0.065 Mcal/kg^{0.75}. A breed adjustment factor of 1.2 was used for Holsteins and Jerseys by the National Research Council (1996), which would then adjust the maintenance requirement to 0.079 Mcal/kg^{0.75}, which is nearly identical to the current value of 0.080 Mcal/kg BW^{0.75} used in this report.

It has been suggested that maintenance requirements among beef cattle breeds varies with milk production. Very few direct comparisons have been made of the effect of dairy cattle breed on energy metabolism. Tyrrell et al. (1991) compared nonlactating and lactating Holstein and Jersey cows. Although actual milk yields were greater for Holstein cows than for Jersey cows, energy output in milk as a function of metabolic weight was similar, and there was no evidence to suggest that energy requirements for maintenance or production differed between breeds.

Lactation Requirements

The NE required for lactation (NE_L) is defined as the energy contained in the milk produced. The NE_L concentration in milk is equivalent to the sum of the heats of combustion of individual milk components (fat, protein, and lactose). Reported heats of combustion of milk fat, protein, and lactose are 9.29, 5.71, and 3.95 Mcal/kg, respectively. Frequently, milk fat and protein but not milk lactose are measured. Milk lactose content is the least variable milk component and is essentially a constant 4.85 percent of milk and varies only slightly with breed and milk protein concentration.

Milk crude protein, when estimated as N times 6.38, contains approximately 7 percent nonprotein nitrogen (NPN) (DePeters et al., 1992). Urea N accounts for about 50 percent of NPN in milk; and ammonia, peptides, creatine, creatinine, hippuric acid, uric acid, and other N-containing components make up the remainder of NPN in milk (DePeters et al., 1992). Based on the average composition and the heats of combustion of individual NPN constituents, the heat of combustion for NPN is 2.21 kcal/g crude protein. Where total and not true protein is determined, the coefficient (weighted average of the different N compounds in milk) for milk crude protein is 5.47 kcal/g. This value is slightly higher than the coefficient of 5.31 determined by regression analysis of milk energy on milk fat, protein, and lactose (Tyrrell and Reid, 1965). Where individual components are measured directly, NE_L concentration in milk is calculated as:

$$NE_L \text{ (Mcal/kg)} = 0.0929 \times \text{Fat \%} + 0.0547 \times \text{Crude Protein \%} + 0.0395 \times \text{Lactose \%} \quad (2-15)$$

When only fat and protein in milk are measured and the lactose content of milk is assumed to be 4.85 percent, the NE_L concentration of milk is calculated as:

$$NE_L \text{ (Mcal/kg)} = 0.0929 \times \text{Fat \%} + 0.0547 \times \text{Crude Protein \%} + 0.192 \quad (2-16)$$

If milk true protein rather than crude protein is measured, the coefficient in the equation above should be changed from 0.0547 to 0.0563, which reflects the relative

proportions of true protein and NPN and their energy values discussed above.

The Gaines formula (Gaines, 1928) for 4 percent fat-corrected milk (4 percent FCM, kg/d = $0.4 \times \text{milk, kg/d} + 15 \times \text{fat, kg/d}$) has been used for more than 70 years as a means to correct milk yields to a constant energy basis. The Gaines formula is based on an assumed NE_L concentration of 0.749 Mcal/kg of milk when milk contains 4 percent fat. The 1989 National Research Council report used a value of 0.74 Mcal/kg, but based on measured heats of combustion (Moe and Tyrrell, 1972), the actual coefficient is 0.749/kg of FCM when calculated using the Gaines equation. The Gaines formula, which is based on volume of milk and total yield of fat, underestimates the energy value of milk when milk fat content is less than 3 percent. When milk fat is the only milk constituent measured, NE_L concentration can be calculated using the Tyrrell and Reid (1965) formula:

$$NE_L \text{ (Mcal/kg of milk)} = 0.360 + [0.0969(\text{fat \%})] \quad (2-17)$$

The feed energy requirements for production of individual milk components have not been defined. The NE_L system in this edition is based on yield of total energy in milk and does not account for many of the differences in metabolic transactions or the substrates required for synthesis of individual milk components. The measured calorimetric inefficiency of use of ME for milk includes losses associated with metabolic transactions for conversion of absorbed nutrients into milk components, the energy required for nutrient absorption, and increased rates of metabolism in visceral tissues required for support of increased milk production. Theoretical calculations of energy requirements for production of individual milk components have been made (Baldwin, 1968; Dado et al., 1993). These estimates only account for energy losses in metabolic transactions associated with production of individual milk components. Theoretical efficiencies for use of ME for milk fat, protein, and lactose synthesis as estimated from Mertens and Dado (1993) were 81, 89, and 77 percent, respectively, each well above the 64 percent measured calorimetric efficiency for use of dietary ME for milk energy production (Moe and Tyrrell, 1972). Metabolic models that incorporate changes in visceral metabolism, transport, resynthesis of metabolites, and other energy costs (Baldwin et al., 1987) account for most of this discrepancy, but it is still difficult to assign these costs to production of individual milk components. It is envisioned that future net energy requirements for milk will be centered more on substrate requirements for production of individual milk components rather than a more general requirement for total milk energy output.

Activity Requirements

The energy required for maintenance includes a 10 percent allowance for activity, which should provide sufficient energy for the usual activity of lactating cows that are fed in individual stalls or drylot systems. At similar production, grazing cattle expend more energy than animals fed in confinement because: 1) the distance between the milking center and pasture is usually greater than the distance between the milking center and most confinement housing areas; 2) grazing cattle may have to walk where elevations change; and 3) grazing cattle spend more time eating than do confinement fed cattle. The increase in energy requirement for grazing cattle is largely a function of the distance walked, topography of the pasture, and BW. Heat production increases 0.00045 Mcal/kg BW for every kilometer a cow walks horizontally (Agricultural Research Council, 1980; Bellows et al., 1994; Coulon et al., 1998). Because no net work is actually done, increased energy required for physical activity is reflected in increased heat production and by definition is equivalent to NE_L required for maintenance. Thus in NE_L units, the energy required for excessive walking was set at 0.00045 Mcal/kg per kilometer walked. Excessive walking was defined as the distance a grazing cow travels between the pasture and the milking center. For a grazing 600-kg cow walking 0.5 km to and from the milking parlor 2 times per day (2 km total), the extra NE_L allowance is 0.54 Mcal or about a 5 percent increase in maintenance requirements.

Based on data generated with growing cattle (Holmes et al., 1978; Havstad and Malechek, 1982), the increased eating activity associated with grazing compared with stall-fed cattle required 0.003 Mcal of ME/kg BW per day or approximately 0.002 Mcal of NE_L /kg BW. That value was for cattle consuming only pasture and should be reduced to reflect the amount of concentrate fed. In this edition, it is assumed that the diet for grazing lactating cows would be 60 percent pasture (dry basis). Therefore the activity allowance for eating act by grazing lactating cows (Mcal of NE_L) is calculated as 0.0012/kg of BW. For good quality, high yielding pastures, we assumed that energy expended walking within a paddock would be similar to that of cows housed in free stall barns. The total increase in the daily energy requirement for maintenance of cows grazing relatively flat, high yielding pasture should be increased 0.00045 Mcal of NE_L /kg BW per km of distance between the pasture and milking center plus 0.0012 Mcal per kilogram BW. For example, a 600-kg cow grazing a flat pasture (comprised 60 percent of total diet) approximately 0.5 km from the milking center and milked twice daily will walk 2 km/d to and from the milking center. The maintenance energy requirement should be increased by $2 \times 0.00045 \times 600 = 0.54$ Mcal for walking and $0.0012 \times 600 = 0.7$ Mcal for eating activity or approximately 1.2 Mcal of NE_L /

day (approximately a 12 percent increase in maintenance requirement).

The energetic cost for cows grazing hilly topography is higher than that for cows grazing relatively flat pastures. The actual cost for a specific situation is difficult to quantify, because the change in elevation usually will not be known, and cows will walk both up and down hills. The Agricultural Research Council (1980) estimated that 0.03 Mcal of NE_L per kg BW is required for a cow to walk 1 vertical km. The committee used a qualitative system to adjust for topography. A 'hilly' pasture system was defined as one in which cows moved a total of 200 m of vertical distance (50 m hill walked 4 times each day). Using the Agricultural Research Council (1980) value, the energy requirement for maintenance of cows grazing a hilly location was increased 0.006 Mcal of NE_L /kg BW. That adjustment is in addition to the increases in energy requirements for walking from the pasture to the milking center and for eating. Using the previous example for a cow that is milked twice daily and is grazing a hilly pasture located 0.5 km from the milking center, maintenance requirements would be increased $(0.00045 \times 600 \times 2) + (0.0012 \times 600) + 0.006 \times 600 = 4.9$ Mcal NE_L /day or an increase in maintenance of about 50 percent. As milk yield increases, appetite and the amount of energy expended gathering food would also increase, but this effect is not included in activity requirement calculations.

The time spent grazing is dependent on the amount of forage consumed and the relative availability of herbage. Where abundance of herbage is low, cows spend more time to consume the same amount of forage. Forage intake is dependent on milk production of cows and the amount of supplemental grain that is fed with the pasture. In a review (CSIRO, 1990), it was estimated that grazing activity increased energy requirements relative to maintenance by 20 percent on flat terrain and by as much as 50 percent on hilly pasture. They proposed a system to account for increased energy costs associated with grazing based on forage intake and digestibility, terrain, and herbage availability. This system was included in the National Research Council's *Nutrient Requirements of Beef Cattle* (1996); however, the proposed equation has not been evaluated. Evaluation of that equation suggested that a 600-kg milking cow, consuming 15 kg of DM from good quality pasture (65 percent DM digestibility) with moderate to good availability of forage (2 to 3 metric tons/hectare), increased NE_L requirements by 4 to 4.4 Mcal/d.

For growing heifers on pasture, energy requirements should be increased to cover increased eating activity and walking. The same energy costs used for lactating cows were used for heifers (NE_M values assumed to be equivalent to NE_L). The energy required for walking by heifers was set at 0.00045 Mcal of NE_M /kg BW per kilometer walked. The distance heifers walk each day will vary

depending on availability of forage and placement of water. Havstad and Malechek (1982) reported that grazing beef heifers walked 3.9 km per day when forage supply was adequate. The committee assumed the average growing heifer would walk approximately twice as much when grazing as when housed in confinement (an increase of approximately 2 km/d). Therefore, the NE_M requirement for walking for grazing heifers was set at $0.00045 \times 2 = 0.0009$ Mcal/kg BW per day. The energy associated with eating activity was the same as that used for lactating cows except pasture was assumed to provide 80 percent of the diet (0.0016 Mcal $NE_M \times BW$). The total adjustment for the daily energetic cost (NE_M , Mcal/day) of grazing for growing heifers is $(0.0016 \times BW) + (0.0009 \times BW)$. The same equation as that used to estimate energy required for walking in hilly pasture for lactating cows was used for heifers. For hilly pastures, maintenance requirements should be increased an additional 0.006 Mcal of NE_M /kg BW per day. For example a 300-kg heifer grazing a hilly pasture would require $(0.0009 \times 300) + (0.0016 \times 300) + (0.006 \times 300) = 2.6$ Mcal of ME for activity (or an increase in maintenance requirement of about 40 percent).

The energy requirements for activity given above are based on many assumptions and very limited data. Accurate information on walking distances, topography, pasture yields, etc., for a specific situation is very difficult to quantify. The actual energy required for activity under specific circumstances could vary greatly from those calculated with the above equations. The previous edition of the *Nutrient Requirements of Dairy Cattle* (National Research Council, 1989) stated that maintenance energy should be increased by 10 percent with good quality, high yielding pastures. Based on available data, that value is probably too low. The value probably ranges from about 10 (flat pasture located close to the milking center) to more than 50 (hilly pasture located far from the milking center) percent of maintenance energy.

Environmental Effects

For lactating cows in cold environments, the change in energy requirement is probably minimal because of the normally high heat production of cows consuming large amounts of feed. Even with the increased use of naturally ventilated free stall housing systems, it is unlikely that cows will require increased intake of energy to counteract cold environments if they are kept dry and are not exposed directly to wind. Young (1976) summarized experiments with ruminants in which an average reduction in DM digestibility of 1.8 percentage units was observed for each 10°C reduction in ambient temperature below 20°C. Much of this lowered digestibility under cold stress may be related to an increased rate of passage of feed through the digestive tract (Kennedy et al., 1976). Because of the effects of low

temperature on digestibility, under extremely cold weather conditions, feed energy values could possibly be lower than expected.

Mild to severe heat stress has been estimated (National Research Council, 1981) to increase maintenance requirements by 7 to 25 percent, respectively (for a 600-kg cow, this equates to between 0.7 and 2.4 Mcal of NE_L /day); however, insufficient data are currently available to quantify these effects accurately. Heat stress induces behavioral and metabolic changes in cattle (West, 1994). Some changes, such as panting, increase energy expenditures, while other changes (reduced dry matter intake, selective consumption, reduced activity, and reduced metabolic rate) will reduce heat production. An equation to adjust maintenance requirement based on environmental factors related to heat stress (ambient temperature, relative humidity, radiant energy, and wind speed) has been developed (Fox and Tylutki, 1998), but it has not been sufficiently validated. Because of limited data, no adjustments for heat stress have been included in the calculation of maintenance requirements of adult cattle in this version. Users, however, should be aware of the effects heat stress has on maintenance requirement and may wish to make dietary adjustments to account for those effects.

Pregnancy Requirements

Estimates of the energy requirements for gestation during the last 100 days of pregnancy are from Bell et al. (1995). The energy required for gestation is assumed to be 0 when the day of gestation is less than 190 and the maximum gestation length is set to 279 days (longer gestation periods result in no change in energy requirements). Bell et al. (1995) serially slaughtered Holstein cows at various stages of gestation and generated a quadratic equation to describe the energy content of the gravid uterus. The first derivative of that equation yields the daily change in energy content. The subcommittee assumed that energy requirements for gestation would depend on birth weight of the calf; therefore, an adjustment relative to the mean birth weight of Holstein calves (45 kg) was included in the Bell et al. equation. Efficiency of ME use by the gravid uterus was assumed to be 0.14 (Ferrell et al., 1976). Therefore, the ME requirement for gestation is described as:

$$ME \text{ (Mcal/d)} = [(0.00318 \times D - 0.0352) \times (CBW/45)]/0.14 \quad (2-18)$$

where D = day of gestation between 190 and 279, and CBW is calf birth weight in kilograms. To convert ME to NE_L an efficiency of 0.64 was used; therefore, the NE_L requirement for pregnancy is:

$$NE_L \text{ (Mcal/d)} = [(0.00318 \times D - 0.0352) \times (CBW/45)]/0.218 \quad (2-19)$$

where D = day of gestation between 190 and 279, and CBW is calf birth weight in kilograms.

Tissue Mobilization and Repletion During Lactation and the Dry Period

The growth model (Chapter 11) computes growth requirements until females reach their mature weight. However, changes in body composition during lactation and the dry period primarily reflect depletion and repletion of tissues when diets provide insufficient or excess energy. The body tissues involved (primarily internal and external fat depots) are commonly called body reserves.

Optimum management of energy reserves is critical to economic success with dairy cows. When cows are too fat or thin, they are at risk for metabolic disorders and diseases, decreased milk yield, low conception rates, and difficult calving (Ferguson and Otto, 1989). Overconditioning is expensive and can lead to calving problems and lower dry matter intake during early lactation. Conversely, thin cows may not have sufficient reserves for maximum milk production and often do not conceive in a timely manner.

The dairy cow mobilizes energy from body tissue to support energy requirements for milk production during early lactation and repletes mobilized tissue reserves during mid and late lactation for the subsequent lactation. As this is a normal physiological process that occurs in all mammals, it should be expected that all cows will mobilize energy stores in early lactation. There have been a number of experiments in which amounts of energy mobilized from tissue during early lactation were measured (Andrew et al., 1994, 1995; Komaragiri and Erdman, 1997, 1998; Chilliard et al., 1991; Gibb et al., 1992). In addition, experiments with bST (Tyrrell et al., 1988; Brown et al., 1989; McGuffey et al., 1991) clearly demonstrate that the initial increase in milk production associated with bST relies on partial mobilization of energy stores. In both early lactation and during a 4- to 6-week period after bST injection, increases in DMI lag behind the increase in milk production. Under these circumstances body tissue is mobilized as a source of energy and to a lesser extent a source of protein to support nutrient requirements for milk production.

Changes in BW of cows may not reflect true changes in stores of tissue energy. In experiments where stores of body energy were measured by slaughter analysis, stores of energy differed by as much as 40 percent, and there was little or no change in BW from calving to 5 to 12 weeks postpartum (Andrew et al., 1994; Gibb et al., 1992). As feed intake increases, gastrointestinal contents (gut fill) increase. The average gut fill in dairy cows is approximately 15 percent of BW. French workers (Chilliard et al., 1991) suggested a 4 kg increase in gut fill for each kilogram increase in DMI. Data from more recent experiments using both direct and indirect measurements of gut fill suggest

gut fill increases 2.5 kg for each kilogram increase in dry matter intake (Komaragiri and Erdman, 1997, 1998; Gibb et al., 1992). Because tissue mobilization during early lactation occurs at the same time that feed intake is rapidly increasing, decreases in body tissue weight are masked by increases in gut fill such that changes in BW do not reflect changes in tissue weight. After peak milk production, feed intake declines and gut fill decreases, such that increases in BW underestimate true changes in body tissue weight.

The energy value of a kilogram of true body tissue that is lost or gained is dependent on the relative proportions of fat and protein in the tissue and their respective heat of combustion. On average, fat-free mass contains 72.8 percent water, 21.5 percent protein, and 5.7 percent ash (Andrew et al., 1994, 1995; Komaragiri and Erdman, 1997, 1998; Chilliard et al., 1991; Gibb et al., 1992); nearly identical to the respective values of 72.91, 21.64, and 5.34 percent reported by Reid (1955).

This committee chose to use the National Research Council (1996) body reserves model with modifications by Fox et al. (1999) to predict body composition based on body condition score (BCS; see section below) of cows of different body sizes and amounts of body reserves. Body condition score (BCS) measurements can be made readily on farms, and BCS is correlated with body fat and energy contents.

Equations relating BCS with body composition were developed from data using a nine point BCS scale (1 to 9 scoring system, BCS(9)) on 106 mature cows of diverse breed types, mature weights and BCSs. The resulting equations that describe relationships between BCS(9) and empty body percentage of fat (Equation 2-20, protein; Equation 2-21, water) and ash were linear. The BCS accounted for 65, 52, and 66 percent of the variation in body fat, body protein, and body energy, respectively between individual animals.

$$\begin{aligned} \text{Proportion of empty body fat} \\ = 0.037683 \times \text{BCS}(9) \end{aligned} \quad (2-20)$$

$$\begin{aligned} \text{Proportion of empty body protein} \\ = 0.200886 - 0.0066762 \times \text{BCS}(9) \end{aligned} \quad (2-21)$$

Equations 2-20 and 2-21 use BCS on a 1 to 9 scale (i.e., BCS(9)); however, a 1 to 5 scale is commonly used for dairy cattle (Wildman et al., 1982; Edmonson et al., 1989; Figure 2-2). In the model, users input BCS on a 1 to 5 scale, and the program internally converts those to the 1 to 9 scale as

$$\text{BCS}(9) = ((\text{Dairy BCS} - 1) \times 2) + 1 \quad (2-22)$$

Equations 2-20 and 2-21 are used to estimate the composition of body tissue gain or loss, which is then used to calculate the energy supplied or required for changes in body reserves. Regression analysis on slaughter data from

		1	2	3	4	5	6	7	8
	SCORE	Spinous processes (SP) (anatomy varies)	Spinous to Transverse processes	Transverse processes	Overhanging shelf (care – rumen fill)	Tuber coxae (hooks) & Tuber ischii (pins)	Between pins and hooks	Between the hooks	Tailhead to pins (anatomy varies)
SEVERE UNDERCONDITIONING (emaciated)	1.00	individual processes distinct, giving a saw-tooth appearance	deep depression	very prominent, > 1/2 length visible	definite shelf, gaunt, tucked	extremely sharp, no tissue cover	severe depression, devoid of flesh	severely depressed	bones very prominent with deep "V" shaped cavity under tail
	1.25								
	1.50								
FRAME OBVIOUS	1.75			1/2 length of process visible					
	2.00	individual processes evident	obvious depression		prominent shelf	prominent	very sunken		bones prominent "U" shaped cavity formed under tail
	2.25			between 1/2 to 1/3 of processes visible					
FRAME & COVERING WELL BALANCED	2.50	sharp, prominent ridge		1/3 - 1/4 visible	moderate shelf		thin flesh covering	definite depression	first evidence of fat
	2.75								
	3.00		smooth concave curve	< 1/4 visible	slight shelf	smooth	depression	moderate depression	bones smooth, cavity under tail shallow & fatty tissue lined
FRAME NOT AS VISIBLE AS COVERING	3.25			appears smooth, TP's just discernable					
	3.50	smooth ridge, the SP's not evident	smooth slope	distinct ridge, no individual processes discernable		covered	slight depression	slight depression	
	3.75						sloping		
	4.00	flat, no processes discernable	nearly flat	smooth, rounded edge	none	rounded with fat		flat	bones rounded with fat and slight fat-filled depression under tail
	4.25						flat		
	4.50			edge barely discernable		buried in fat			bones buried in fat, cavity filled with fat forming tissue folds
SEVERE OVERCONDITIONING	4.75								
	5.00	buried in fat	rounded (convex)	buried in fat	bulging		rounded	rounded	

FIGURE 2-2 Body condition scoring chart adapted from Edmonson et al. (1989).

25 cows at various stages of lactation (Andrew et al., 1991) suggested a heat of combustion for body fat and protein of 9.2 and 5.57 Mcal/kg, respectively. These values are similar to the values of 9.4 and 5.55 Mcal/kg reported for growing steers (Garrett, 1987). The committee chose 9.4 and 5.55 Mcal/kg for body fat and protein. To determine the total energy contained in 1 kg of reserves, the heats of combustion are multiplied by the estimated proportions of fat and protein:

$$\begin{aligned} \text{Total reserves energy (Mcal/kg)} \\ &= \text{Proportion empty body fat} \times 9.4 \\ &\quad + \text{proportion of empty body protein} \times 5.55 \quad (2-23) \end{aligned}$$

The amount of energy per kilogram of BW for different BCS are shown in Table 2-4. Reserve energy when used to support milk production has an efficiency of 0.82. Therefore NE_L provided by body reserves is:

$$\begin{aligned} \text{NE}_L \text{ from body reserve loss (Mcal/kg)} \\ &= \text{Reserve energy (Equation 2-23)} \times 0.82 \quad (2-24) \end{aligned}$$

The measured efficiency of use of dietary ME for body tissue energy deposition was 0.60 percent in nonlactating cows and 0.75 in lactating cows (Moe et al., 1971). If the efficiencies of ME used for milk production and BW gain by lactating animals are 0.64 and 0.75, respectively, the amount of NE_L required for 1 kg of gain in reserves during lactation is:

$$\begin{aligned} \text{NE}_L \text{ (Mcal/kg gain)} \\ &= \text{Reserve energy (Equation 2-23)} \\ &\quad \times (0.64/0.75) \quad (2-25) \end{aligned}$$

In nonlactating cows, the efficiency term in the previous equation is (0.64/0.60). Because digestibility is decreased when large amounts of feed are consumed by cows, the feed required for tissue gain during the dry period would

be less than projected because of greater digestibility of any given diet when cows are fed at maintenance. The NE_L provided by loss of reserves or needed to replenish reserves is shown in Table 2-4 for cows with different BCS.

To estimate the amount of energy provided by or required for a one-unit change in BCS, change in BW relative to change in BCS must be calculated. The mean change in empty BW (EBW) per one-unit change in BCS (5-point scale) is 13.7 percent (Fox et al., 1999). The EBW is calculated as $0.851 \times \text{shrunk BW}$; shrunk BW = $0.96 \times \text{BW}$; therefore, $\text{EBW} = 0.817 \times \text{BW}$. The BCS 3 (5-point scale) was set as the base (1.00); the relative EBW (or BW) can be calculated at other BCS (Table 2-4). For example, a 600-kg cow with a BCS of 3 (EBW of 513 kg) would be expected to weigh 518 kg (600×0.863 ; Table 2-4) at a BCS of 2. The amount of tissue energy required per kilogram gain in EBW (Table 2-4) is calculated as the energy provided by fat and protein at the next higher BCS (weighted by EBW at next higher BCS), subtracted from the energy provided by fat and protein at the current BCS (weighted by EBW at the current BCS), divided by EBW at next higher BCS minus EBW at current BCS. To calculate energy provided per kilogram of EBW loss, the same equation is used except values at current BCS are subtracted from values at next lower BCS.

This model was validated with the data of Otto et al. (1991), as described by Fox et al. (1999). In this study, body composition and BCS of 56 Holstein cows selected to represent the range in dairy body condition scores 1 to 5 were determined. 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 percent. The relationship between BW change and BCS in these Holstein cows was 84.6 kg/BCS ($r^2 = 0.96$). This value of 84.6 kg/BCS compared well to 80 kg predicted by the model and 82 kg in the data previously mentioned

TABLE 2-4 Empty Body (EB) Chemical Composition at Different Body Condition Scores (BCS), Relative EB Weight (EBW), and NE_L Provided by Live Weight (LW) Loss and NE_L Needed for LW Gain^a

BCS	% of EB				EBW (% of BCS 3)	Energy, Mcal/kg EBW change ^b	Mcal NE _L /kg of LW loss ^c	Mcal NE _L /kg of LW gain ^c
	Fat	Protein	Ash	Water				
1.0	3.77	19.42	7.46	69.35	72.6	5.14	...	3.60
1.5	7.54	18.75	7.02	66.69	79.4	5.72 (5.14)	3.44	4.01
2.0	11.30	18.09	6.58	64.03	86.3	6.41 (5.72)	3.83	4.50
2.5	15.07	17.42	6.15	61.36	93.1	6.98 (6.41)	4.29	4.90
3.0	18.84	16.75	5.71	58.70	100.0	7.61 (6.98)	4.68	5.34
3.5	22.61	16.08	5.27	56.04	106.9	8.32 (7.61)	5.10	5.84
4.0	26.38	15.42	4.83	53.37	113.7	8.88 (8.32)	5.57	6.23
4.5	30.15	14.75	4.43	50.71	120.6	9.59 (8.88)	5.95	6.73
5.0	33.91	14.08	3.96	48.05	127.4	(9.59)	6.43	...

^aEmpty body weight = $0.817 \times \text{live weight}$.

^bTissue energy contained in 1 kg of EBW gain going to next higher 0.5 BCS. Values in parentheses are tissue energy contained in 1 kg of EBW loss going to next lower 0.5 BCS.

^cValues were calculated by converting tissue energy per kilogram of EBW into tissue energy per kilogram of BW ($\text{EBW} \times 0.855$) and then converting to dietary NE_L using an efficiency of 0.82 for converting tissue energy from live weight loss to dietary NE_L, and an efficiency of 1.12 for converting dietary NE_L to tissue energy for live weight gain.

TABLE 2-5 Energy Provided by or Needed to Change Body Condition Score (BCS) of Cows of Different Live Weights and BCS

	Live weight (kg)							
BCS	400	450	500	550	600	650	700	750
Mcal of NE _L provided by a loss of one BCS ^a								
2	230	259	288	317	346	375	404	432
3	245	276	307	338	368	399	430	460
4	257	289	321	353	385	417	450	482
5	266	299	332	365	399	432	465	498
Mcal of NE _L needed to gain one BCS ^b								
1	287	323	359	395	431	467	502	535
2	298	335	372	410	447	484	522	559
3	306	344	382	421	459	497	535	574
4	312	351	390	429	468	507	546	585

^aRepresents the NE_L provided by mobilization of reserves when moving to next lower score. For example, a 400-kg cow in BCS 3 will provide 245 Mcal of NE_L when BCS decreases one unit.

^bRepresents the NE_L required to replenish reserves when moving to the next higher score. For example a 600-kg cow in BCS 3 will require 459 Mcal of NE_L to increase BCS one unit.

in this chapter. Although the evaluation strongly supports the use of this model, further validation with other data sets should be conducted.

This model predicts energy reserves to be 5.47 Mcal/kg live weight loss from BCS 3.0 to BCS 2.0. The mean value of tissue energy is 6 Mcal/kg (Gibb et al., 1992; Andrew et al., 1994; Komaragiri and Erdman, 1997; Tamminga, 1981) and that is the value used in the 1989 edition (National Research Council, 1989). The predicted energy content of weight loss ranged from 4.36 Mcal/kg at BCS 1.5 to 7.59 Mcal/kg at BCS 4.5 compared to CSIRO (1990) values of 3.0 and 7.1, respectively. Protein in the weight loss from BCS 3 to BCS 2 was predicted to be 68 g/kg, compared to 135, 138, and 160g/kg weight loss for the CSIRO (1990), AFRC (1993), and National Research Council (1989).

Body Condition Scoring

Body condition scoring (BCS), although subjective in nature, is the only practical method of evaluation of body energy stores in dairy cows. In the U.S., the most common systems of BCS use a five-point scale originally proposed by Wildman et al. (1982) with a BCS of 1 being extremely thin and a score of 5 being extremely fat. This system included a combination of both visual appraisal and manual palpation to score individual cows. Edmonson et al. (1989) suggested a BCS chart system using a 5-point scale based on visual appraisal of only 8 separate body locations. Analysis of variation due to cows and to individuals assessing BCS suggested that visual appraisal of two key locations (between the hooks and between the hooks and pins) had the smallest error due to assessor and accounted for the greatest proportion of variation due to individual cows.

Figure 2-2 shows the suggested BCS chart based on these two key areas.

Loss of BCS is expected during early lactation when a cow is mobilizing body fat in support of energy needs for lactation. Typical observed changes in BSC range from 0.5 to 1.0 condition score units during the first 60 days postpartum. A 1-unit decrease in BCS for a cow weighing 650 kg at calving (BCS 4) would provide 417 Mcal of NE_L (Table 2-5). That amount of NE_L is sufficient to support 564 kg of 4 percent fat-corrected milk.

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