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.

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

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

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

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 feeds are shown assuming intake at 3 and 4X maintenance and a total diet TDN_{1X} 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_{1X}) 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_{1X} 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 to100 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.

Truly digestible NFC (tdNFC)

$$= 0.98\ (100 - [(NDF - NDICP) + CP + EE + Ash]) \times PAF \qquad (2\text{-}4a)$$

Truly digestible CP for forages (tdCPf)

$$= CP \times \exp[-1.2 \times (ADICP/CP)] \qquad (2\text{-}4b)$$

Truly digestible CP for concentrates (tdCPc)

$$= [1 - (0.4 \times (ADICP/CP))] \times CP \qquad (2\text{-}4c)$$

Truly digestible FA (tdFA)

$$= FA \quad \text{Note: If } EE < 1\text{, then } FA = 0 \qquad (2\text{-}4d)$$

Truly digestible NDF (tdNDF)

$$= 0.75 \times (NDFn - L) \times [1 - (L/NDFn)^{0.667}] \qquad (2\text{-}4e)$$

In Equations 2-4a, 2-4b, 2-4c, 2-4d, 2-4e, NDICP = neutral detergent insoluble N × 6.25, PAF = processing adjustment factor (see below), ADICP = acid detergent insoluble N × 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_{1X} is then calculated using Equation 2-5.

$$TDN_{1X}\ (\%) = tdNFC + tdCP + (tdFA \times 2.25) + tdNDF - 7 \qquad (2\text{-}5)$$

Equations 2-4 and 2-5 were used to calculate TDN_{1X}, 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 nonchemical 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

[a] See Chapter 13 for details on how values were calculated. For feeds not shown, PAF = 1.0.

[b] Mean of several experiments, actual PAF depends on particle size. Finer grinding will increase PAF.

[c] Mean density of 0.36 kg/L; PAF should be negatively correlated with density.

[d] Mean 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_{1X} was estimated using Equation 2-6.

$$TDN_{1X}\ (\%) = \text{CPdigest} \times CP + FA \times 2.25 + 0.98(100 - CP - Ash - EE) - 7 \quad (2\text{-}6)$$

Where CPdigest = estimated true digestibility of CP (Table 2-2) and FA = EE − 1. The CPdigest 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_{1X} 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_{1X} values of different fat supplements were calculated from measured fatty acid digestibility. Partial digestion coefficients (Table 2-3) of fatty acids from supplemental 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_{1X}. After adjusting digestibility for intake (Table 2-3), digestible fat was multiplied by 2.25 to convert to TDN_{1X} (Equations 2-7a and 2-7b).

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	—	—

For fat sources that contain glycerol:

$$TDN_{1X}\ (\%) = (EE \times 0.1) + [\text{FAdigest} \times (EE \times 0.9) \times 2.25] \quad (2\text{-}7a)$$

For fat sources that do not contain glycerol:

$$TDN_{1X}\ (\%) = (EE \times \text{FAdigest}) \times 2.25 \quad (2\text{-}7b)$$

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 × 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 × 0.044 = 0.3 Mcal/kg.

For most feeds:

$$DE_{1X}\ (Mcal/kg) = (tdNFC/100) \times 4.2 + (tdNDF/100) \times 4.2 + (tdCP/100) \times 5.6 + (FA/100) \times 9.4 - 0.3 \quad (2\text{-}8a)$$

For animal protein meals:

$$DE_{1X}\ (Mcal/kg) = (tdNFC/100) \times 4.2 + (tdCP/100) \times 5.6 + (FA/100) \times 9.4 - 0.3 \quad (2\text{-}8b)$$

For fat supplements with glycerol:

$$DE_{1X}\ (Mcal/kg) = 9.4 \times (FAdigest \times 0.9 \times (EE/100)) + (4.3 \times 0.1 \times (EE/100)) \quad (2\text{-}8c)$$

For fat supplements without glycerol:

$$DE_{1X}\ (Mcal/kg) = 9.4 \times FAdigest \times (EE/100) \quad (2\text{-}8d)$$

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_{1X} would be 3 percentage units per multiple of maintenance, while the depression for a diet containing 60 percent TDN_{1X} 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., 1882; Moe et al., 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 $= 0.18 \times TDN_{1X} - 10.3$ ($r^2 = 0.85$). 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:

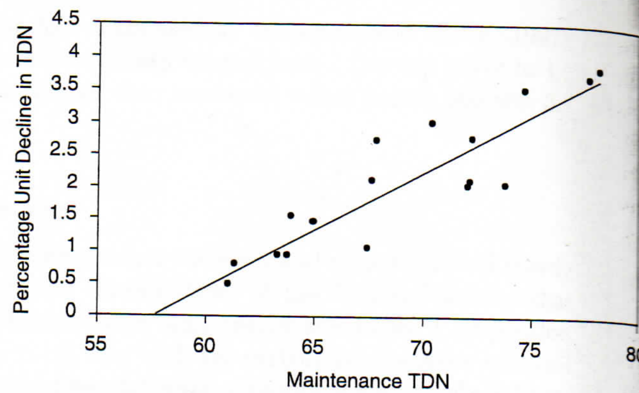

FIGURE 2-1 The relationship between feeding level expressed as multiples of maintenance and the unit decline in diet TDN per multiple of maintenance where TDN percentage unit decline $= 0.18 \times -10.3$, $r^2 = 0.85$.

$$\text{Discount} = [(TDN_{1X} - [(0.18 \times TDN_{1X}) - 10.3]) \times \text{Intake})]/TDN_{1X} \quad (2\text{-}9)$$

where TDN_{1X} 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_{1X} 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_{1X} 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_{1X} is negligible; therefore, for diets with 60 percent or less TDN_{1X} 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_{1X} by increasing dietary fat above 3 percent would not affect