Energy in the New Dairy NRC

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Introduction

Energy is vital to the function of all cells, and thus physiologically, it is vital for tissue maintenance, tissue growth, milk synthesis, and fetal development. Level of activity and environmental stress affect the energy required for body maintenance. Providing the energy needs of an animal necessitates the summary of a lot of research on energy needed for different metabolic functions, the energy content of tissue and milk, and the efficiency of energy utilization by different tissues and as affected by activity and stressors. Equally important is determining the energy availability from different feeds. Composition of the feeds, physical and chemical forms of the feeds, and the affects of DM intake by the animals on digestibility affect the actual energy available from the feeds. These two components, the feeds and the animals, have been intertwined into a dynamic model in the new NRC (2001) for dairy cattle.

Terminology

Energy is broadly defined as "*the capacity for performing work*". Cells can perform work by using the chemical energy stored in food. All forms of energy can be converted quantitatively to heat, and the basic unit of heat energy is called a calorie. The amount of heat energy in a feedstuff can be measured using a bomb calorimeter. This measurement will provide the gross energy (**GE**) in a diet. The digestible energy (**DE**) can be determined by subtracting the amount of energy excreted in feces from the GE. Fecal DM output can be measured by total collection of the feces or using a digestibility marker (e.g. chromic oxide). The fecal DM can be sampled and bomb calorimetry used to determine fecal energy. However, if we are interested in the energy value of a single feedstuff, we have sampled feces that have resulted from the entire ration. Because dairy animals are seldom fed diets consisting of a single ingredient and the type and amounts of feeds in the diet can affect digestibility, especially ruminal fermentation patterns and rate of passage, it really is not very practical to think of the energy value of individual feeds but to think of energy contributed by the diet consumed by the animal. Digestibility of a diet decreases with increased DM (energy) intake, thus the NRC (2001) discounts (decreases) digestibility based on the energy intake above maintenance, thus referred to as discount factors based on multiples of maintenance. For example, if a lactating cow is consuming 40 Mcal/day of NE_L and 10 Mcal/day of NE_L are needed for maintenance, then energy intake is at 4X maintenance.

Energy lost from the animal by gas and through the urine is not available for cell function, thus this energy subtracted from DE provides the amount of metabolizable energy (**ME**). Urinary energy can be determined in total collection digestibility trials, but energy lost from gas is much more difficult to measure (requires energy chambers so that the gas output can

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be measured). The heat loss from fermentation of feed in the digestive tract (primarily in the rumen) and from metabolism of cells is referred to as heat increment (**HE**). The ME minus HE provides the amount of energy actually available for cell function, thus referred to as net energy (**NE**). In the total digestible nutrient (**TDN**) system as a measure of energy, fecal energy and some of the urinary energy were accounted for in the measurements, thus it falls short in accounting for the gaseous and heat energy. Forages cause more heat of fermentation and methane production than grains, and thus the TDN system underestimates the energy of grain relative to the energy of forages.

The NE unit is subdivided into the energy needed for maintenance, growth, and lactation. The reason for this is that energy used for different processes is used with different efficiencies. For mature dairy cattle, only NE_L is used because the efficiency of energy utilization for maintenance (0.62) is similar to that for lactation (0.64) (Moe and Tyrell, 1972). Therefore, the NE_L for dry cows includes the energy needed for maintenance and fetal growth, and the NE_L for lactating cows includes the energy needed for maintenance and lactation. Because energy use for growth is only 50 to 70% as efficient as the energy for maintenance, NE_m and NE_g are used for growing dairy animals.

Energy Values for Feeds

Energy values for feeds used in the previous version of NRC (1989) were TDN values assigned to feedstuffs that were determined experimentally using similar feeds. The concentrations of DE, ME, and NE were then calculated from TDN using published equations. The equations used for converting TDN to DE and ME assumed intake at 1X maintenance, and the equation used to convert TDN to NE_L was derived from cows fed at 3X maintenance. The conversion of TDN to NE assumed an 8% reduction in digestibility for cows fed at 3X maintenance.

Problems with the approaches used in the 1989 NRC are: 1) TDN values are from experiments conducted several years ago and new feed compositional data are available, 2) the TDN value for a feed is appropriate only when the nutrient composition is similar to that of the feedstuff being fed, 3) TDN values for many feeds are inaccurate because the feeds were fed in mixed diets and associative effects of feeds occur, 4) the ME and NE values actually available are for mixed diets and not individual feedstuffs, and 5) all cows do not have intake at 3X maintenance, with the average intake for a herd possibly ranging from 2 to 4X maintenance. Because of these problems, the following tabular values for energy in feeds are provided in the published copy of the NRC (2001): TDN at 1X maintenance, DE at 1X maintenance, ME at 3X maintenance, NE_L at 3 and 4X maintenance, and NE_m and NE_g at 3X maintenance. The tabular NE_L values at 3 and 4X maintenance are based on a dietary TDN value of 74% at 1X maintenance. In the computer model, only TDN and DE are provided for individual feeds.

The TDN values at 1X maintenance were not taken from digestibility experiments but were calculated from nutrient compositional data. The compositional components included digestible nonfiber carbohydrates (**NFC**), crude protein (**CP**), fatty acids (**FA**) [ether extract (**EE**)-1], and NDF (Weiss et al., 1992). A processing adjustment factor (**PAF**) is used in the NRC (2001) to account for the effect that particle size, heat, and steam have on the digestibility of NFC. True digestibility of NFC was assumed to be 0.98 and 0.90 at 1 and 3X maintenance, respectively. Thus, the PAF factors published in the NRC and the default values in the computer model were based on 3X maintenance and determined by dividing in vivo starch digestibility by 0.90. Thus, the PAF adjustment will overestimate NE_L values of feeds fed at 1X maintenance.

Because animal products do not contain actual fiber (measured as NDF), the TDN values at 1X maintenance were determined using digestible CP, FA x 2.25, 0.98 x (100-CP-ash-EE), and adjustment for metabolic fecal TDN (-7). The TDN at 1X maintenance for fat supplements was determined by published studies with the fat supplements, with indirect calculation of the partial digestion coefficient for FA by difference. For fat sources with glycerol, the FA composition was assumed to be 90%. For fat sources without glycerol, the TDN equation was: EE x FA digestibility x 2.25. Since most of the studies were conducted with cows consuming energy at 3X maintenance, the digestibility coefficient for TDN at 1X maintenance was calculated using the FA digestibility from cows fed at 3X maintenance divided by 0.92.

The estimated DE of individual feeds is calculated using the digestible nutrient concentrations (NFC, NDF, CP, FA, or EE), times the heats of combustion (4.2 Mcal/kg for carbohydrates, 5.6 Mcal/kg for protein, 9.4 Mcal/kg for FA, and 4.3 Mcal/kg for glycerol), and subtracting the metabolic fecal DE of 0.3 Mcal/kg for all feeds except fat supplements. The DE at 1X maintenance is then discounted for each multiple of energy intake above maintenance using the following equation:

$$\text{Discount} = [(TDN_{1X} - [(0.18 \times TDN_{1X}) - 10.3]) \times \text{incremental energy intake above maintenance})]/TDN_{1X}$$

For example, a dairy cow with a consumption at 3X maintenance of a diet with 74% TDN at 1X maintenance would result in the following discount factor:

$$[(74 - [(0.18 \times 74) - 10.3]) \times (3X\text{-}1X))]/74 = 0.918 \text{ or an 8\% discount.}$$

For diets with $\leq$ 60% TDN, no discount occurs (discount factor = 1.0), and the maximum discount is set so that the lower limit for dietary discounted TDN is no less than 60%. The discounts do not apply to the DE contributed from supplemental fat provided in excess of 3% of the dietary DM. The DE at production intake is calculated by multiplying DE at 1X maintenance times the appropriate discount factor.

The ME values for all feeds except fat supplements was calculated from DE using the following equation:

ME (Mcal/kg) = (((1.01 x DE) – 0.45) + 0.0046) x (EE – 3). For fat supplements, ME was assumed to equal DE.

The NE_L content of feeds in the published NRC (2001) were calculated from ME and adjusted for the amount of fat over 3% of dietary DM. For fat supplements, NE_L = 0.8 x ME. The equations for NE_m and NE_g were taken from the NRC (1996), assuming intake at 3X maintenance, ME = DE x 0.82, and then estimating NE from ME. The NE_m and NE_g of fat supplements was calculated, assuming DE = ME and with ME x 0.80 and ME x 0.55, respectively.

In the computer model, the focus is on the energy concentration of the diet instead of the individual feeds. The variables that can affect NE of the diet in the computer model are summarized in Table 1. It must be kept in mind that even the dietary energy values generated by the computer model are based primarily on the chemical composition of feeds and assume that feed characteristics limit energy availability. However, the associative effects of the individual ingredients in the diet, ruminal conditions, and health of animals will affect the actual energy gained from a diet.

Energy Requirements

The NE requirement for maintenance of mature dairy cattle is assumed to be 0.08 Mcal/kg $BW^{0.75}$. This value was taken from a requirement determined at 0.073 Mcal/kg $BW^{0.75}$, but because this was determined with animals in tie stalls, a 10% activity allowance was added to account for normal voluntary activity.

The NE required for lactation is defined as the energy contained in the milk, contributed by the fat, protein, and lactose. The heat of combustion for milk fat, true protein, and lactose are 9.29, 5.71, and 3.95 Mcal/kg, respectively. The equation used for calculating NE_L for milk yield is:

$$NE_L \text{ (Mcal/kg)} = (0.0929 \times \% \text{ fat}) + (0.0563 \times \% \text{ true protein}) + (0.0395 \times \% \text{ lactose})$$

If lactose is not available, 4.85% should be assumed. Milk CP is determined by N x 6.38, and milk CP contains about 7% non-protein nitrogen. The coefficient in the above equation for milk CP would be 0.0547.

The energy requirements for maintenance and growth of growing dairy animals were calculated using many equations to account for body size, fat and protein content of tissue at different body sizes (affected by BW relative to mature weight), the average daily gain, and the fat and protein content of tissue occurring at different rates of growth.

Adjustments to Energy Requirements

Activity. The energy required for maintenance increases as the activity exceeds the 10% increase in maintenance requirements to account for normal activity. The NRC (2001) computer model increases energy for maintenance for grazing animals. The increased activity during grazing is attributed primarily to: 1) distance between the parlor and pasture, 2) grazing cattle spend more time eating, and 3) grazing cattle walk in areas of varied elevation. The NE_L is increased 0.00045 Mcal/kg BW per kilometer walked from the parlor to the pasture (this distance will depend on number of milkings per day). Previous research indicated that increased eating activity associated with grazing compared to stall-fed cattle required an additional 0.002 Mcal/kg BW, but the diet consisted of only pasture for these animals. Thus, it was assumed that pasture provided 60% of the diet for grazing lactating cows, and the activity allowance for eating was set at 0.0012/kg BW. The options exist in the computer model to select whether the terrain is flat or hilly. If a hilly terrain is selected, an additional amount of energy for maintenance is determined: 0.006 Mcal/kg BW. It was assumed that heifers would walk twice as much than when confined: (0.00045 x 2)/kg BW. For growing dairy animals, it was assumed that pasture consisted of 80% of the diet for calculation of energy for eating activity. The same adjustment for hilly terrain was used for both mature and growing dairy animals.

Environment. Heat and cold stress can affect the energy requirements of animals; however, because of limited data, no environmental adjustments were made in the computer model for energy requirements of dry or lactating cattle (even though temperature is allowed as an input variable). However, environmental adjustments are made for growing dairy animals. Input variables include: current and previous temperature, wind speed (mph), coat condition (clean/dry, wet/matted, some mud, or covered with snow and mud), heat stress (none, rapid/shallow, or open mouth), hair coat (inches), and night cooling (yes, no). These adjustments are primarily taken from NRC (1996). For the young milk-fed calf, adjustments are made for cold stress only. Once temperature drops to 10^oC, the NE_m will be increased 1.13 to 2.34 times depending on the age of the calf (less than or greater than 2 months of age) and the temperature.

Pregnancy. Additional energy for the growing fetus is included for the last 100 days of pregnancy and is based on the expected birth weight of the calf.

Tissue Mobilization and Repletion. Changes in BW of animals may not really reflect true changes in stores of tissue energy. Cows lose BW during early lactation, but DM intake is increasing, and as DM intake increases, gastrointestinal contents (gut fill) increase. After a few weeks beyond peak lactation, DM intake and gut fill decrease, and changes in BW may underestimate actual changes in body tissue weight. The energy in a unit of body tissue gain or loss depends on the amount of fat and protein in the tissue. The NRC (2001) calculates empty body fat and protein based on body condition score (**BCS**). Energy reserves are then calculated from empty body fat and protein. The NE_L from BW loss is calculated using the body reserve energy and an efficiency of 0.82. The NE_L needed for BW gain is calculated from body reserve energy times 0.85 and 1.07 for lactating and dry cows, respectively. The amount of energy available in a one-unit change in BCS is determined by the change in BW relative to the change in BCS and the composition of the BW at different BCS.

Conclusions

Many improvements were made in the 2001 versus the 1989 versions of NRC for dairy cattle relative to the energy available from feeds and the energy requirements of animals. A new database on composition of feeds was provided, and TDN is determined based on actual composition of the feeds. The NE content of feeds is adjusted based on the source (feeds) of the nutrients and the affects of intake by the animals on digestibility. Overall, the NE_L values at 3X maintenance for all feeds were 2% lower in the 2001 versus the 1989 versions, but major differences in NE_L values occurred for some specific feeds.

The computer model provides for a more accurate assessment of energy availability because it accounts for factors affecting the energy from the entire diet and not just summing the energy from individual feeds. The computer model also provides for more accurate determination of energy requirements under given conditions based on the additional input variables allowed. Even with these advancements, some critical points to remember are that energy values on lab reports are estimated and may not be the values to use in ration formulation, the program neither fully accounts for associative affects of feeds in mixed diets (almost all animals are fed mixed diets) nor has the method of accounting for associative effects been validated, and animal management and health variables are not included in the model. Additional efforts are needed in relating environmental factors to energy needs. Our responsibilities as users of the NRC are to recognize the strengths and limitations of the new NRC program and to always compare animal appearance (e.g. BCS) and performance to expectations.

References

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Table 1. Variables in the NRC (2001) computer model that affect the energy concentration of a feed or diet.[1]

Item	Options (Example)	Effect on Energy Concentration[2]
Energy equation class	Forage Concentrate Animal Fat[3] Fatty acids[3]	Determines which equations are used for TDN, DE, ME, and NE
Processing factor (PAF)	Input actual value (increase/decrease)	Increase/ decrease (digestibility of NFC) based on particle size and heat or steam processing
TDN, % of DM	Can not be edited	…
DE, Mcal/kg	Can not be edited	…
NDF, % of DM	Input actual value (increase)	Decrease
Lignin, % of DM	Input actual value (increase)	Decrease
CP, % of DM	Input actual value (increase)	Increase
NDFIP, % of DM	Input actual value (increase)	Increase (increases NFC)
ADFIP, % of DM	Input actual value (increase)	Decrease (Decrease CP digestibility in feeds not of animal origin)
Fat, % of DM	Input actual value (increase)	Increase
Ash, % of DM	Input actual value (increase)	Decrease
Protein digestibility, %[4]	Input actual value (increase)	Increase
NDF digestibility, %[5]	Calculated or input actual value (increase)	Increase
Fat digestibility, %[6]	Input actual value (increase)	Increase
DM intake, kg/day[7]	Estimated or actual input (increase)	Decrease

[1]TDN = total digestible nutrients, DE = digestible energy, ME = metabolizable energy, NE = net energy, NFC = nonfiber carbohydrates, CP = crude protein, NDF = neutral detergent fiber, NDFIP = neutral detergent fiber insoluble nitrogen, and ADFIP = acid detergent insoluble nitrogen.

[2]This represents the most likely effect on the energy concentration if no other variable is changed. Also, a change in the energy concentration in a feed may not change the energy concentration in the diet because of the discounts used in computing the concentration of dietary energy.

[3]Option only for fat supplements

[4]Value can only be changed for animal protein feeds.

[5]Default value is calculated from NDF, NDFIP, and lignin.

[6]Value should only be changed for fat supplements.

[7]Adjusts DE and thus NE of diets for multiples above maintenance intake.