Energy in the 2001 Dairy NRC: Understanding the System

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Introduction

The purpose of this paper is to review the energy system in the 7*th* Edition of the Nutrient Requirements of Dairy Cattle (NRC-2001). In evaluating the energy system, both animal requirements and the supply of energy (feeds) must be considered. Previous editions of the Dairy NRC were found to have energy supplied from feeds or input energy 5 to 7% greater than energy output (Weiss, 1998). A fundamental law in thermodynamics states energy is neither created nor destroyed, but can be changed in form. Thus, the goal of the NRC-2001 was to update the energy system and make the system balanced, i.e. energy input should equal output. Also, in previous editions of the Dairy NRC, the dietary nutrient requirements were static and did not account for animal or feedstuff variations that could affect the requirement or supply of nutrients. The NRC-2001 relies heavily on a computer model to dynamically predict dietary nutrient requirements. The dietary energy requirements in the NRC 2001 consider feedstuff digestion dynamics as well as the energy requirements for maintenance, growth, lactation, reproductive status and activity of the animal. This paper will primarily focus on energy as related to the lactating cow.

Dry Matter Intake

The NRC-2001 predicts dry matter intake (DMI) of lactating cows. The DMI equation is a combined equation of two published equations (Rayburn and Fox, 1993; Roseler et al., 1997). The equation is universal in that it is applicable during all stages of lactation, and to cows in first lactation and greater:

$$\text{DMI (kg/d)} = (0.372 \times 4\%\ \text{FCM} + 0.0968 \times \text{BW}^{.75}) \times (1 - e^{(-0.192 \times (\text{WOL} + 3.67))})$$

4% FCM	=	4% fat corrected milk
BW	=	body weight (kg)
e	=	2.71828[1]
WOL	=	week of lactation

The term $(1 - e^{(-0.192 \times (\text{WOL} + 3.67))})$ adjusts for stage of lactation (Figure 1). Differences in DMI between first and second or later lactation cows will be accurately differentiated with the use of correct BW and 4% FCM. A difference of 100 kg in BW changes DMI by 1.5 kg/day.

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DMI is a critical component in the model's derivation of diet energy and rumen undegradable protein (RUP) values. These values are dynamic and change with DMI of the animal. As DMI increases, energy concentration of the diet decreases and RUP content of the diet increases.

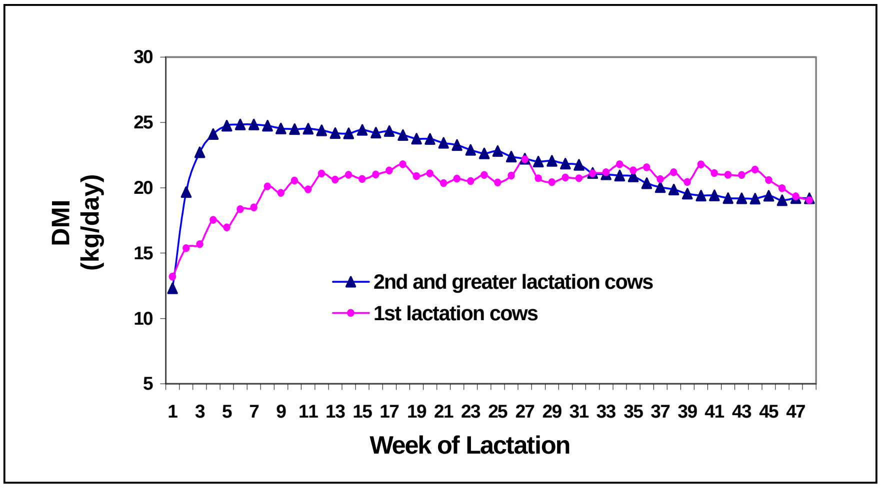

Figure 1. DMI of first lactation cows and second or greater lactation cows during the first 48 weeks of lactation.

Energy

The net energy system is retained in NRC-2001 as it was in previous editions. The Net Energy (NE) scheme is shown in Figure 2. Energy values for feeds, diets and requirements of lactating and dry cows (maintenance, lactation, activity, pregnancy and growth) are expressed in net energy of lactation (NE_L) units.

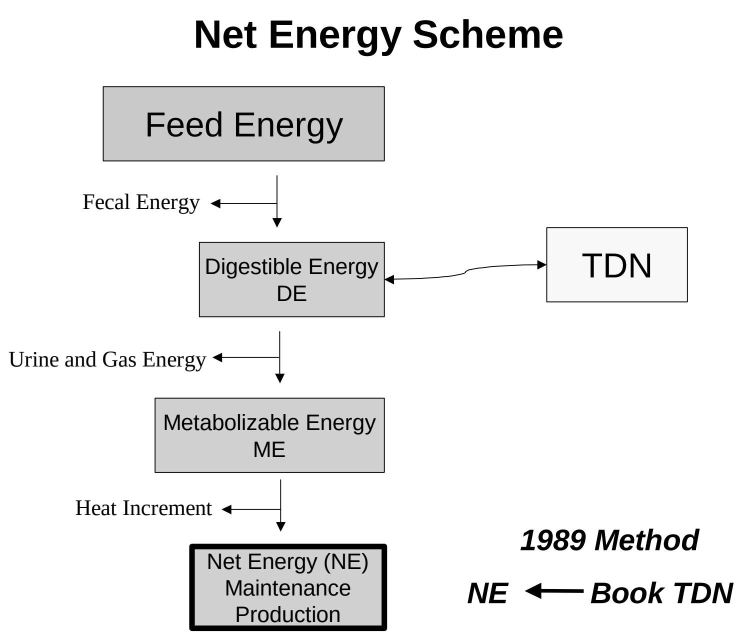

Figure 2. Net energy scheme.

ENERGY REQUIREMENTS

Maintenance. Energy requirements for maintenance are the same as they were in NRC-1989; NE_L, Mcal/day = 0.08 x $BW^{.75}$ (BW=body weight in kg). Maintenance energy is needed for life's normal daily processes including eating and walking short distances. The NE_L required for maintenance includes a 10% increase for activity. This should be satisfactory for most non-grazing tie stall housed cows. However, for cows in free stalls or dry lot facilities that are walking considerable distances to and from the milking parlor, additional energy above maintenance will be required. In NE_L units, the energy required for activity is set at 0.00045 Mcal/kg BW for every kilometer walked. A 600-kg cow that walks 2 kilometers per day needs an additional 0.54 Mcal of energy per day or about a 5.5% increase in maintenance requirement. For grazing cows, the activity requirement plus an additional 0.0012 Mcal/kg of BW under good pasture conditions or 0.006 Mcal/kg of BW for hilly and sparse pasture conditions needs to be added to the maintenance requirement.

Lactation. The energy components of milk are fat, protein and lactose. In NRC-1989, only fat was considered and milk energy was expressed relative to 4% fat corrected milk. Equations for calculating the NE_L required for milk production are as follows:

NE_L (Mcal/kg) = 0.0929 x Fat % + 0.0547 x Crude Protein % + 0.0395 x Lactose % or
NE_L (Mcal/kg) = 0.0929 x Fat % + 0.0547 x Crude Protein % + 0.192

For most Holsteins with average milk components of 3.5% fat and 3.0% true protein (3.2% crude protein), there is no noticeable difference in lactation requirements between 1989 and 2001. Lactation requirements have increased slightly for high component cows with the addition of protein and lactose.

Pregnancy. Unlike NRC-1989 where pregnancy requirement was fixed at 30% of maintenance, energy requirements for gestation increase with gestation length in NRC-2001. Below 190 days of gestation, no additional energy above maintenance is needed for pregnancy. Between 190 and 279 days of gestation, pregnancy requirements of the average Holstein cow increase from 2.5 to 3.7 Mcal/day, respectively. Gestations longer than 279 days do not increase pregnancy requirements beyond those at 279 days.

Growth and Body Reserves. In the NRC-2001 model, comprehensive equations compute desired growth rate for first and second lactation cows from current age and BW relative to the mature BW desired or average of the breed. For changes in body reserves or body composition, the NRC-2001 considers changes in body condition score (BCS). The energy associated with 1 kg of BW loss from a cow with a BCS of 2 is 3.8 Mcal compared with 5.6 Mcal for a cow with a BCS of 4. Conversely, the energy needed for 1 kg of gain at a BCS of 2 is 4.5 Mcal compared with 6.2 Mcal for a BCS of 4.

Feed and Diet Energy

1989 NRC. The NE_L value of feeds was calculated from TDN. [NE_L (Mcal/kg) = 0.0245 x TDN (%) - 0.12]. Limitations to this method were:

- TDN values for most feeds were determined many years ago and mostly using sheep or cattle at maintenance.

- For several feeds, the TDN value cannot be determined directly as they cannot be the sole ingredient in a diet. Therefore, inaccuracies in calculating the TDN of a single feed in a diet of mixed feeds can occur because of associative effects.

- Nutrient composition of feeds has changed over the years, but TDN value did not.

- Energy values for feeds were discounted a constant 8% to assimilate DMI at 3 times maintenance. This single correction in digestibility or energy content of the diet is not correct for many cows today.

<u>2001 NRC.</u> The approach used in the NRC-2001 is to calculate the energy value of feeds and diets directly from their nutrient composition. The equations for calculating the TDN of a feed or diet at maintenance intake (TDN_{1X}) are:

	Feed fraction - truly digestible (td)		Equation
1a	Crude protein forages (td CP_f)	=	$[(CP \times \exp^{(-0.012 \times ADICP/CP)})]$
1b	CP concentrates (td CP_c)	=	$[(1 - (.04 \times {}^{ADICP}/CP)) \times CP$
2	Nonfiber carbohydrates (td NFC)	=	$[(.98 \times (100 - [(NDF - NDICP) + CP + EE + Ash])) \times PAF]$
3a	Fatty acids (td FA) or	=	FA
3b	Ether extract (td EE)	=	$(EE - 1)$
4	Neutral detergent fiber (td NDF)	=	$[0.75 \times ((NDF - NDICP) - Lignin) \times (1 - (Lignin/(NDF - NDICP))^{0.667}$ or rumen in vitro digestible NDF at 48 hours
TDN_{1X}, %		=	$[1a \text{ or } 1b] + [2] + [3a \text{ or } 3b] + [4] - 7^{**}$

[*] All composition data is expressed as a percent of the dry matter. ADICP = acid detergent insoluble nitrogen x 6.25; NDICP = neutral detergent insoluble nitrogen x 6.25; PAF = processing adjustment factor.

[**] Metabolic fecal TDN.

Adjustments to the above TDN_{1X} equation are made for animal protein meals because of no structural carbohydrates, and for fat supplements (see chapter 2 in NRC- 2001 for specific equations).

<u>Processing adjustment factor (PAF).</u> Because starch availability of a feed can be affected by physical or chemical processing, a PAF factor was developed to account for the differences in starch digestibility and, hence, energy value of the feed. The PAF is an empirical factor based on dividing in vivo starch digestibility of the feed by 0.9. Ground corn is generally accepted as the standard and was found to have an in vivo starch digestibility of about 90%; thus, the PAF of ground corn is 1. For cracked dry corn where starch would be less available for digestion, the PAF is 0.95 and for steamed flaked corn with higher starch digestion than ground corn, the PAF is 1.04. The PAF adjustment is applied only to the nonfiber carbohydrate (NFC) fraction of the truly digestible NFC (tdNFC) equation.

Converting TDN to Net Energy. After the TDN value of a feed or diet is determined, the next step is to convert TDN_{1X} to Digestible Energy (DE) for use in the Net Energy system. The approach is to multiple each digestible nutrient component in the TDN calculation by its appropriate heat of combustion to determine the truly digestible (td) nutrient component. The td components are then summed and a metabolic fecal fraction (0.3) is subtracted to obtain the DE at maintenance.

DE_{1X}, (%) = (tdNFC + tdCP + tdEE + tdNDF) – 0.3

tdNFC = truly digestible nonfiber carbohydrates x (4.2^{**}/100)
tdCP = truly digestible crude protein x (5.6^{**}/100)
tdEE = truly digestible ether extract x (9.4^{**}/100)
tdNDF = truly digestible neutral detergent fiber] x (4.2^{**}/100)
0.3 = metabolic fecal DE value

Because DE at maintenance is not representative of the energy value of a feed or diet at production intake levels, a discount factor based on DMI and TDN_{1X} was developed to correct for decreased digestibility as DMI increased. An intake corrected DE (discounted DE) is then used to calculate ME and finally NE_L. This approach means the energy value of feeds and diets decreases with increasing DMI.

The standard discount applied to energy values in NRC-1989 was a 4% reduction from maintenance energy value per multiple of DMI above maintenance. Almost all feed tables and diets in NRC-1989 used energy values at 3 times (3X) maintenance DMI for an 8% discount in energy value from maintenance. In NRC-2001, a variable discount is applied to the DE of diet based on TDN_{1X} and DMI.

Discount factor = (TDN_{1X} – [((0.18 x TDN_{1X}) – 10.3) x Intake]/ TDN_{1X}

For example, a cow eating 21 kg of DMI per day with a maintenance DMI of 7 kg is eating at 3X maintenance (21 kg/7 kg). Intake above maintenance is 2 (3X – 1X for maintenance). If maintenance TDN (TDN_{1X}) is 75%, a discount of 0.915 is applied to maintenance DE to calculate a production DE_p. No discount is applied to diets below 60% TDN_{1x}.

The following equations are used to convert DE at maintenance to production levels of DE_p, Metabolizable Energy (ME_p) and NE_{Lp}.

DE_p, Mcal/kg = DE x discount factor
ME_p, Mcal/kg = (1.01 x DE_p – 0.45) + (0.0046 x (EE – 3))
NE_{Lp}, Mcal/kg = (.703 x ME_p – 0.19) + {[(0.097 x ME_p + 0.19)/0.97] x (EE – 3)}

Feed energy values. The NE_L value of feeds in NRC-2001 averages 2% lower at 3X than those found in the previous edition. Feeds decreasing most in energy value were forages and, particularly, low quality forages. High protein feeds generally increased in energy value while most grains (starch sources) have a similar energy value to NRC-1989. The NE_L value change from NRC-1989 to NRC-2001 for some common feed ingredients is shown in Table 1.

Table 1. NE_L values at 3X (DM basis) of some common feed ingredients and change from 1989 to 2001 Dairy NRC.

Feed	1989 edition	2001 edition	% of 1989
Alfalfa hay <40% NDF	0.68	0.62	91.2
Alfalfa hay >46% NDF	0.59	0.51	86.4
Corn silage - average	0.73	0.71	97.3
Barley	0.88	0.84	95.5
Corn grain, ground	0.89	0.91	102.2
Corn, flaked	0.93	0.95	102.2
Corn gluten feed	0.87	0.78	89.7
Hominy	0.91	0.92	101.1
Bakery byproduct	0.94	1.00	106.4
Brewers grains, wet	0.68	0.78	114.7
Cottonseed, lint	1.01	0.88	87.1
Molasses, beet	0.78	0.81	103.8
Wheat midds	0.71	0.76	107.0
Blood meal, ring	0.68	1.06	155.9
Distillers grain/solubles	0.93	0.89	95.7
Soybean meal-44	0.88	0.96	109.1
Soybeans, roasted	0.99	1.23	124.2
Fats			
Calcium soaps		2.28	
Tallow			
Hydrolyzed	2.65	2.45	92.5
Partially hydrogenated		1.35	
Vegetable oils	2.65	2.56	96.6

Carbohydrates. The NRC-2001 acknowledges two equations for calculating NFC. The equation used in energy calculations and the most correct equation for estimating NFC because it does not double count the CP in the NDF fraction is:

(1) NFC, % = 100 – (CP, % + Fat, % + Ash, % + NDF, % + NDFICP, %)

The NFC equation used in providing dietary NFC recommendations (Table 1) is:

(2) NFC, % = 100 – (CP, % + Fat, % + Ash, % + NDF, %)

The NFC values from equation 1 will generally be 2 to 4% higher than from equation 2. Thus, if equation 1 is used to calculate NFC values, the guidelines in Table 1 should be adjusted to reflect the difference.

Recommendations for fiber and nonfiber carbohydrates (NFC) in lactating cow diets are shown in Table 1. The total NDF, NDF from forage and acid detergent fiber (ADF) recommendations, are minimums; whereas, NFC recommendations are maximums. An important relationship among the values in Table 2 is that as forage NDF decreases, total NDF must increase and NFC should decrease. This will reduce the risk of acidosis when low forage diets are fed.

Table 2. Recommended total NDF, forage NDF, ADF, and NFC concentrations in the diets of lactating cows fed total mixed rations[1]

Minimum % of diet DM			Maximum % of diet DM
Forage NDF	Total NDF	ADF	NFC[2]
19	25	17	44
18	27	18	42
17	29	19	40
16	31	20	38
15	33	21	36

[1] Assumes forage particle size is adequate and ground dry corn is starch source.
[2] NFC = 100 – (NDF + CP + Fat + EE). All analyses are % on a DM basis.

Forage particle size and/or effective fiber recommendations are commonly given in the field, but the lack of standard validated measures and published information relating these measures to requirements precluded NRC-2001 from establishing specific recommendations for these parameters in diets. Several research studies have shown that a minimum forage particle length of 3 mm is needed to maintain good rumen pH and adequate rumination activity, and prevent depressions in milk fat percentage (Allen, 1997; Beauchemin et al., 1994; Grant et al., 1990a,b). The Penn State shaker box for particle sizing forages is an excellent field tool, but quantifying screen particle size to chewing activity, rumen health and milk fat percentage is needed.

EVALUATION OF ENERGY – NRC 2001

Did the NRC-2001 achieve the goal of improving the accuracy of energy intake equaling output? Weiss (2001) tested the accuracy of calculating energy intake of lactating cows against energy requirements and utilization using the approach discussed above. Twenty-five research papers from the Journal of Dairy Science were used for the evaluation. The approach used in the NRC-2001 was accurate (Figure 3) with energy intake averaging only 2% more than expenditures.

The model in the NRC-2001 was developed as a tool for users to better understand the dynamics of nutrient requirements, rumen nutrient metabolism and nutrient digestion. It is intended to be an evaluator of diets and not a formulation program. Thus, in most situations, users should have already defined the diet and the characteristics of the animals being fed the diet. The NRC-2001 model is a tool to help nutritionists fine-tune the formulated diet and understand the dynamics associated with nutrient utilization. However, VandeHaar (2002) has evaluated the NRC-2001 from a diet formulation perspective and found some legitimate concerns with the energy system when it is applied to formulation of diets. These were:

- The energy value of protein feeds may be over evaluated. Protein feeds are considered to be about 60% digestible or equivalent to starch digestibility. A more realistic digestibility value is 30 to 40%. The effect of the over estimation is the energy concentration in diets can be increased by feeding higher protein diets.

- The NDF digestibility equation does not consider feed type. Lignin does effect digestibility of the NDF, however, the effect is variable with feed type and with forages the cutting and/or the environment grown in. Wisconsin research has shown for forages the 48 hour in vitro NDF digestibility does not substitute directly for the calculated NDF digestibility value.

- The digestibility discount may be too aggressive with high energy feeds or diets. The more digestible a feed or diet is, the larger is the discount applied. The rationale for this is that as digestibility of the diet increases, the greater the increase in DMI and thus, the faster rate of feed passage through the digestive tract. This assumption is correct when grain is added to diets between about 0.72 and 0.77 Mcal/lb. However, to increase the energy density of diets above 0.78 Mcal/lb, fat is usually the energy source added. At high levels of fat feeding (> 6% of the DM), DMI can be depressed decreasing the rate of passage of feed through the digestive tract. Confounding this problem is fiber length or particle size is not accounted for in the model and this will impact DMI.

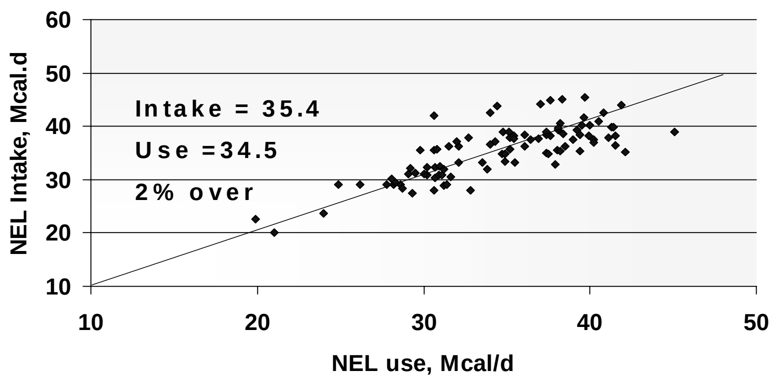

Figure 3. Comparison of NE_L intake and expenditure by lactating cows calculated from NRC-200. (Weiss, 2001)

References

Allen, M.S. 1997. Relationship between fermentation acid production in the rumen and the requirement for physically effective fiber. J. Dairy Sci. 80:1447-1462.

Beauchemin, K.A., B.I. Farr, L.M. Rode, and G.B. Schaalje. 1994. Effects of alfalfa silage chop length and supplementary long hay on chewing and milk production of dairy cows. J. Dairy Sci. 77:1326-1339.

Grant, R.F., V.F. Colenbrander, and D.R. Mertens. 1990a. Milk fat depression in dairy cows: role of particle size of alfalfa hay. J. Dairy Sci. 73:1823-1833.

Grant, R.F., V.F. Colenbrander, and D.R. Mertens. 1990b. Milk fat depression in dairy cows: role of silage particle size. J. Dairy Sci. 73:1823-1833.

National Research Council. 1989. Nutrient Requirements of Dairy Cattle. 6*th* Rev. Ed. National Academy of Sciences, Washington, D.C.

National Research Council. 2001. Nutrient Requirements of Dairy Cattle. 6*th* Rev. Ed. National Academy of Sciences, Washington, D.C.

Rayburn, E.B., and D.G. Fox. 1993. Variation in neutral detergent fiber intake of Holstein cows. J. Dairy Sci. 76:544-554.

Roseler, D.K., D.G. Fox, L.E. Chase, A.N. Pell, and W.C. Stone. 1997. Development and evaluation of equations for the prediction of feed intake for lactating Holstein dairy cows. J. Dairy Sci. 80:681-691.

VandeHaar, M. J. 2002. Energy and protein in the 2001 dairy NRC: Challenges for a ration formulation program. Tri-State (IN, MI, OH) Dairy Nutrition Conf. Fort Wayne, IN. Pages 81-98.

Weiss, W. P., 1998. Estimating the available energy content of feeds for dairy cattle. J. Dairy Sci. 81:830-839.

Weiss, W. P., 2001. Dairy NRC 2001: Energy system. Four-State Applied Nutrition and Management Conf. LaCrosse, WI. Midwest Plan Service–4SD11. Pages 37-42.