OVERVIEW AND APPLICATION OF THE 2001 NRC ENERGY SYSTEM[1]

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Introduction

In 2001, the 7th Revised Edition of the Nutrient Requirements of Dairy Cattle was published (NRC, 2001). A major goal of the subcommittee was to make the energy system used in the new NRC (2001) balanced, i.e., energy supply should equal energy output. Reviews of the 1989 NRC (NRC, 1989) system found that energy intake (concentration of energy in feed times dry matter intake) was 5 to 7% greater than energy expenditures (Vermorel and Coulon, 1998; Weiss, 1998). Because both papers suggested the error was more likely related to energy supply than energy requirements, the NRC (2001) completely changed the approach used to obtain feed energy values. The 2001 NRC also includes updated equations to estimate energy requirements of dairy cattle. This paper will provide an overview of the new NRC energy system and will discuss how these changes might affect diet formulation strategies and diet evaluation. The necessary equations can be found in NRC (2001) and will not be discussed in detail in this paper. Changes were made for all classes of dairy cattle (calves, growing heifers, lactating and dry cows), however, this paper will emphasize lactating cows.

Problems Associated with 1989 NRC Feed Energy Values

Several generations of the Dairy Requirement Series of the NRC used total digestible nutrients (TDN) concentrations of feeds that were measured using sheep (most commonly) or cattle fed at maintenance as the foundation of feed energy values. A simple linear equation was used to convert TDN to net energy for lactation (NEL) concentrations. This approach has many limitations:

1) Feed composition has changed over time because of plant genetics, crop management, and processing methods. Many TDN values were determined decades ago and have not been changed. This means that the nutrient composition of a feed may be disconnected from the energy value. For example, in the Beef publication (NRC, 1996) whole cottonseed has 90% TDN, 17.5% ether extract and 51.6% NDF. In the 1989 NRC, cottonseed has 90% TDN, 20% ether extract, and

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44% NDF. How can two feeds that differ by 2.5 percentage units of ether extract and 8 units of NDF have the same energy value? Clearly this cannot occur.

2) The use of a single energy value for a given feedstuff assumes that every sample of that feedstuff has the same energy value regardless of changes in nutrient composition. Variation in the composition of forages is an accepted fact but the nutrient composition of concentrates also can vary considerably (Belyea et al., 1989; Kertz, 1998). Energy values of feeds should reflect this variability.

3) Intake and diet composition affects digestibility of feedstuffs. The equation used to convert TDN (determined at maintenance intake) to NEL (for cows at productive levels of intake) includes a constant discount of 8% (NRC, 1989). The 8% discount is based on a 4% reduction in digestibility per increment of energy intake above maintenance and an assumed intake of 3 times maintenance. The average Holstein cow in the U.S. currently produces at about 3.5 times maintenance, but significant variation exists among cows and herds. Diet composition also affects digestibility of individual feedstuffs. The best example of this is the negative effect excess grain (starch) has on fiber digestibility. A specific feed could have a different digestibility when fed as part of a high forage diet than when fed as part of a high grain diet. Feed energy values should reflect variability in both intake and diet composition.

The 2001 NRC System for Estimating Feed NEL Values

Feed NEL values are obtained by first estimating digestible energy (DE) concentration of feeds when fed at maintenance intake from feed composition data. A discount factor is calculated using dry matter intake and TDN of the total diet to estimate DE at productive levels of intake. The discounted DE is converted to metabolizable energy (ME) which is then converted to NEL (Figure 1). This approach allows for variation in feed composition, intake, and diet composition. This approach also means that NEL values of feeds will not be constant. The TDN (at maintenance) concentrations of most feeds are calculated using equations based on those of Conrad et al. (1984) and Weiss et al. (1992). The feed composition data needed for these equations are: neutral detergent fiber (NDF), crude protein (CP), ash, lignin, crude fat (or fatty acids), acid detergent insoluble CP (ADICP), and neutral detergent insoluble CP (NDICP). For most feeds, actual values should be used for NDF, CP, ash, and lignin, and table values can be used for fat, ADICP, and NDICP. If a feed has an appreciable concentration of fat (e.g., cottonseeds), a fat analysis is recommended. Concentrations of ADICP and NDICP should be measured in heat-damaged forages and in byproducts with high concentrations of NDF and CP (e.g., brewers grains). The TDN values obtained are only used to calculate the discount factor; TDN is not used to directly calculate other expressions of energy. The same basic equations are used to calculate DE (at maintenance) except that each fraction is multiplied by an appropriate heat of combustion.

Because feed processing can affect digestibility, but not necessarily feed composition, a method was needed to account for processing effects. The subcommittee compiled digestibility data from experiments using only lactating dairy cows. These studies generally compared starch digestibility of different starch sources (e.g. cracked corn vs. steam-flaked corn). Starch digestibility of different feeds relative to the value for ground dry corn was used to develop a Processing Adjustment Factor (PAF). The estimated digestibility of the nonfiber carbohydrate (NFC) fraction is multiplied by the PAF to account for processing effects. Ground dry corn was given a PAF of 1.0. Feeds that had starch digestibility greater than ground dry corn were give PAF values greater than 1 and feed with starch digestibility less than dry ground corn were given values less than 1. The PAF can be altered by users which can change the NEL content of feeds, especially feeds with high concentrations of NFC. Based on a review of the literature a reasonable range for PAF is about 0.8 to 1.1. Values outside this range are extremely unlikely except for whole kernel dry corn. The PAF of feeds in the 2001 NRC are means and in certain situations are not correct. For example, high moisture ground corn (mean DM of 75%) has a PAF of 1.04. Starch digestibility increases as DM content of high moisture corn decreases. If high moisture corn has 70% DM a higher PAF should probably be used (maybe 1.05 or 1.06). Steam-flaked corn (mean density of 33 lbs./bu) has a PAF of 1.04. If the steam-flaked corn has a higher density a lower PAF might be appropriate. Normal corn silage has a PAF of 0.94 but processing usually increases starch digestibility about 5%. Therefore for processed corn silage an appropriate PAF would be 0.98 or 0.99.

The DE at maintenance is calculated based on chemical composition of the feeds and PAF. However, that value is not appropriate when feeds are fed at higher intakes and in mixed diets. The NRC (2001) developed a multiple regression equation based on intake and digestibility of the total diet (diet digestibility is estimated as total diet TDN) to estimate the discount factor. The discount increases as intake and diet digestibility increases (Figure 2). The DE (at maintenance) is multiplied by (1 - Discount) to obtain DE at productive levels of intake.

Feed ME concentrations are calculated from discounted DE concentrations. The NRC (2001) modified the standard DE to ME equation to account for the increased efficiency of fat. The final step in determining feed energy values is to calculate NEL concentrations from ME values. The NRC (2001) modified a previously published equation (Moe et al.,1972) to more accurately estimate NEL of high fat feeds.

2001 NRC Energy Requirements

Maintenance requirements include the energy needed to maintain the cow and allow for normal activity associated with eating, walking short distances, etc. No new data were available suggesting that the1989 method of calculating maintenance energy was incorrect, therefore, no changes were made. Energy expended for activity will be higher for grazing cows than for cows in confinement.

The 1989 NRC stated that maintenance requirement for cattle grazing good pasture should be increased 10% (about 1 Mcal of NEL for a 1350 lb. cow) and up to 20% when cows are grazing sparse pastures. This approach ignores the distance cows must walk to and from the parlor and ignores the topography of the pasture. In the 2001 NRC, an activity allowance was added to the maintenance requirement for cows that are grazing. User inputs include the distance from the paddock to the parlor, the number of one-way trips between the paddock and the parlor, and a qualitative assessment of topography (hilly or flat). Depending on distance and topography grazing activity could increase maintenance requirement by 15 to 50%.

The NEL content of milk represents the amount of gross energy in the milk. The components of milk that contain energy are fat, protein, and lactose; all of which can be measured routinely by most milk testing laboratories. If the concentrations of fat, protein, and lactose are known, the energy value of the milk can be calculated extremely accurately. The NRC (2001) lactation requirement is based on concentrations of milk fat, protein and lactose and their respective heats of combustion. If lactose is not known, assuming a constant lactose concentration (4.8%) does not reduce the accuracy substantially. In the 1989 publication, milk energy was expressed relative to 4% fat-corrected milk (FCM). Protein and lactose concentrations were not explicitly considered (probably because they were not routinely measured at that time). Overall, expressing the lactation requirement on an FCM basis works fairly well because milk fat and protein are positively correlated and lactose concentration is essentially constant. However, when milk fat is depressed because of dietary manipulations, FCM will underestimate the NEL requirement for lactation. The 2001 lactation requirement (per pound of milk produced) will be higher for cows producing depressed fat-test milk and will be higher for breeds that produce high protein milk (e.g., Jerseys).

Energy required for growth and body reserves. In the 1989 NRC, growth requirement for first and second lactation cows was not quantified. The committee simply stated that maintenance requirement should be increased by 20 and 10% for first lactation and second lactation cows. This approach does not make biological sense. A first lactation cow that weighs 1350 lbs. will have a ‘growth’ requirement of 1.9 Mcal NEL/day while a smaller cow (1100 lbs.) that presumably has to grow more than the larger cow will have a growth requirement of 1.7 Mcal/day. Growth models used in the Nutrient Requirements for Beef Cattle (NRC, 1996) were used to estimate growth requirement of lactating cows (first and second lactation).

Changes in body reserves reflect changes in energy balance; they are not the same as growth. In the 1989 NRC, the NEL available for milk and maintenance from 1 lb. of body reserves was 2.2 Mcal. The energy required to restore 1 lb. of body reserves was 2.3 Mcal of NEL. In the 2001 NRC, body condition score (BCS) was incorporated into the system used to calculate energy needed to regain or energy provided by changes in reserves. This approach was taken because body composition (fat and protein) is not constant across different condition scores. A thin cow (BCS 2) has less body fat to mobilize or replenish than a fat cow (BCS 4). On average, a loss of 1 lb. of body reserves from a cow with a BCS of 2 will provide about 1.7 Mcal of NEL compared with 2.5 Mcal for a cow with a BCS of 4. Conversely, a cow with a BCS of 2 will require about 2.0 Mcal of NEL compared with 2.8 Mcal for a cows with a BCS of 4 to gain 1 lb. of body reserves.

In the 1989 NRC, pregnancy requirements were assumed to be 0 until the last 60 days of gestation. During the last 60 days of gestation the pregnancy requirement was approximately 3.2 Mcal/day for an average Holstein cow. The 2001 NRC established a pregnancy requirement starting at 190 days of gestation through 280 days of gestation. Fetal growth increases as gestation progresses and the new requirement is a function of day of gestation and estimated birth weight of the calf. For an average Holstein, pregnancy requirement at 190 day of gestation is about 2.5 Mcal of NEL/day. At 280 days of gestation, the requirement is about 3.7 Mcal of NEL/day.

Bottom Line Differences Between the 1989 and 2001 NRC Systems

Although several modifications were made to the equations used to estimate NEL requirements of lactating cows, total NEL requirements will not differ greatly between the 1989 and 2001 systems for most lactating cows (Table 1). Energy requirements for an average dry cow during the last 60 days of gestation also are essentially equal using the 1989 and 2001 NRC systems, however the NEL requirements of prefresh cows (last 21 days of gestation) will be 0.3 to 0.5 Mcal/day higher with the 2001 than with the 1989 system.

Table 1. Comparison of the 1989 and 2001 NRC daily requirements for NEL.

	Average Holstein cow	Holstein cow with depressed fat test	Average Jersey cow	Grazing Holstein cow[1]
Body weight	1400 lbs	1400 lbs	1100 lbs.	1400 lbs.
Milk yield	80 lbs	80 lbs	55 lbs	80 lbs
Milk fat	3.7%	3.2%	4.7%	3.7%
Milk protein	3.0%	3.0%	3.6%	3.0%
1989 NEL req’t	35.8 Mcal	33.8 Mcal	28.9 Mcal	36.8-37.9 Mcal
2001 NEL req’t	35.9 Mcal	34.3 Mcal	29.4 Mcal	37.1-40.8 Mcal

[1] For the 2001 requirement, the paddock was assumed to be 1000 ft from the milking center and the cow made 4 one-way trips each day. The low requirement assumes flat terrain and the high value assumes hilly terrain.

The concentrations of NEL in feeds and diets, unlike NEL requirements, could differ substantially between the 1989 and 2001 NRC systems. The biggest difference is that NEL concentrations of feeds are *not* constant in the 2001 system; they will vary depending on feed composition, diet composition, and DM intake. A common observation by users of the 2001 NRC model is that replacing forage with starchy feeds (e.g., corn grain) often does not increase the NEL concentration of the diet. This is not a 'bug' in the program, but rather reflects the negative effect of starch on fiber digestion. Increasing the proportion of concentrate in a diet often does not increase digestibility of the diet (i.e., energy content) but usually increases DM intake resulting in increased NEL intake. We conducted a study (Weiss and Shockey, 1991) comparing orchardgrass silage with alfalfa silage fed in diets with 20, 40, or 60% concentrate (the concentrate was mostly corn grain and soybean meal). Digestibility (TDN) was measured using total collection. Although diets differed tremendously in NDF concentration and forage to concentrate ratio, TDN of the diets did not differ. Intake of TDN, however, increased with decreasing dietary NDF concentration and increasing concentrate (Table 2).

Table 2. Effect of decreasing the forage to concentrate ratio on intake and TDN values of diets when fed to lactating dairy cows (Weiss and Shockey, 1991)[1].

			Intake, lbs./day	
Diet	NDF, %	TDN, %	DM	TDN
Alfalfa silage				
+ 20% concentrate	35.4	63.1	46.9	29.5
+ 40% concentrate	30.6	61.7	49.3	30.4
+ 60% concentrate	25.6	63.9	51.0	32.6
Orchardgrass silage				
+ 20% concentrate	45.8	66.2	37.6	24.9
+ 40% concentrate	39.1	65.7	44.7	29.5
+ 60% concentrate	30.9	69.1	47.3	32.7

[1] The forage to concentrate ratio did not affect TDN concentrations but DM and TDN intake increased linearly ($P < 0.05$) with increasing concentrate.

On average, dietary concentrations of NEL will be about 5% lower with the 2001 system, but differences for specific feedstuffs can be much greater (approximate range is -20% to +15%). Some of the differences are caused mainly by the different approach used to calculate feed NEL and some of the differences are caused by changes in feed composition. A comparison of NEL values of some select feeds is shown in Table 3. If an 8% discount is used (same as used in NRC, 1989), the estimated (NRC, 2001) NEL content of mature, low quality forages will be 20 to 25% lower and 10 to 15% higher for oilseed meals than 1989 values. On average, estimated (NRC, 2001) NEL values for high quality hay crop forages and for starchy concentrates will be similar to 1989 values. The NEL concentrations for corn silage and whole cottonseed when calculated from nutrient composition data in the 2001 NRC Feed Composition Table are about 10 and 13% lower, respectively than 1989 values (assuming an 8% discount). Because of the common use and economic importance of these feeds, additional discussion is warranted.

Table 3. Comparison of NEL concentrations (Mcal/lb. of DM) estimated using the 2001 NRC system and 1989 table values. To eliminate effects of dry matter intake, the 2001 values assume an 8% discount (identical to that used in the 1989 NRC).

Feedstuff	NRC, 1989	NRC, 2001[1]	
		1989 Composition	2001 Composition
Orchardgrass, full head	0.55	0.40	0.51
Alfalfa, immature	0.68	0.68	0.63
Alfalfa, midbloom	0.59	0.53	0.58
Corn silage, normal	0.73	0.62	0.66
Corn, ground	0.89	0.94	0.91
Citrus pulp	0.80	0.74	0.80
Wheat middlings	0.71	0.77	0.76
Whole cottonseed	1.01	0.98	0.88
Soybean meal, 44% CP	0.88	0.99	0.97

[1] The column identified as 1989 Composition used the 2001 NRC equations with the nutrient composition data from the 1989 NRC feed composition table. The column identified as 2001 Composition used the 2001 NRC equations and feed composition data from the 2001 feed composition table.

Corn Silage. The NEL concentration of 'well-eared' corn silage in the 1989 NRC was 0.73 Mcal/lb. From my personal experience, NEL values for corn silage as estimated by feed laboratories (usually estimated using ADF-based equations) are often 0.73 to 0.77 Mcal/lb. Based on production data and limited NEL measurements (not estimated) these values seem illogically high. An early study by the USDA (Tyrrell and Moe, 1972) fed lactating cows a diet with 70% corn silage, 16% ground corn, 13% soybean meal, and 1% minerals and the measured (using calorimetry) NEL concentration of the diet was 0.75 Mcal/lb. If the NEL value of the corn silage is assumed to be 0.73 Mcal/lb (NRC, 1989), then the NEL value of the concentrate (53% corn meal, 44% soybean meal, and 3% mineral) would be 0.81 Mcal/lb. or only about 11% higher than that of the corn silage. These data raise the question, does a feedstuff consisting of 40 to 50% high moisture corn and 50 to 60% very mature grass (i.e., corn stover) have only about 11% less energy than a mixture of corn meal and soybean meal?

A more recent experiment clearly shows that the NEL value of corn silage is less than the 1989 value. Tine et al. (2001) fed all corn silage (either a conventional hybrid or a brown midrib hybrid) diets to dry cows and a diet with 60% corn silage (same hybrids as fed to dry cows), 18% soybean meal, 13% corn meal, 5% expellers soybean meal, 1% Megalac, and 3% minerals to lactating dairy cows and measured NEL concentrations. The dry cows were fed at maintenance (14 lbs. of DM/day) and lactating cows were fed ad libitum (50 and 55 lbs. of DM/day for the conventional and brown midrib hybrids, respectively). The NEL concentration of the corn silages when fed to dry cows was 0.67 Mcal/lb (no difference between hybrids). The NEL concentrations of the total diets when fed to lactating cows was 0.73 Mcal/lb (no difference between treatments). The measured NEL of a diet with 60% corn silage and 40% concentrate was approximately equal to the NEL concentration often used for corn silage. When feed composition, diet composition, and intake data from that study were entered into the 2001 NRC model, estimated NEL concentrations of the corn silages when fed to dry cows was 0.71 Mcal/lb, and estimated NEL concentrations of the mixed diet was 0.73 Mcal/lb. These data support the lower NEL value given to corn silage in the 2001 NRC.

Whole Cottonseed. The NEL concentration of whole cottonseed given in the feed composition table of the 2001 NRC is 0.88 Mcal/lb. (assuming an 8% discount) which is substantially lower than the value in the 1989 NRC (1.01 Mcal/lb). Most of this difference simply reflects changes in the nutrient content of whole cottonseed. The whole cottonseed in the 2001 Table has an average fat concentration of 19% (compared to 20% in 1989) and an average NDF concentration of 50% (compared to 44% in 1989). The composition of whole cottonseed can vary and certain lots will contain more fat and less NDF than the average values in the table resulting in higher NEL concentrations. Furthermore, because of the method used to calculate the discount factor, in certain diets cottonseed could have appreciably more NEL than the table value. For example, when cottonseed replaced a portion of ground corn in a diet with an acceptable concentration of forage and NDF, no difference in milk production was observed (Adams et al., 1995) and when data from that experiment were entered into the 2001 NRC model, estimated NEL concentration of the total diets were the same (0.75 Mcal/lb.) suggesting that in that diet ground corn and whole cottonseed had similar NEL concentrations. In a diet with excessive concentrate (low NDF diet), replacing a substantial amount of rolled barley with cottonseed increased milk production (Smith and Vosloo, 1994) and estimated (NRC, 2001) NEL concentrations of the total diet were increased with cottonseed (0.73 vs. 0.78 Mcal/lb.). This suggests that in certain diets (and at certain intakes) whole cottonseed and ground corn have similar NEL values but in other diets, whole cottonseed may have substantially more NEL than corn. This also clearly shows that using table values to compare NEL values of feeds is inappropriate. One should compare NEL values of a feed in specific diets at specific DM intakes.

How Should the 2001 NRC Energy System be Used in Ration Formulation

The obvious question by users of the 2001 NRC is: Since NEL values of feeds are not known until I formulate a diet, how can I balance diets for NEL? The answer is simply, diets should not be explicitly balanced for NEL. Rather NEL balance (not NEL concentration) should be used to *evaluate*, not formulate, diets. When using the 2001 NRC model, a user inputs cow information (body weight, milk production, etc.), feed composition data, diet composition (i.e., ingredient make up of the diet), and dry matter intake (the model will also estimate intake if intake is not known). After data entry, the user should evaluate the diet. Pertinent data regarding energy is found in the ‘Summary Report’ and the ‘Energy and Protein Supply’ report. The Energy and Protein Supply report contains estimated NEL values for each feed. In the Summary Report, the following results should be evaluated:

- NEL balance (Mcal/day)
- NEL allowable milk (lbs./day)
- Days to change one condition score
- Daily weight change due to reserves

The most important result is NEL balance. This number is calculated as the difference between total NEL requirement (maintenance, lactation, growth, and pregnancy) and NEL intake. A positive value means that cows are consuming more NEL than required and should be gaining body condition and weight. A negative value means that NEL intake is less than requirement and cows will lose body condition and weight. Depending on the stage of lactation a positive or negative value can be acceptable. In early lactation, all mammals are programmed to lose body fat in support of lactation. Therefore cows in early lactation (approximately the first 2 months of lactation) should be expected to be in negative energy balance. A reasonable NEL balance for the first 2 months (averaged over the entire period) for a Holstein cow is about -3 Mcal/day (NEL balance will be more negative the first few weeks of lactation and should be approaching 0 by the eighth week of lactation). During the third and perhaps fourth month of lactation, NEL balance should be approximately 0 and during the last 6 months of lactation NEL balance should be about +1 Mcal/day. Over the entire lactation NEL balance should be about 0 assuming cows started the lactation in good body condition. If a formulated diet does not meet these guidelines, changes may be necessary. For example, if NEL balance is too negative in early lactation, the diet should be changed to either stimulate intake (usually the better option) or increase the energy density of the diet (this if often quite difficult). If NEL balance is too high in late lactation, energy density of the diet should be reduced.

The quantity of NEL allowable milk is calculated directly from NEL balance. If NEL balance is 0 then NEL allowable milk equals actual milk. When NEL balance is negative NEL allowable milk will be less than actual milk and when NEL balance is positive NEL allowable milk will be greater than actual milk. In early lactation, NEL allowable milk should be less than actual milk.

Days to change one condition unit and daily weight change are also calculated directly from NEL balance. Days to change one condition unit is useful in evaluating NEL balance. A general recommendation is that cows not lose more than 1 (ideally not more than 0.5) body condition score unit (1 to 5 scale) during early lactation (first 60 days). If the situation you are evaluating results in a more rapid lose of body condition modifications are needed. If days to gain one condition score for cows past peak milk production suggests that cows might be too fat at the end of lactation, dietary modifications might be needed for that group.

Summary

The 2001 NRC energy system is substantially different from the 1989 system. Some of the equations used to estimate NEL requirements were changed to account for more sources of variation, but for a typical cow, total NEL requirements will not be greatly different from the 1989 system. The approach to calculate NEL supply, however, is completely different. Previously, NEL values were determined from fixed (i.e., table) TDN concentrations. The new system calculates NEL based on user entered feed composition, diet composition, and DM intake. The NEL content of feeds and diets will not be constant. As DM intake increases, NEL concentrations will decrease and as the proportion of grain in a diet increases, the NEL concentration of a diet will increase at a decreasing rate. The 1989 system overestimated the NEL content of feeds, but the new NEL system appears to accurately estimate NEL balance for lactating cows fed a variety of diets. The new system should be useful in evaluating the effects of a diet on future energy status of cows (i.e., changes in body condition).

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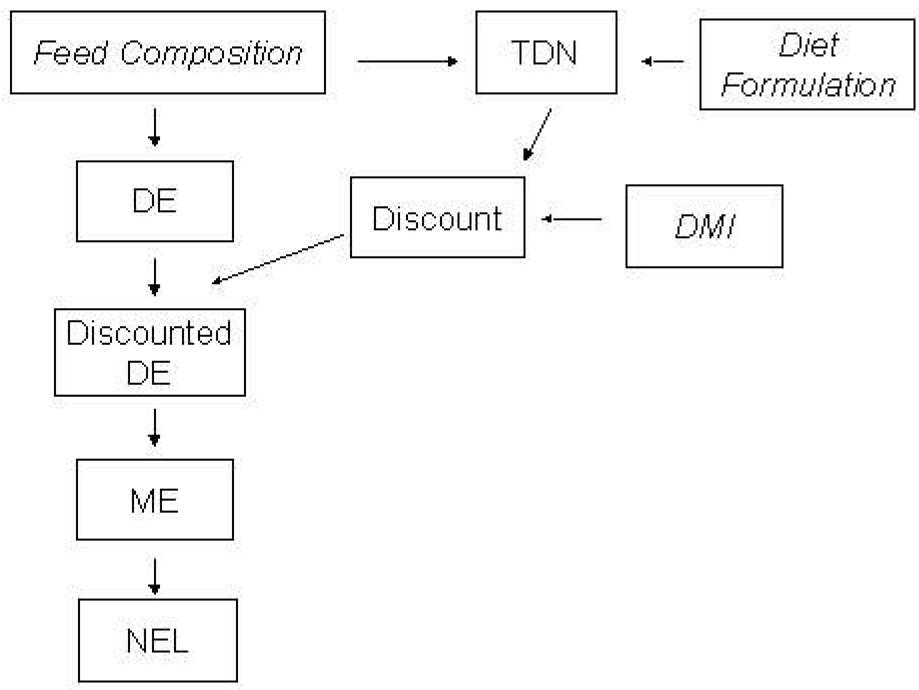

Figure 1. Overview of the method (NRC, 2001) used to calculate NEL in feeds. Terms in italics are entered by the user, all other values are calculated using NRC software. The 'TDN' value is the TDN (at maintenance) of the entire diet and DMI = dry matter intake.

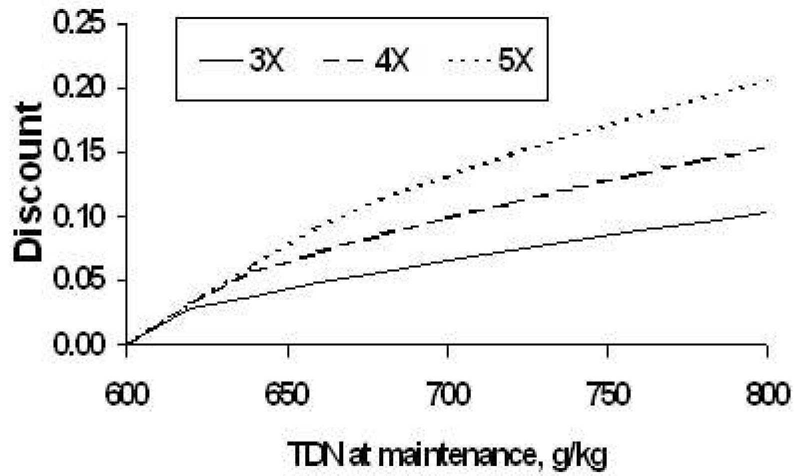

Figure 2. Discount factor calculated using the 2001 NRC. Feed DE values estimated at maintenance are multiplied by (1 - Discount) to estimate DE values at energy intakes of 3, 4, and 5 times maintenance energy intake.