Feed Energy Applications[a]

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Introduction

A feed energy system has two main purposes: ration formulation and economic valuation of feedstuffs. For ration formulation, energy requirements for maintenance, pregnancy, milk production, and growth are estimated, feedstuffs are given energy values, and then linear programming is used to find the combination of feedstuffs that meet the energy requirement within a set of constraints. The logic behind balancing diets for energy is to provide a diet that has adequate energy for milk production while maintaining desirable body condition. Within a local market, nutritionists have dozens of different feedstuffs available to be included in diets. Usually one feed is chosen over another because it provides a nutrient or nutrients at a lower cost. Because energy is a primary nutrient for cows, the energy concentration of a feed has a major impact on its economic value. If a feed can be assigned an accurate energy concentration and if we know the value of a unit of energy, then economically wise decisions regarding feed choices can be made.

The most widespread energy system used for both these purposes is the net energy for lactation (**NEL**) system. On a theoretical basis the NEL system is far superior to other energy systems such as TDN. However, the current NEL system (and any other energy system) has serious flaws that should limit it value, especially in ration formulation. We need to continue develop and eventually adopt better methods for ration formulation but until such methods are available we need to make the current NEL system as accurate as possible. The purposes of this paper are to: 1) review the basics of the NEL system including its limitations, and 2) discuss adjustments in the current system that should make it more accurate.

Review of the NEL System

The underlying basis of the NEL system is the first law of thermodynamics and all things, including cows, must obey that law. In terms relevant to animal nutrition, the first law of thermodynamics can be stated as: Energy input must equal energy output plus or minus any change in body energy. If we can accurately estimate the NEL of a diet and NEL requirements, then energy balance can be calculated and we can project changes in body energy reserves (i.e., body condition). The health and long term productivity of a cow depends on proper management of body condition. The average energy flow calculated from many different diets is shown in Figure 1. On average about one-third of the energy consumed is lost via feces, about one-fourth is lost via heat and only about one-third of the energy consumed is converted to NEL. In comparison, a gasoline-powered car converts about 15% of the chemical energy in gasoline to mechanical energy.

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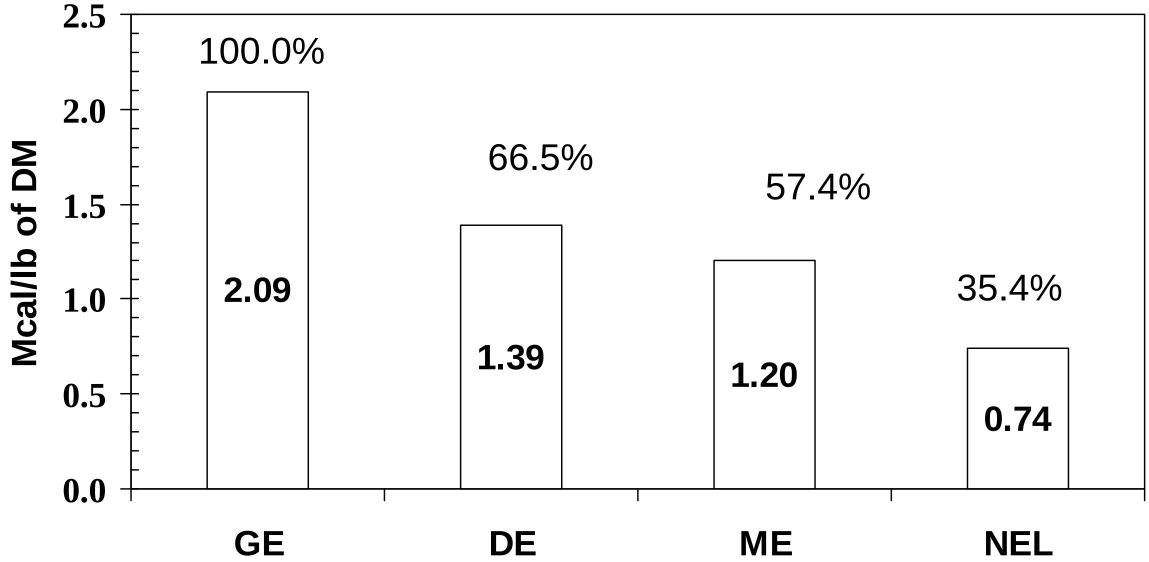

Figure 1. Average energy concentrations of mixed diets fed to dairy cows. Data derived from USDA Beltsville energy lab.

Gross energy (GE) is the total amount of chemical energy in the diet (Mcal/lb of diet dry matter) and is measured by completely burning a sample in a bomb calorimeter. This measurement is easy, precise, and accurate. The concentration of GE depends solely on the chemical composition. Ash, carbohydrate, fat, organic acids, and protein have different energy values per unit of mass and as the concentrations of these fractions change, GE changes. High protein and high fat feeds will have more GE than high carbohydrate feeds and feeds with high ash will have less energy than lower ash feeds.

Digestible energy (DE) is the energy remaining in the diet after fecal energy is subtracted. Because measurement of DE requires measurement of fecal output it is less accurate and less precise than measuring GE and can only be measured by feeding animals. The DE is a function of GE and all factors (animal and feed) that affect digestibility. The digestibility of the carbohydrate fraction of diets is extremely variable and has a substantial impact on GE. Dry matter intake is the major cow factor that influences energy digestibility; the marginal efficiency of digestion decreases as dry matter intake increases.

Metabolizable energy (ME) is the energy remaining after urinary and gaseous energy arising from fermentation (essentially methane) is subtracted from DE. Collection of urine, bomb calorimetry of urine, and measuring methane is difficult and prone to errors plus measurement of ME includes all the errors associated with measuring DE; therefore ME is less accurate and less precise than DE. Dietary fiber increases methane production in the rumen and high protein increases synthesis of urea both of which reduce the efficiency of converting DE to ME. High starch diets and ionophores such as monensin reduce methane production and increase the efficiency of converting DE to ME.

Net energy for lactation is the energy consumed by a cow that actually does something; it is the energy secreted in milk, retained in the body (fat, growth, fetus), and used to perform maintenance functions such as pumping blood. It is calculated as ME minus the heat generated by the inefficiency of transforming energy from one form to another (i.e., the heat increment). Heat increment cannot be measured directly; it is calculated from total heat production measured using a whole animal calorimeter. Because these instruments are extremely expensive and only a few are available in the entire world, measured NEL data are extremely limited. Type of carbohydrate and concentrations of dietary fat and protein affect the efficiency of converting ME to NEL. As fiber and protein increase, the efficiency of converting ME to NE usually decreases and as fat and starch increase, efficiency increases. Measurement of NEL is the least accurate and precise measure of energy because it includes all errors associated with measuring GE, DE, and ME plus the errors associated with measuring heat increment.

Why we Should Stop Using the NEL System

The NEL system (as all current energy systems) has two serious problems. First, cows do not really have an energy requirement, they have requirements for ATP and the substrates that produce ATP. Energy was something we could measure and therefore energy systems were developed as proxies to the requirements for ATP-generating compounds. The second problem with the NEL system is that feeds do not have NEL, diets have NEL. We assign feeds NEL concentrations so that we can use linear programming to formulate diets. This approach assumes nutrients from different feedstuffs are additive (i.e., the ingredient and nutrient composition of the final diet has no effect on the nutrient value of the individual ingredients). The metabolizable protein (MP) concept is the best example of non-additivity Urea is an excellent source of MP when added to a diet deficient in rumen degradable protein (RDP), but if urea was added to a diet with excess RDP it would contribute no MP. With the MP system, feeds are not given MP values, only the diet has an MP concentration. Similar to MP, NEL should be considered non-additive and only diets, not ingredients, should have an NEL value. Although difficult and expensive, we can measure NEL concentrations of diets. We cannot measure the NEL of individual feedstuffs within a diet, therefore, it is not possible to determine whether the value used for a feed is correct. However, because with most ration balancing software, the only way a nutritionist can change the energy value of the diet is to adjust the NEL values of individual feeds. This paper will present approaches to fine-tune NEL values of selected feeds. However the reader must remember that individual feed ingredients do not have NEL values. As our knowledge base, computing capacity, and analytical abilities increase, practical nutritional models will be developed that do not include energy.

Living with What We Have: The Application of NEL System

Although the NEL system has flaws, it still have useful applications for feeding cows as the following example illustrates. A dairy farmer has a group of 100 Holstein cows. Actual body weights (BW) are not known but you estimate the average BW is about 1400 lbs (636 kg). The farm has the ability to measure milk weights and the average milk yield for that group is 75 lbs and milk from that pen averages 3.7% fat and 3.0% protein. The group averages about 150 days in milk (most cows are pregnant but at least 100 days from calving). Feed delivered to the pen and feed refusal is measured and average dry matter intake is 50 lbs. Knowing that you should not balance for the average cow, you formulate a diet that will support 90 lbs of milk (20% more milk than the current average).

The daily NEL requirements (NRC, 2001) for the average cow are:

Maintenance: $636^{0.75}$ x 0.08 = 10.1 Mcal/day
Lactation: 75 lbs x 0.32 Mcal/lb = 24.0 Mcal/day
Total NEL use = 34.1 Mcal/day

The diet was formulated to contain 0.77 Mcal NEL/lb because that will support 90 lbs of milk without any change in body condition at an intake of 50 lbs.

NEL intake = 50 lbs x 0.77 = 38.5 Mcal/d
NEL balance = NEL intake - Maintenance - Milk energy = 38.5 - 10.1 - 24.0 = 4.4 Mcal/d

Cows in this example have an average daily surplus of 4.4 Mcal of NEL which should result in a daily increase in body energy reserves equal to 1.9 lbs of BW. Therefore, if the NEL system is accurate, cows in that group will on average produce 75 lbs of milk per day and gain approximately 1.9 lbs of BW and if cows continue to consume this diet for 110 days, body condition score will increase by an average of 1unit. To project body condition changes, you must compare NEL intake to actual NEL expenditures (i.e., use actual mean milk production, not the target milk production).

Now comes the part that requires a good nutritionist rather than just a computer. You must evaluate estimated energy balance by asking: Is the value reasonable? Is it reasonable to expect a group of cows to produce an average of 75 lbs of milk **AND** gain an average of almost 2 lbs of BW per day with a feed intake of 50 lbs? The probable consensus among nutritionists is that it is unlikely and therefore not reasonable. The focus of this paper is to discuss adjustments that a nutritionist may have to make to obtain reasonable projected energy balances. Measuring dietary concentrations of NEL is extremely difficult and measuring some NEL requirements is problematic. A good nutritionist should not hesitate to make appropriate adjustments to either feed NEL values or requirements based on apparent energy balance and experience.

Errors in Calculated Energy Balance Because of Incorrect Maintenance Requirement

The past several versions of NRC has calculated maintenance requirement (Mcal NEL/day) as: 0.08 $BW^{0.75}$ where BW is in kilograms. That equation was derived from calorimetry data mainly from USDA, but because maintenance requirements cannot be directly measured, the accuracy of that equation is subject to debate. An analysis of calculated energy balances (Ellis et al., 2006) suggested that the average maintenance requirement should be calculated as $0.096*BW^{0.75}$ (equivalent to a 20% increase of the NRC equation) and that maintenance changed from about $0.08*BW^{0.75}$ at calving to $0.098*BW^{0.75}$ at 15 weeks of lactation. The problem with that paper is that all the difference between estimated energy balance and BW change was assumed to be caused by an error in the maintenance requirement. Feed NEL concentrations were not measured and changes in BW in early lactation may not reflect change in body energy. Although an error of the magnitude (i.e., 20%) suggested Ellis et al. is unlikely, the NRC equation may underestimate maintenance expenditure in many situations. With large pens and 3X milking, the distance some cows walk can be substantial and the NEL used for activity (included in the maintenance requirement) is probably underestimated. A typical Holstein cow needs about 0.1 Mcal of NEL to walk 1000 ft on flat surfaces so even with large pens, long distances between the pen and milking parlor, and 3X milking, a 3 to 5% increase in maintenance requirement will probably cover the NEL used for increased walking.

Errors in Estimating Gross Energy of Feeds

The nutrient fractions that have the greatest impact on GE concentrations are ash, crude protein (CP), carbohydrate, and fat. The ‘carbohydrate’ fraction as defined by NRC contains NDF, starch, simple sugars, organic acids, and several minor compounds. The GE concentration of starch and NDF are similar but simple sugars such as sucrose have about 10% less GE per pound than starch. This means that the NRC system will overestimate GE of feeds that contain substantial amounts of simple sugars (e.g., molasses). The predominant organic acids found in well-fermented silage have about 15% less GE than does starch which means that silage will have less GE than the value estimated by NRC. The NRC value for GE of CP is a reasonable estimate for plant-based feeds that contain predominantly true protein. A large proportion of the CP in silage can be nonprotein N which generally has a lower GE concentration than protein, therefore GE of silage CP is overestimated by the NRC system. The GE value for long chain fatty acids used by NRC is a reasonable average, but GE/lb increases as fatty acid chain length increases and saturated fatty acids have slightly more GE per pound than unsaturated fatty acids. Although several factors affect GE that are not considered in the NRC model, in practice most of these factors will not greatly affect the end results. The GE concentration of silage is probably overestimated by 1 or 2%. For feeds with a high concentration of simple sugars, GE may overestimated by about 6%, but those feeds generally make up a small proportion of the diet and the overall effect on diet NEL would be small.

Error is Estimating Digestibility

Energy digestibility (86 treatment means) of mixed diets fed to lactating cows varied from 60 to 78% (mean = 68%) and DE concentrations varied from 1.28 to 1.54 Mcal/lb. (mean = 1.38 Mcal/lb) (Wilkerson et al., 1997). Although the variation in energy digestibility and DE concentrations are much less among diets than among feedstuffs, the variation is still substantial and important sources of variation must be identified and modeled. For the purpose of estimating energy values, feeds can be broken down into five major nutrient fractions (CP, fatty acids, NDF, starch, and the non-starch portion of NFC). Of the common nutrient fractions, digestibility of NDF is most variable, but digestibility of starch can also vary substantially. For a wide range of diets, total tract NDF digestibility measured in lactating dairy cows ranged from 29 to 64% with an average of 46% (Wilkerson et al., 1997). Firkins et al. (2001) reported a range in total tract starch digestibility in lactating dairy cows of 70 to 99% (average = 91%). Because starch and NDF comprises 50 to 60% of diet DM for typical diets, variation in digestibility of those fractions has a large impact on the DE concentration in the diet.

The other fractions make up a relatively small portion of the diet or digestibility is less variable. The non-starch portion of NFC is a heterogeneous mixture of mostly simple sugars, organic acids, and neutral detergent soluble fiber all with expected high digestibility (approximately 100%). The digestibility of CP is variable but the equations used by NRC (based on acid detergent insoluble CP) appear to account for most of the variation. The NRC assumes that digestibility of fatty acids is constant except for fat supplements. This probably is not true and better models of fat metabolism are being developed. The most important fine-tuning that should be done regarding the energy contribution of fat is to use accurate fatty acid concentration data. Feeds that contain appreciable concentrations of fatty acids should be assayed for fatty acids. The NRC has averages of measured digestibilities for several common fat supplements and the use of these values gave good estimates of measured diet DE (Weiss and Wyatt, 2004). If the NRC does not contain a digestibility value for a specific fat supplement, users should request the information from the manufacturer of the supplement. Because fat supplements are only fed to provide NEL, I would not use a product if fatty acid digestibility (measured in lactating dairy cows) data were not available.

Corn Grain

Diets for lactating cows typically contain between about 20 and 35% starch (dry basis) and total tract starch digestibility ranges from about 70% to 100% with a mean of 91% (Firkins et al., 2001) Assuming an average dietary starch concentration of 28%, a range in starch digestibility equal to the mean (91%) plus or minus two standard deviations (7%) would cause DE concentrations of diets to vary by $\pm$ 0.07 Mcal/lb from the DE value calculated using average starch digestibility. Varying NFC digestibility using the Processing Adjustment Factor (PAF) in the NRC model will only change discounted DE concentrations by about $\pm$ 2%. Clearly the NRC model does not account for all the variation in high starch feeds.

Dry Grinding of Corn. Total tract digestibility of starch is higher when cows are fed 'ground' corn compared with 'cracked' corn (Firkins et al., 2001). Because particle size of the corn was not reported in most studies, a quantitative relationship between particle size of corn and digestibility cannot be derived at this time. Based on differences in digestibility, measured dietary NEL, and milk yields, diets with ground dry corn have 1 to 3% more NEL than do diets with cracked corn but the NRC model only estimates a difference of about 1%. *Proposed adjustment* : Reduce NEL-3X (i.e., NEL concentration calculated using NRC (2001) equations assuming an 8% discount factor) value for cracked corn by 2.5% and increase NEL-3X value for ground corn by 2.5%. These values were derived by assuming diets with cracked corn have 2% less NEL than diets with ground corn and corn comprised 30% of the diet.

High Moisture Corn. Based on digestibility, measured NEL and production data, diets with high moisture corn have 4 to 6% more NEL than diets with dry corn, but the NRC model estimates about a 1% difference. The effect of moisture concentration of high moisture corn on digestibility in lactating cows is lacking but in vitro digestibility of starch is usually higher for wetter corn; however this does not mean that extremely wet corn is more digestible than normal high moisture corn. *Proposed adjustment*: Increase NEL-3X value of high moisture corn by 10%. This value was derived by assuming that diets with high moisture corn have 4% more NEL than diets with dry ground corn and that corn comprised 30% of the diet. As the DM concentration of high moisture corn increases above 75%, a smaller adjustment would presumably be appropriate.

Steam-flaked corn. Most data with dairy cows suggests that diets with steam-flaked corn have 1 to 2% more NEL than diets with dry corn but NRC estimates the difference at about 0.5%. As flake density increases above 28 to 30 lbs/bushel, steam-flaked corn becomes more similar to ground corn and steam-rolled corn (38 lbs/bus) was essentially equal to dry ground corn (Firkins et al., 2001). Extremely low density flakes may have detrimental effects on ruminal digestion and may result in lower, not higher, dietary NEL values. *Proposed adjustment*: For steam-flaked corn with a density of approximately 29 lbs/bu, NEL-3X values should be increased by 3 or 4%. This value was derived by assuming that diets with steam-flaked corn have 1.5% more NEL than diets with dry ground corn and that corn comprised 30% of the diet. As density increases, the adjustment will be less.

Starch Chemistry. Corn starch can be branched (amylopectin) or linear chains (amylose) of glucose. Corn grain with mostly amylopectin is less dense (more floury or lower vitreousness) than corn with a high proportion of amylose (more flinty or higher vitreousness). Across corn hybrids, the structure of starch is a continuum ranging from very floury to very flinty with average dent corn being intermediate. In situ and in vitro studies have shown that vitreousness has a strong inverse relationship with ruminal starch digestibility (Correa et al., 2002) but data from experiments with lactating dairy cows is limited. Density of whole kernels is positively correlated with vitreousness (Correa et al., 2002) suggesting that density might have value in fine-tuning NEL values of different types of corn hybrids. More data with lactating cows are necessary before the effect of starch chemistry on starch digestibility can be quantified but flinty corn probably has less NEL than floury corn.

Corn Silage

Corn silage contains appreciable concentrations of both starch and NDF and variation in digestibility of either fraction can have a substantial affect on its energy value. Although highly variable, the average starch concentration for corn silage is about 30% and NDF averages about 45%. The digestibility of starch and NDF provided by corn silage cannot be directly measured in lactating dairy cows fed mixed diets because diets contain other sources of starch and NDF. However digestibility of total dietary starch by lactating dairy cows ranged from about 88 to 98% when corn silage provided 20 to 65% of the dietary starch (Bal et al., 1997; Johnson et al., 2003; Weiss and Wyatt, 2000) which is within the range of starch digestibilities when most of the starch comes from corn grain. Digestibility of dietary NDF by lactating dairy cows fed mixed diets when corn silage was the sole forage range from 46 to 55%.

Maturity Effects. The DM concentration of corn silage is positively correlated with maturity (drier plants tend to be more mature). Data from three different experiments (Bal et al., 1997; Johnson et al., 2003) were compiled to derive an equation to adjust energy values of corn silage based on DM. If the change in dietary DE concentration is assumed to be caused entirely by the corn silage, DE concentration of the corn silage decreases 0.01 Mcal/lb of DM per every 1 percentage unit increase in DM concentration. Assuming an average efficiency of converting DE to NEL of 0.54, the NEL of corn silage decreases 0.005 Mcal/lb for every 1 percentage unit increase in DM concentration above 28%. Although the only variable included in the regression was DM, the nutrient composition of silage change as plant mature (e.g., lignin as a percent of NDF tends to increase). The difference in NEL between a corn silage with 35% DM and 45% DM (i.e., 10 x 0.005 = 0.05 Mcal NEL/lb.) was the same as that estimated by NRC between average normal (35% DM) and average mature (44% DM) corn silage suggesting that, the NRC model accounts for the affect of corn silage maturity. The affect of plant maturity on NEL of corn silage is dependent on hybrid. For a hybrid in which the vitreousness of the grain did not change appreciably with maturity, DE concentrations did not change appreciably but a hybrid in which vitreousness increased with maturity, DE concentrations decreased with maturity (Johnson et al., 2003). This suggests that more accurate estimates of energy from corn silage will require information regarding vitreousness. *Proposed adjustment:* Analyze the silage for standard nutrients and calculate NEL-3X. For silages with DM concentrations equal or less than 28%, set PAF at 1.00 and for every 2 unit increase in DM concentration decrease PAF by 0.015 units.

Hybrid Effects. Corn silage hybrids have been developed to have high NDF digestibility, different concentrations of nutrients (e.g., starch, NDF and fatty acids), and different physical characteristics of starch. These differences should lead to differences in NEL; however, reported differences in DE, digestible organic matter, TDN, or NEL concentrations between diets with different corn silage hybrids have been remarkably modest (from several experiments published in the Journal of Dairy Science). For example, the measured NEL concentration of a diet based on brown midrib (bmr) corn silage was the same as that for a diet based on its isogenic control when fed at ad libitum intake (Tine et al., 2001). Interactions have been found between hybrid and kernel processing, hybrid and maturity, and hybrid and diet formulation for dietary energy values. At the current time we do not have adequate data to quantify the effects of these interactions based on measurable inputs.

Kernel Processing. On average kernel processing of corn silage has little effect on energy values (e.g., DE, TDN, DM digestibility) of diets when fed to lactating cows (Bal et al., 2000; Johnson et al., 2003; Johnson et al., 2002; Schwab et al., 2002; Weiss and Wyatt, 2000). An interaction between processing and corn silage maturity has been reported (Johnson et al., 2002). In that study, diets with processed immature corn silage tended to have less DE than diets with unprocessed corn silage but processing tended to increase dietary DE with mature corn silage. *Proposed adjustment*: Inadequate data are available to determine whether kernel processing consistently reduces the energy value of immature corn but no data are available showing a benefit. More data are available showing that kernel processing usually increases the energy value of more mature corn silage (>two-thirds milk line). To obtain accurate estimates of NEL, use actual composition data, and then increase the NEL-3X of mature corn silage by 7.5% when processed. This was derived by assuming processing increased DE concentrations by 3% and that corn silage comprised 40% of the diet. Corn silage from different hybrids probably responds differently to processing but those changes cannot be quantified at this time.

Use of In Vitro NDF Digestibility to Estimate NEL

The NRC system estimates NDF digestibility using lignin but allows users to enter in vitro NDF digestibility (IVNDFD). Brown midrib corn silage generally has higher IVNDFD than its isogenic control, however when fed to lactating dairy cows as a component of a mixed diet in vivo NDF digestibility has not been consistently higher, and a diet with bmr corn silage had the same measured NEL as a diet with the isogenic hybrid when fed to lactating cows at ad libitum intakes (Tine et al., 2001). Intake of NEL was significantly increased when bmr was fed, but energy concentration was not affected by hybrid. Beckman and Weiss (2005) found that using in situ or in vitro NDF digestibility (both 30 h) to estimate dietary DE was less accurate than using the lignin-based NRC equation in corn silage based diets that included different concentrations of soyhulls and cottonseed hulls. Although the data base is extremely limited, available in vivo data with lactating cows fed mixed diets do not support the use of IVNDFD to estimate in vivo NDF digestibility or NEL concentrations of feeds but it can be used to estimate NEL intake (higher IVNDFD = higher DMI).

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Additional Author Notes for Slides (Weiss)

The slide number is in lower right corner of each slide, if there are no notes for a slide it is because the slide should be self-explanatory.

Slide 2. The 3 primary uses of assigning a NEL (energy) value to individual feeds are shown in this slide. As you will see, they are not necessarily valid

Slide 3. The values obtained in this table is via a least squares method (See J. Dairy Sci. 83:1402 for details). The prices shown are valid only for Ohio and only at the time when the analysis was done. The actual values depend on local markets and may differ substantially from what is shown. This is for demonstration only.

Slide 4. Based on feed prices when this analysis was conducted, 85% of the price of corn grain was because of its supply of energy and 65% of the value of soybean meal (48% CP) is because of its NEL concentration. Actual percentages will vary depending on local markets.

Slide 5. This just shows the way most software and nutritionists balance diets.

Slide 6. This is to emphasize that NEL is the only expression of energy that allows full accounting of energy losses and therefore can be used to estimate changes in body energy reserves.

Slide 7. Classic energy scheme. FHP = fasting heat production (essentially the same as maintenance).

Slide 8. Average concentrations of gross (GE), digestible (DE), metabolizable (ME) and net energy (NEL) of DIETS fed to lactating cows from numerous studies conducted at USDA. The blue number is as % of GE. For example, 57.3% of GE on average is converted to ME. The numbers in black are as % of preceding energy value. For example 61.8% of ME on average is converted to NEL. The black words/numbers represent variation. In our data base (not USDA), about 67% of the variation observed in DE is caused by diets, 33% is cow to cow and error (cannot separate cow effects from error). From USDA data, about 40% of the variation in diet NEL concentrations is caused by diet and 60% is cow to cow and error.

Slide 9. This slide explains why giving a diet ingredient is wrong. NEL are not additive. Therefore adding up the NEL provided by each feed in a diet is wrong.

Slide 10. Data from a paper (Anim Feed Sci Tech 126:43) in which NEL of DIETS were measured using respiration chambers compared to NEL calculated from feed tables. For some diets, the error was huge (i.e., 18% different) for other diets, it was not too bad. This means either the table values were not very good or when you put feeds together you get different NEL.

Slide 11. Data from a study of brown midrib corn (BMR) or its isogenetic control (Iso). The NEL of the corn silage was measured by feeding dry cows a diet made of only silage (at maintenance). BMR had higher NEL. When diets were formulated, the silage made up 60% of the diet (the only difference was hybrid, the rest of the diet was identical), you would expect diet NEL to reflect difference in NEL of silage. What was observed was that when the diets were fed to lactating cows, no difference was observed in measured DIET NEL concentrations. Paper published in J. Dairy Sci 84: 885.

Slide 16. This slide is based on a large data set from our lab. It shows variation in gross energy of common feedstuffs (from US). Feeds vary greatly in their GE concentration. However, when put into typical diets (N = 90 different diets), GE concentrations are not very variable. Overall, at the diet level, GE is not a major source of variation.

Slide 17. Feed factors that affect digestibility.

Slide 18. DMI and rumen conditions affect digestibility. The feedstuffs, diet and cow interact to actually determine DMI and rumen conditions.

Slide 19. Although source of energy (e.g., fat vs protein vs carbohydrate) greatly affect energetic efficiency (i.e, conversion of ME to NE) because DIETS do not differ greatly in concentrations of starch, fat, and fiber, overall the effects on efficiency of altering concentrations of nutrients is not large.

Slide 20. This shows a suggested scheme for estimating energy value of diet. Start by assigning feeds an energy value, formulate the diet, then apply effects of DMI, diet composition, etc to get actual NEL concentration of diet. This is for evaluation not formulation.

Slide 21. This slide discusses the effect intake has on digestibility. Generally as intake increases digestive efficiency decreases. The historic effect (used by NRC 2001 and previous editions) is a 4% decrease in digestibility per increment of maintenance intake. For a Holstein cow, this converts to about 0.6 percentage unit decrease per 1 kg increase in DMI. A large data set we have, found that the discount was only about 0.3% units per 1 kg increase in DMI and there was substantial variation among diets.

Slide 22. Histogram of data from our lab showing relationship between DMI and digestibility. Average was -0.3%/kg of DMI but slopes were highly variable.

Slide 23. This slides shows the interdependence DMI and NEL have on each other. Changing DMI can affect NEL and changing NEL can affect DMI. This is a major problem when diets are formulated using NEL.

Slide 24. Show the important NEL has on DMI when fat is supplemented. Adding fat increased the estimated NEL concentration in the diet but DMI decreased so energy intake was less than anticipated for both early and late lactation cows. Data from Anim Feed Sci Tech 115:65.

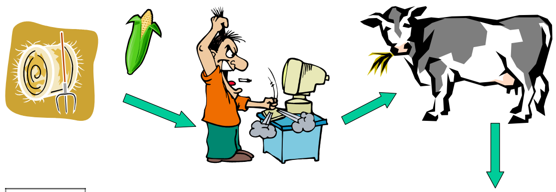
Slide 25. Numerous non-nutrition factors (i.e., management) can affect efficiency and must be considered when evaluating diet energy. Cited papers are from J. Dairy Sci.

Slide 28. Data from paper in J. Dairy Sci (89:1546) that evaluated estimated NEL intake with estimated NEL expenditures. Review found that NEL intake was apparently 3 to 7% greater than expenditures. This means that the system is not balanced and has errors.

Slide 29. Using average bias from previous slide over a 300 d lactation, the bias is quite substantial. The missing energy is equal to about 720 kg of milk or 100 kg of body tissue.

Slide 31. LP = linear programming (most common technique used to formulate diets).

Practical Aspects of Energy Nutrition for High Yielding Cows



Bill Weiss
Dept of Animal Sciences
Wooster, OH , USA

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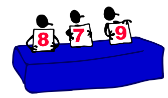
Potential Uses of Energy System

1. Economic valuation of feeds 
2. Diet formulation 
3. Diet evaluation (milk yield and **projection** of body condition)



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1. Economic Evaluation of Feeds

Cost of a feed = Σ value of its nutrients

Nutrient	Current	5 yr Avg
NEL, $/Mcal	0.15	0.05
MP, $/lb	0.29	0.19
eNDF, $/lb	0.014	0.018

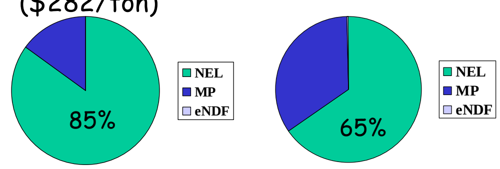
See: **http://dairy.osu.edu** (Buckeye dairy news)

3

Relative Value of Nutrients

Ground Corn ($282/ton)

SBM-48 ($410/ton)



Based on OH prices, July, 2008

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2. Diet Formulation

1. All ingredients given an energy value
2. Input cow data (BW, milk, desired BC, etc)
3. DMI entered or estimated
4. Equations generate requirements
5. LP techniques used to generate recipe

5

Why NEL?

We (and animals) must obey the laws of thermodynamics

The NEL system is an application of the 1^{st} and 2^{nd} laws of thermodynamics

NEL, in theory, gives accurate projections Of change in body energy (BCS)

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Gross Energy

Energy Flow

Fecal Energy

Digest. Energy

Urine/CH_4 Energy

Metabolizable

Heat (minus FHP)

Net Energy

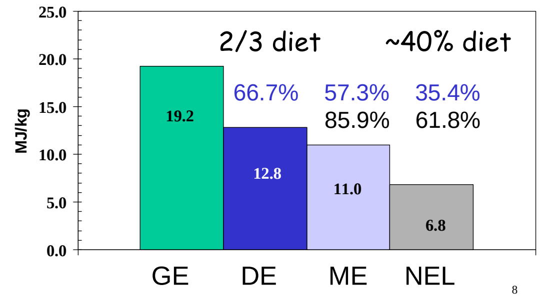
Maint + Work

+/- Retained

7

Average Energy Values
(Beltsville Energy Lab)

N = 301



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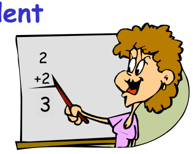
Fundamental Flaw

NEL (or any energy measure) is non-additive and non-independent



Examples:

1. Adding grain to low fiber diet can reduce fiber digest.
2. Adding grain to high fiber diet can stimulate digestibility

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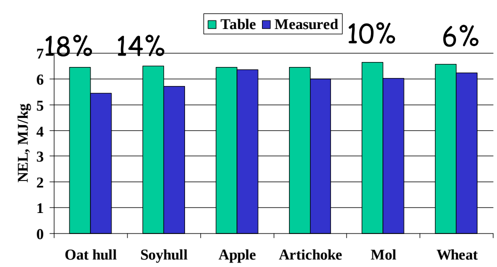
Feed Values vs Diets



Hindrichsen et al., 2005

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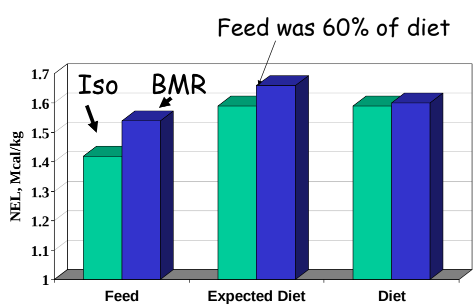
Feed Differences ≠ Diet Differences



Tine et al., 2001

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Energy Principle

NEL (or DE or ME) is a function of the feedstuff, interactions among dietary ingredients, interactions among intake and diet, and probably interactions between above and individual cows

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Energy Principle 2

Feedstuffs do <u>not</u> have energy values !

Diets have energy values.

Energy Supply

DMI

GE

Digestibility

Metabolizability

Efficiency

Energy Expenditures

Maintenance

Activity

Conceptus

True growth

Milk

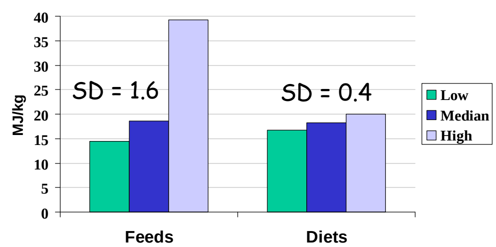
<u>+</u> ***Body fat***

Important Variation: GE

1. Depends only on chemical composition
   - Ash, fat, protein, CHO, acids

2. GE decreases when:
   - Ash ↑ , protein or fat ↓
   - sugars replace CHO polymers
   - sugars ferment to organic acids

Variation in GE



Important Variation: DE/GE

1. **Inherent digestibility of feedstuffs**
   - Concentration of fiber
   - Lignin
   - Protein damage
   - Starch chemistry and physical form
   - Particle size

Important Variation: DE/GE

2. **DMI**
   - Retention time
   - Physical breakdown of particles
3. **Rumen conditions**
   - pH
   - Bacterial populations
   - Substrate availability

Cow Interactions

Variation: ME/NEL

Affected by feed, DMI, rumen environment, physiologic state of animal, product produced and the cow

Efficiency changes for typical diet change

1. ⬆ fat = higher efficiency (~3%)
2. ⬆ starch = higher efficiency (~6%)
3. ⬆ protein = lower efficiency (~2%)

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'Inherent Diet Energy' (Σ of feedstuffs) — Equations / In vitro/enzymes / Tables

⬅ DMI effects

⬅ Associative effects on digestion

⬅ Nutrient effects on ME/NE efficiency

⬅ Other effects

Average 'True Diet Energy'

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DMI Effect on Digestibility

- Avg historic effect (US) ~ -0.6/kg DMI (i.e., 4%/increment of maintenance)
- Avg more recent data (~-0.3/kg DMI)
- Highly variable among diets
  - Corn silage < alfalfa based
  - Finely ground maize < coarse maize
  - High starch > low starch

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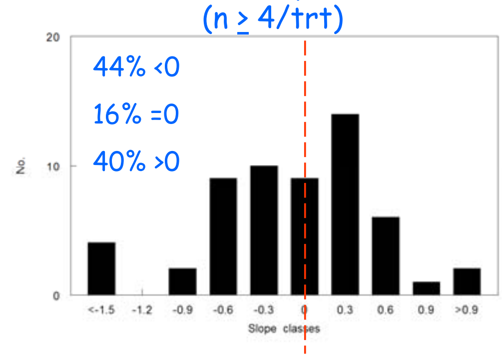
DMD vs. DMI (slopes within trt) (n ≥ 4/trt)



Weiss, unpub.

23

Formulate a higher NEL diet

⬆ DMI ⇩ Digestibility ⬇

DMI ⬇

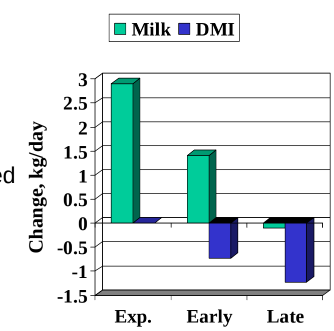
Change in NEL intake less than anticipated

23

Supplemental Fat and NEL

Assumptions

- 2.5% added fat
- 22.7 kg DMI
- Diet NEL increased from 1.63 to 1.72 Mcal/kg



Onetti and Grummer, 2004

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Other Factors to Consider

1. Fermentation modifiers (Rumensin, probiotics, etc.) ⇧~3-5% in NEL
2. Times fed (2x vs. 5X/d) ⇧~5% NEL (Mantysaari et al., 2006)
3. Jerseys > Holstein in chewing/kg DMI and NDF digest (⇩Associative effects?) Aikman et al., 2008
4. Diet starch ⇩ milk energy ⇧ body energy (opposite of high fat) Van Knegsel et al 2007

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Other Factors to Consider

5. Big pens, 3X milking, grazing ⇧ energy use
6. Overcrowding, poor comfort ⇧energy use
7. Heat stress ⇧ME/NE and ⇧ FHP

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To Evaluate Diet Energy:

Energy Use Must Equal Energy Supply

NEL intake > requirements: ⬆ BCS

NEL intake < requirements: ⬇ BCS

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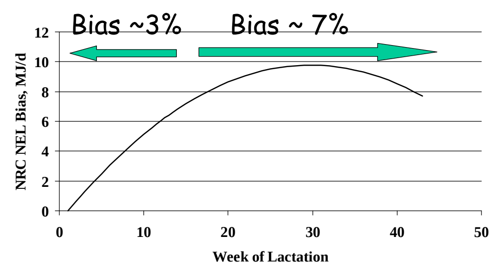
NRC NEL Supply > NEL Use

5 whole lactation studies (21 diets)



(Ellis et al., 2006)

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Potential Cumulative Error by NRC

For 300 d lactation:

Approximate total NEL use: 37,700 MJ

Total bias: 2180 MJ (~6%)

~720 kg of milk *or*

~100 kg of BW

Where are the errors?

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Possible Errors

Cows apparently ate 2180 MJ of NEL than used

1. Diet NEL concentration overestimated
2. Maintenance underestimated (0.096 ?)
3. Energy content of tissue underestimated
4. Activity underestimated
5. **Some combination of all above**

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Summary

1. LP balancing not appropriate for energy
2. NEL system useful to evaluate **mean** BC change
3. Numerous ‘minor’ factors effect energy use and must be considered
4. Substantial improvement unlikely with current approach (use of means)

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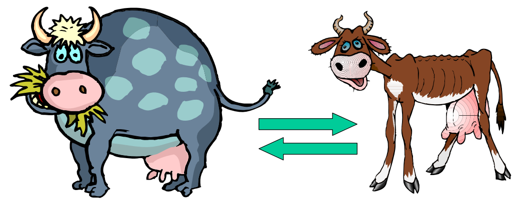
NEL: Don’t forget the cow



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Questions

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