

ADJUSTING NET ENERGY VALUES OF FEEDS FED TO DAIRY COWS

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Summary

The concentrations of NEL of feeds are currently used by most ration formulation programs to balance diets for dairy cows. This practice is inherently incorrect because feeds do not have NEL values; only diets have NEL values. However, because commonly used programs require NEL values for feeds, this paper provides adjustment factors that can be applied to feed NEL values to increase the accuracy of the NEL value of the diet. The NRC (2001) approach should be used to generate initial NEL concentrations with the exception that a standard discount of 0.92 (i.e., 8%) is used. This NEL-3X value can be calculated by feed analysis labs and be printed on feed analysis reports. The NRC model does not appear to adequately adjust NEL values for different types of corn grain (e.g., high moisture, steam-flaked, or finely ground) and the values may need to be adjusted by up to 10%. The NRC model appears to adequately estimate NEL values of diets with different types of corn silage, but adjustments are needed when the corn silage is processed ($\pm 7.5\%$). Nutritionists should be aware that additional adjustments may be needed for certain feeds.

Introduction

Fine-tuning is defined as making small adjustments to improve the performance or accuracy of something. Implicit in that definition is that you have a reasonably accurate starting point. For NEL concentrations, the starting point is usually a value from a table or from a feed analysis report. Those values are entered into a computer program and a diet is formulated. 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. For example, urea is an excellent source of MP when added to a diet deficient in rumen degradable protein, but if urea was added to a diet with excess rumen degradable protein it would contribute no MP. With the MP system, feeds are not given MP values, MP concentration is calculated only for the diet. Similar to MP, NEL should be considered non-additive and only diets, not ingredients, should have an NEL value. We should not 'fine-tune' NEL values for feeds; however, we can and often

should fine-tune NEL values for diets. This causes a conundrum because with most ration balancing software, the only way a nutritionist can fine-tune 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.

To fine-tune the NEL concentration of a diet, you must have an initial NEL value, and the amount of fine-tuning required depends on the accuracy of that value. For this paper, the initial NEL values will be those calculated using the NRC (2001) model and standard feed composition inputs (CP, NDF, ash, lignin, fat, and neutral detergent insoluble and acid detergent insoluble CP). The NRC model adjusts NEL values for dry matter (DM) intake and for the interaction between diet composition and intake, but feed laboratories will not know DM intake or diet composition. A standard discount of 8% was used to calculate NEL-3X concentrations. On average, NEL values calculated using NRC equations appear accurate (NRC, 2001).

Variation in Gross Energy

The nutrient fractions that have the greatest impact on GE concentrations are ash, CP, 'carbohydrate', and fat, and accurate data are essential for these fractions. In the NRC system, carbohydrate is defined as NDF plus nonfiber carbohydrate (NFC) which is defined as $100 - \text{NDF} - \text{CP} - \text{fatty acids} - \text{ash}$. The use of these crude fractions introduces some error into the GE calculation. The 'carbohydrate' fraction contains NDF, starch, simple sugars, organic acids (if the feed is fermented), and several minor compounds. The GE concentrations of starch and NDF are similar, but simple sugars such as glucose and sucrose have about 10% less GE per pound than does starch. The NRC system will overestimate GE of feeds that contain substantial amounts of simple sugars. The predominant organic acids found in well-fermented silage (acetic and lactic) have about 15% less GE than does starch which means that silage will have less GE than the value estimated by NRC. The GE contributed by CP is a function of the amino acid composition of the protein and the proportion of true protein and nonprotein N. The NRC value for CP is a reasonable estimate for non-fermented, plant-based feeds. 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 for fatty acids contained in common feeds. As fatty acid chain length increases, the GE/lb increases, and saturated fatty acids have slightly more GE per pound than unsaturated fatty acids. Although several factors affecting GE are not accounted for by the NRC system, in practice most of these factors will not greatly affect the end results. The GE concentration of silage is probably overestimated by 1 to 3%. For feeds that contain a large proportion of simple sugars (e.g., molasses) GE could be overestimated by about 6%, but because those feeds generally make up a small proportion of the diet, the overall effect on diet NEL would be small.

Variation in Digestibility

Schneider (1947) contains digestibility data measured using sheep that were fed diets comprised of a single feedstuff (about 900 observations). The concentration of total digestible nutrients (TDN) in those feeds (i.e., diets) ranged from less than 25% to more than 125%. If feeds that will probably never be fed to dairy cows in the U.S. (e.g., tree leaves) are removed, the range in TDN was 35% to 125%. These data, however, may not be appropriate for dairy cattle. Lactating dairy cows are usually not fed diets with only one ingredient and the variability in energy digestibility is much less among mixed diets than among feedstuffs. 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., 1997b). Although the variation in energy digestibility and DE concentrations are much less among diets than among feedstuffs, the variation is still substantial.

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 probably the 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., 1997b). 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 can have a large impact on the DE concentration in the diet. The other fractions either 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 simple sugars, organic acids, neutral detergent soluble fiber, and a host of minor compounds. Most of these constituents would be expected to be highly digestible. 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 the digestibility of fatty acids from all feeds except fat supplements is constant. This probably is not true but we have not been able to quantify factors that significantly affect the digestibility of fatty acids. For linted cottonseed and roasted soybeans, particle size (ground vs. whole seeds) did not consistently affect fatty acid digestibility (Pires et al., 1997; Tice et al., 1993). Roasting soybeans has not consistently affected fatty acid digestibility (Aldrich et al., 1995; Tice et al., 1994). Probably the most important fine-tuning that should be done regarding the energy contribution of fat from plant-based feeds is to base the values on accurate fatty acid concentration data. Feeds that contain appreciable concentrations of fatty acids should be assayed for fatty acids, and the actual analytical data be used to estimate NEL. Accurate estimates of fatty acid digestibility are essential for fat supplements. The NRC has averages of measured digestibilities for fatty acids from several common fat supplements. Although variation exists in digestibility of fatty acids within a fat supplement, NRC average values gave good estimates of dietary DE when evaluated using independent data (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 supplier 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.

General Approach

The general approach for fine-tuning NEL concentrations are outlined in Tables 1 and 2. The first step is to calculate NEL-3X concentrations using NRC (2001) equations. Those values are then either increased or decreased by a certain percentage. The proposed adjustments are empirical and are based on changes in digestibility, milk yield, yield of components and (or) changes in gross efficiency (yield of fat-corrected milk divided by dry matter intake).

Table 1. Suggested method to estimate NEL values of feeds.

Step	Procedure
1	Calculate DE of feeds using Equation 2-8 (NRC, 2001)
2	Assume an 8% discount factor (i.e., multiply value from step 1 by 0.92)
3	Calculate ME of feeds using Equation 2-10 (NRC, 2001)
4	Calculate NEL (Mcal/kg) by 2.2 to obtain NEL (Mcal/lb) if desired
5	Divide NEL (Mcal/kg) by 2.2 to obtain NEL (Mcal/lb) if desired
6	Apply necessary adjustments to NEL value for certain feeds ^a

^a See Table 2

Table 2. Proposed adjustments of NEL values for selected feeds.^a

Feed	Adjustment
Cracked dry corn (mean particle size >1 mm)	NEL -3X times 0.975
Ground dry corn (Mean particle size <1mm)	NEL -3X times 1.025
High moisture ground corn (DM = 75%)	NEL -3X times 1.10
Steam-flaked corn (density = 28 lbs/bu)	NEL-3X times 1.035
Mature corn silage	Reduce PAF 0.008 units/1 percent unit increase in DM above 28%
Processed immature corn silage	NEL-3X times 0.925
Processed mature corn silage	NEL-3X times 1.075
Corn silage with high NDF digestibility	Calculate NEL-3X using measured NDF and lignin

^a The NEL-3X value is initially calculated as described in Table 1.

Corn Grain

The only means of adjusting starch (actually NFC) digestibility incorporated into the NRC model is the processing adjustment factor (PAF). Diets for lactating cows typically contain 20 to 35% starch (dry basis) and total tract starch digestibility measured using lactating dairy cows range from about 70% to 100% (Firkins et al., 2001). Assuming an average dietary starch concentration of 28% and no interactions between starch digestibility and digestibility of other nutrients, 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 ± 0.07 Mcal/lb from the DE value calculated using average starch digestibility (approximately $\pm 5\%$ of a reasonable average for DE concentrations of dairy diets). Varying NFC digestibility using the PAF in the NRC model will vary discounted DE concentrations by about $\pm 2\%$ suggesting that additional fine-tuning may be required for corn grain. Factors known to influence digestibility of corn grain include:

- Particle size
- Chemical form of starch (amylopectin vs amylose)
- Maturity at harvest (i.e., high moisture vs. dry corn)
- Heat and steam treatment
- Interactions of the above factors

Dry Grinding

Most studies report increased total tract digestibility of starch when cows are fed 'ground' corn compared with 'cracked' corn (reviewed by 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 although one undoubtedly exists. Based on DM digestibility, measured NEL, and differences in milk production (Firkins et al., 2001; Wilkerson et al., 1997a) and ascribing all differences in response to corn grain, ground corn has 4 to 6% more DE/lb. and 1 to 3% more NEL/lb. than cracked corn. Those differences are greater than the difference estimated by the NRC model ($< 1\%$) for most diets suggesting that the NRC model under estimates the NEL of ground corn and (or) overestimates the NEL of cracked corn. *Proposed adjustment:* Reduce NEL-3X 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 on average 1.5% less NEL than diets with ground corn and by assuming corn comprised 30% of the diet.

High Moisture Corn

By all measures, diets with high moisture corn, on average, have more energy than diets with dry corn. The average difference in organic matter digestibility is about 4% (Firkins et al., 2001), differences in DE and NEL ranged from 5 to 8% (Tyrrell and Varga, 1987; Wilkerson et al., 1997a), and differences in milk energy output relative to intake averages about 4% (Firkins et al., 2001). The NRC model estimates about a 1% difference between diets with high moisture corn and diets with

dry corn. Based on limited data, diets with ground (particle size not measured) high moisture corn had statistically equal NEL values as diets with rolled high moisture corn (Wilkerson et al., 1997a). The effect of moisture concentration of high moisture corn on digestibility and milk production in lactating cows is lacking. Presumably, as moisture concentration of high moisture corn becomes more similar to dry corn, differences between the two would diminish; however, this does not mean that extremely wet high moisture corn has more energy than average high moisture corn. *Proposed adjustment:* Increase NEL-3X value of high moisture (rolled or ground) 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 the NRC model underestimates differences between ground dry corn and high moisture corn by 3%, and by assuming 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

Digestibility of organic matter for diets with steam-flaked corn is 1 to 2% higher than diets with ground or cracked dry corn which is similar to the change in energy-corrected milk yield (Firkins et al., 2001). On average the NRC estimates that diets with steam-flaked corn have about 0.5% more NEL than diets with ground corn. To fine-tune the energy value of steam-flaked corn, flake density must be known. As flake density increases above about 28 to 30 lbs/bushel, steam-flaked corn becomes more similar to ground corn. In the review by Firkins et al. (2001), steam-rolled corn (approximate density of 38 lbs/bus) was essentially equal to dry ground corn with respect to organic matter digestibility and milk production. The relationship between flake density and energy value is likely not linear. 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, that the NRC model underestimates that difference by 1 percentage unit, and that corn comprised 30% of the diet. As density increases, the adjustment will be less.

Chemical Structure of Starch

Corn starch can be branched (amylopectin) or linear chains (amylose) of glucose. Corn grain with mostly amylopectin is less dense and more floury when ground than corn with a high proportion of amylose (more flinty). Across corn hybrids, the structure of starch is a continuum ranging from very floury to very flinty. Average dent corn is intermediate. Vitreousness is a measure of flintiness (flinty corn has high vitreousness). In situ and in vitro studies have shown that vitreousness has a strong inverse relationship with ruminal starch digestibility (Allen et al., 2003; Correa et al., 2002) suggesting that ruminal starch digestibility in vivo will be higher

for floury corn than for flinty corn with dent corn being intermediate. Very little data are available comparing different types of corn grain on total tract digestibility or milk yield with lactating dairy cows. Based on two studies (Akay and Jackson, 2001; Schroeder et al., 1996), diets with waxy corn (very low vitreousness) had about 4% more energy than diets based on dent corn. 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. *Proposed adjustment:* None at this time, but the NEL of very dense, highly vitreous corn is probably overestimated and floury corn may be under estimated.

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 provided by corn silage and the digestibility of NDF provided by corn silage cannot be directly measured in lactating dairy cows fed typical mixed diets because diets contain other sources of starch and NDF. However digestibility of 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 fed and provided most of the dietary NDF range from 46 to 55% (Beckman, 2003; Tine et al., 2001; Weiss and Wyatt, 2000). Factors that can affect digestibility of starch and/or NDF from corn silage include:

- Corn plant maturity at harvest
- Hybrid
- Kernel processing
- Interactions among those factors

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) in which corn silages with different DM concentrations were fed and digestibility measured were compiled to derive an equation to adjust energy values of corn silage based on DM (i.e., maturity). Digestible energy values of the total diet were taken from the papers or calculated from organic matter digestibility and regressed on DM concentration of the corn silage with trial effects included in the model. If the change in DE concentration is assumed to be caused entirely by corn silage, DE concentration of the corn silage decreased 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 would change 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 concentration, the nutrient composition of corn silage changes as plants mature. The difference in NEL between a corn silage with 35% DM and 45% DM (i.e., $10 \times 0.005 = 0.05$ 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 on average, the NRC model accounts for the effect of corn silage maturity. The effect 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 for 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 increased NDF digestibility, different concentrations of nutrients (e.g., starch, NDF and fatty acids), and different physical characteristics of starch. These differences could lead to differences in available energy concentrations of diets that include silage from different hybrids. However, reported differences (within experiments) in concentrations of DE, digestible organic matter, TDN, or NEL between diets with different corn silage hybrids have been remarkably small (Akay and Jackson, 2001; Johnson et al., 2002; Kuehn et al., 1999; Nennich et al., 2003; Tine et al., 2001; Weiss and Wyatt, 2000; 2002). At the current time we do not have adequate data to quantify the effects of these interactions based on measurable inputs. *Proposed adjustment:* Current data do not support adjusting NEL-3X values from those calculated from measured nutrient composition.

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. Interactions between hybrid and processing are also likely (Weiss and Wyatt, 2000). *Proposed adjustment:* The NEL-3X value of Immature corn silage (< one-third milk line) that has been processed should be reduced 7.5% and the NEL-3X of mature corn silage (> two-thirds

milk line) should be increased by 7.5%. These values were derived by assuming processing reduced DE concentrations by 3% when immature corn silage was processed and increased DE concentrations 3% when mature corn silage was processed and by assuming corn silage comprises 40% of the diet. Corn silage from different hybrids probably respond differently to processing, but those changes cannot be quantified at this time.

Use of In Vitro NDF Digestibility

The NRC system estimates NDF digestibility using lignin, but in vitro (IVNDFD) and in situ NDF disappearance are two other options that can be used. Brown midrib (bmr) corn silage generally has higher IVNDFD than its isogenic control (Eastridge, 1999), however when fed to lactating dairy cows as a component of a mixed diet in vivo NDF digestibility has not been consistently higher when bmr silage is fed (Oba and Allen, 2000; Tine et al., 2001). Furthermore, a diet with bmr corn silage had the same measured NEL concentration 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 NEL concentration was not affected by hybrid. In another study cows fed a corn silage from a hybrid selected to have high IVNDFD (not a bmr) had equal in vivo NDF digestibility as did cows fed a typical corn silage even though IVNDFD differed between the hybrids (Weiss and Wyatt, 2002). Beckman (2003) found that using in situ NDF digestibility (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 available energy concentrations of corn silage. The accuracy of using IVNDFD to calculate energy values of other feeds when fed in mixed diets to lactating dairy cows has not been evaluated.

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