New Perspectives on Energy Values and Supplementation Levels of Supplemental Fats

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▪ Take Home Messages

- Use of supplemental fat is a proven method to improve energy balance of cows, which may result in increased milk yield, better body condition, and improved reproductive performance.
- Energy values of fats are difficult to determine and are highly dependent on digestibility of the supplemental fat.
- Estimated energy values for some fat sources are provided based on research conducted at the University of Illinois.
- Providing the optimal amount of supplemental fat will result in the greatest profits to dairy producers. Evidence is provided that the optimal amount of supplemental fat likely is about 3% of total dietary dry matter.

▪ Introduction

Supplemental fats have become common ingredients in diets for high producing dairy cows. Because of their greater energy density, fats are useful to increase the net energy for lactation (NE_L) content of diets for cows during times when total feed intake may limit milk production. The long-chain fatty acids supplied by dietary fats and oils are metabolized more efficiently by cows than are volatile fatty acids (VFA) from carbohydrate fermentation. Recent research has suggested that fats may benefit reproductive performance in dairy cows, both by improving energy balance and through specific effects on the reproductive tissues (Staples et al., 1998).

A variety of fats and oils are used in dairy rations. Oils, which are unsaturated fats that are liquid at typical body or environmental temperatures, are not widely used in the free form but are very common as components of oilseeds such as canola, cottonseed, or soybeans. Animal fats such as tallow and grease are widely used, as are various commercially processed dry fats, often called “inert” fats or “bypass” fats.

Despite nearly a quarter-century of intensive research on use of supplemental fats, several key issues remain controversial. First, it is difficult to define an energy value for supplemental fats. Second, the impact of fats on rumen fermentation and the interactions of fats with other ingredients still are not easily predicted with accuracy (Jenkins, 1997). Finally, optimal supplementation levels for maximum profitability remain unknown, and likely differ from maximal supplementation rates.

A major source of confusion on these issues results from variability among experiments for digestibility values of supplemental fats. Many factors contribute to this variation, including methodological differences between laboratories. However, substantial variation exists in digestibility measurements of the same fats within the same experiment or similar experiments from the same laboratory. Such differences indicate that differences in dietary composition, feeding management, or other animal sources likely impact fatty acid digestibility more than has been appreciated (Doreau and Chilliard, 1997).

Over the last decade, our research group at the University of Illinois has conducted numerous experiments on fat supplementation for dairy cows. Thus, a substantial data set exists that has been derived from a single laboratory, where genetic variation of cows, dietary ingredients, feeding strategies, and analytical methodology likely have been more uniform than when considering experiments across a number of research sites. In this paper, data from these Illinois experiments are used to propose some digestibility and energy values of a variety of fats and oilseeds, and to examine the idea of an optimal supplementation rate. Focusing on our own data set is not meant to ignore or diminish the contributions of others who have been key contributors to the area.

▪ Digestibility of Supplemental Fats

The largest source of variation in NE_L values among different fats is digestibility. Obviously, fats can contribute nothing toward improving the energy status of cows unless their long-chain fatty acids can be absorbed into the body from the digestive tract. Fat digestibility is best determined by measuring fatty acids rather than older techniques of determining ether extract or crude fat. Consequently, older data from experiments in which fat digestibility was determined by using ether extract techniques are of little value in developing quantitative models of fatty acid digestibility.

Digestibility of fatty acids in fat sources depends on the chemical characteristics of the fat, the physical nature of the fat source or oilseed, characteristics of the dietary ingredients to which fat is added, and level of intake.

The most important factor determining fatty acid digestibility is the chemical nature of the fat itself, principally the degree of saturation and the degree of esterification. Saturated fats are solid at body temperature and thus are used to prepare commercial dry fats. For example, chemical hydrogenation of tallow results in a product that can be made into a free-flowing granular mixture at typical temperature. Such fats are less able to interfere with rumen fermentation, but as saturation increases, digestibility decreases. Esterification refers to whether fatty acids are attached to glycerol as triglycerides (esterified fatty acids), or are present as the free fatty acids. Some commercially available fats consist of mostly saturated free fatty acids or as the free fatty acids complexed with calcium.

We have shown in steers (Elliott et al., 1999) that digestibility of fatty acids decreases from 74.4% in native tallow to 39.1% in highly hydrogenated (saturated) tallow. Digestibility of a mixture of highly saturated fatty acids of similar profile to the highly hydrogenated tallow was 63.2%, indicating that free fatty acids are much more highly absorbed than the same fatty acids present in hydrogenated triglycerides.

The physical nature of the fat source also impacts fatty acid digestibility. Small particle size and uniform dispersal of liquid fats into the diet result in improved digestibility compared with larger particle sizes (Drackley et al., 1994; Elliott et al., 1994; Aldrich et al., 1995). Roasting of soybeans improves fatty acid digestibility compared to raw soybeans (Tice et al., 1994; Aldrich et al., 1995).

The nature of the dietary ingredients to which a fat is added appears to affect fatty acid digestibility (Elliott et al., 1995; Grum et al., 1996; Ruppert et al., 1996). The reasons for these effects are not known, nor is it possible as of yet to accurately predict the magnitude of this effect.

Although digestibility of most nutrients decreases as intake of those nutrients increases, whether the amount of fat in a diet affects fatty acid digestibility remains a controversy. Palmquist (1991) presented evidence that fat digestibility declined at higher intakes of fat. On the other hand, from a review of data in the scientific literature, Doreau and Chilliard (1997) concluded that intestinal fatty acid digestion was not affected by the amount of fat fed. Data for total tract fatty acid digestibility from four of our experiments with lactating cows in which more than one amount of the same fat was fed are shown in Figure 1. In these experiments, fatty acid digestibility decreased on average six percentage units for every one percent increase in the amount of supplemental fat added to the diet over the range of 2% to 7.5% supplemental fatty acids. In another recent experiment, digestibility of tallow decreased about three percentage units for each percentage unit increase in supplementation (Ruppert et al., 1996).

The importance of the decreased fatty acid digestibility with increased fat intake is that it decreases the NE_L value of the fat. The effect of the changes shown in Figure 1 would translate to the NE_L value for a fat changing from, for example, 5.8 megacalories (Mcal) per kilogram when fed at 2.5% of the total dietary dry matter (DM) to 4.7 Mcal/kg if fed at 5% of the dietary DM.

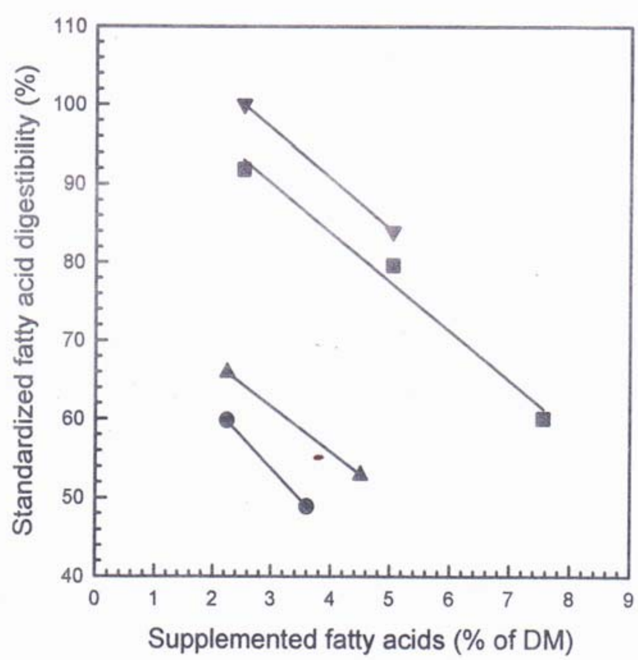

Figure 1. Changes in total tract fatty acid digestibility as affected by the amount of the fat added to the diet. On average, fatty acid digestibility decreased 6 percentage units for every 1 percentage unit increase in supplemental fat in the diet. Data are from references 12, 23, 24, and 25.

Because of all these factors that can impact fatty acid digestibility, it is risky to assign NE_L values to fats on the basis of an individual experiment. To aid in ration formulation, I have compiled digestibility values obtained in our experiments for several sources of fat (Table 1). Data presented represent digestibilities for the fatty acids in the fat source itself, obtained by the so-called "difference method" (change in fatty acids digested in diet with supplemental fat compared with the control diet, divided by the change in intake of the fatty acids). This is one method used to estimate the "true digestibility" of the fat source. So that inferences could better be made among experiments by removing experiment-to-experiment variation, the digestibility values were standardized by first expressing them as a percentage of the control diet within each experiment, and then multiplying this percentage by the average fatty acid digestibility for a no-fat control diet across 11 experiments (72.4%). Control diets were generally similar across experiments, containing corn silage and alfalfa haylage as forage sources, corn grain as the primary energy concentrate, and soybean meal as the major protein supplement.

While this approach certainly is open to criticism for several reasons, the derived "standardized" digestibilities provide a useful way to compare relative digestibilities of fat sources and provide some "ball-park" numbers for the resulting variation in NE_L content. A somewhat similar approach was employed by Chandler (1993) to compare digestibility values across a large number of experiments from different research groups.

It is apparent in scanning through the data in Table 1 that significant variation remains in estimates of digestibilities, even when considering only values from a single research site and after attempting to standardize the values across experiments. This emphasizes the challenges that remain in accurately determining digestibility and NE_L values for various fat sources.

Table 1. "Standardized" fatty acid digestibility for several fat sources (see text for details on calculation).

Fat source	Inclusion rate of ingredient in diet (% of DM)	Standardized digestibility (%)	Reference
Whole soybeans	10	42.9	Schauff et al., 1992b
Whole soybeans[1]	16	71.2	Aldrich et al., 1995
Roasted soybeans[1]	16	75.9	Aldrich et al., 1995
Extruded soybeans	6	61.2	Schauff, 1992
Extruded soybeans	12	52.8	Schauff, 1992
Extruded soybeans	18	55.7	Schauff, 1992
Canola seed (processed)	11.2	65.4	Aldrich et al., 1997
High-oil corn	44.5	91.9	Elliott et al., 1993
Tallow	2.5	59.8	Schauff et al., 1992b
Tallow	4	48.9	Schauff et al., 1992b
Tallow	2.5	65.9	Elliott et al., 1993
Tallow	5	52.9	Elliott et al., 1993
Tallow[2]	2	73.9	Ruppert et al., 1996
Tallow[2]	4	66.4	Ruppert et al., 1996
Tallow[3]	2	69.9	Ruppert et al., 1996
Tallow[3]	4	63.8	Ruppert et al., 1996
Choice white grease	5	53.9	Drackley et al., 1994
Partially hydrogenated tallow	4	48.4	Drackley and Elliott, 1993
Hydrogenated tallow[4]	5.6	41.5	Elliott et al., 1994

Fat source	Inclusion rate of ingredient in diet (% of DM)	Standardized digestibility (%)	Reference
Energy Booster™ (flake)[4]	5	65.0	Elliott et al., 1994
Energy Booster™[4]	5	72.5	Elliott et al., 1994
Energy Booster™	2.5	60.3	Elliott et al., 1995
Energy Booster™	5	52.6	Elliott et al., 1996
Hydrogenated palm distillate	5.2	52.1	Elliott et al., 1996
Megalac™[5]	6.1	67.7	Elliott et al., 1996
Megalac™	3	~100	Schauff et al., 1992a
Megalac™	6	84.0	Schauff et al., 1992a
Megalac™	5.6	83.5	Aldrich et al., 1997
Megalac™	3	91.8	Schauff and Clark, 1992
Megalac™	6	79.6	Schauff and Clark, 1992
Megalac™	9	60.1	Schauff and Clark, 1992

[1]Data obtained using steers.
[2]Corn silage-based diet.
[3]Alfalfa silage-based diet.
[4] Data obtained using nonlactating cows. Energy Booster is a mixture of mostly saturated free fatty acids, in prill form, produced by Milk Specialties Co., Dundee, IL.
[5]Megalac is calcium salts of palm fatty acids, in granular form, produced by Church and Dwight Co., Inc., Princeton, NJ.

▪ Energy Values of Supplemental Fats

As stated earlier, the importance of fatty acid digestibility is in determining the NE_L values of the fat source. The indigestible portion of the fat source represents energy lost in the feces, which is subtracted from the gross energy or intake energy of the fat. Gross energy is determined by bomb calorimetry and is the total potential chemical energy present in the molecular structure of the fat. Gross energy of triglycerides such as canola or soybean oils or animal fats like tallow is about 9.2 Mcal/kg. For free long-chain fatty acids, the gross energy content is about 9.39 Mcal/kg. Calcium salts of long-chain fatty acids contain about 8.03 Mcal/kg (DM basis; Andrew et al., 1991).

In digestion and metabolism of fats, no energy is lost as methane or in urine, so metabolizable energy is assumed to be equal to digestible energy. The metabolizable energy of long-chain fatty acids is used with high efficiency by lactating cows. Once absorbed, the efficiency of use of fatty acids is not known to differ depending on the profile of the fatty acids supplied by the fat source, so a common metabolic efficiency value can be used for all fats with little error. Andrew et al. (1991) measured the efficiency of use of long-chain fatty acids to be 77.2%, while Chilliard (1993) determined an average value of 81% from a survey of research data. A value of 80% for efficiency of use of metabolizable energy was used by the National Research Council (1989) and is used here in the following calculations.

In Table 2, the mean NE_L content of fats from sources studied in our research group has been calculated. These values were estimated using the gross energy of the fat as described in the previous paragraph, multiplied by the mean standardized digestibility for the fat as calculated from Table 1, and then multiplied by an efficiency of 80% (0.8). The range of values also is shown based on the range in measured digestibilities from Table 1.

Mean values for NE_L content of the fat sources generally are lower than values typically used by the feed industry. For example, the National Research Council (1989) reports the NE_L value of fats and oils to be 5.84 Mcal/kg. The value obtained for calcium salts of fatty acids (Megalac™), when corrected to a 100% fatty acid basis (field measurements report that fatty acid content generally is about 84%), is 6.19 Mcal/kg of fatty acids, which is similar to the widely used thumbrule for fats of 6 Mcal/kg. The slightly lower NE_L values derived here actually provide a better fit to typical milk production responses to supplemental fats observed in many research studies.

If nothing else, this exercise highlights the importance of digestibility measurements in determining the NE_L value of supplemental fats. To complicate the issue even further, the impact of fats in the total diet depends on

Table 2. Estimated NE_L values for fat from various sources (see text for details on calculation).

Source of fat	Mean NE_L (Mcal/kg fat)	Range[1]
Soybeans	4.41	3.16 – 5.59
Canola	4.81	---
Tallow	4.62	3.60 – 5.44
Choice white grease	3.97	---
Partially hydrogenated tallow	3.54	---
Hydrogenated tallow	3.04	---
Energy Booster™	4.70	3.95 – 5.45
Megalac™	5.20	3.86 – 6.42

[1]Based on the range of digestibilities in Table 1 where multiple determinations were made.

their effects on rumen fermentation and feed intake. For example, fats such as those from oilseeds and animal sources may alter rumen fermentation and suppress methane production. Thus, fats would have an "associative" effect and result in greater improvements in NE_L content of the total diet than would be predicted by the NE_L content of the fat itself. On the other hand, fats may decrease feed intake, which decreases their effectiveness in increasing energy intake by the cows.

▪ What is an Optimal Amount of Supplemental Fat?

A great deal of research has been conducted during the last 20 years, including at our research station, in part to determine *maximal* rates of supplementation with fat. Although in some situations as much as 8 to 10% supplemental fat could be fed, the question of most importance to dairy producers is what is the most ***profitable*** amount of supplemental fat to feed. Even commodity fats priced at $0.80/kg (Canadian) are more expensive sources of energy than corn or barley grain, so overfeeding fat can add significantly to daily feed costs per cow.

Responses of cows to supplemental fat are complex, relating to restoration of body condition, reproductive performance, and milk composition as well as just milk production. Responses of energy balance, which directly affects gain of body condition and reproductive success, generally have been positive to fat supplementation. Furthermore, if fats are fed “correctly” at moderate amounts, with proper attention to dietary contents of effective fiber and undegradable protein, impacts on milk composition are relatively modest. Thus, focusing on effects on milk yield provides the best indicator of what the optimal supplementation level should be.

Like any dietary component, supplemental fats should be expected to display a classic “diminishing returns” type of response. In this situation, addition of the ingredient (fat) to the diet provides an increasing response (milk production) to some point, at which time the additional response (called the “marginal response”) to further dietary additions starts to decrease. A plateau may be reached, with no additional response despite continued increases in the ingredient. Finally, after too much of the ingredient is added, the response may actually decrease because of nutrient imbalances or decreased feed intake. This concept has been discussed for fats by Jenkins (1997) and a graphical depiction is shown in Figure 2.

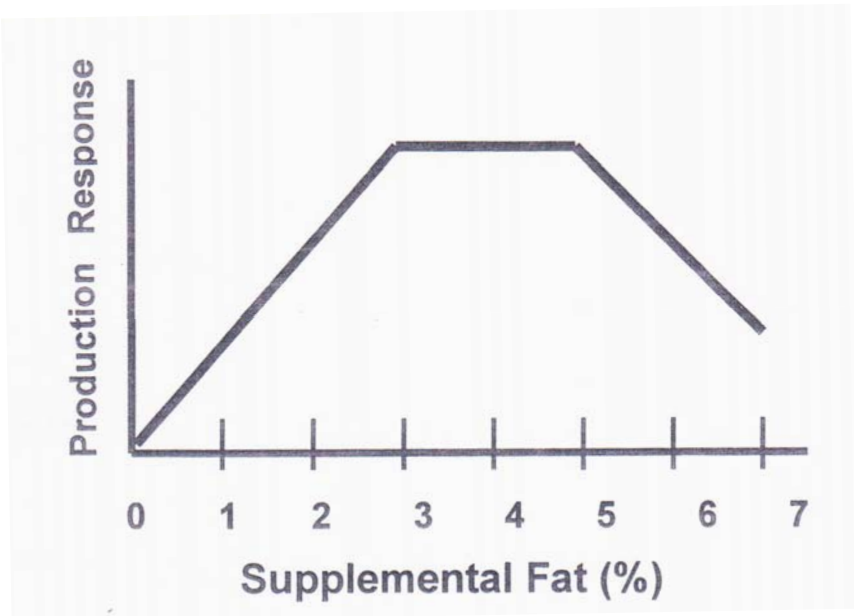

Figure 2. Theoretical depiction of expected responses of milk yield to supplementation of fat in the diet. A similar concept has been presented by Jenkins (1997).

From the standpoint of dairy producers, we need to know at what point milk yield response starts to flatten out or enter the "diminishing returns" segment of the curve in Figure 2. Beyond that point, additional cost for more supplemental fat will not pay for itself in increased milk production.

One of the best practical methods for determining the amount of supplemental fat to feed was derived by Palmquist (1993) and states that the total amount of fat in the diet should be equal to the amount of milk fat produced. This concept has some founding in the biology of how cows use fat. As an example if a group of cows is producing 40 kg of milk daily containing 3.7% fat, the group produces on average 1.48 kg of milk fat daily. The average fat content of forage and concentrate rations without supplemental fat sources is about 3%. Assuming that these cows consume 23 kg of DM daily, they consume about 0.69 kg of fat from the basal ration. Thus, 1.48 minus 0.69 equals 0.79 kg of fat that could be supplemented. This amount of supplemental fat is about 3.4% of total DM consumed.

Consequently, a good rule of thumb for high producing cows is supplementation of about 3% fat, or about 0.6 to 0.75 kg per cow daily. Data from 10 studies conducted by our research group at the University of Illinois in which fat was fed are plotted in Figure 3.

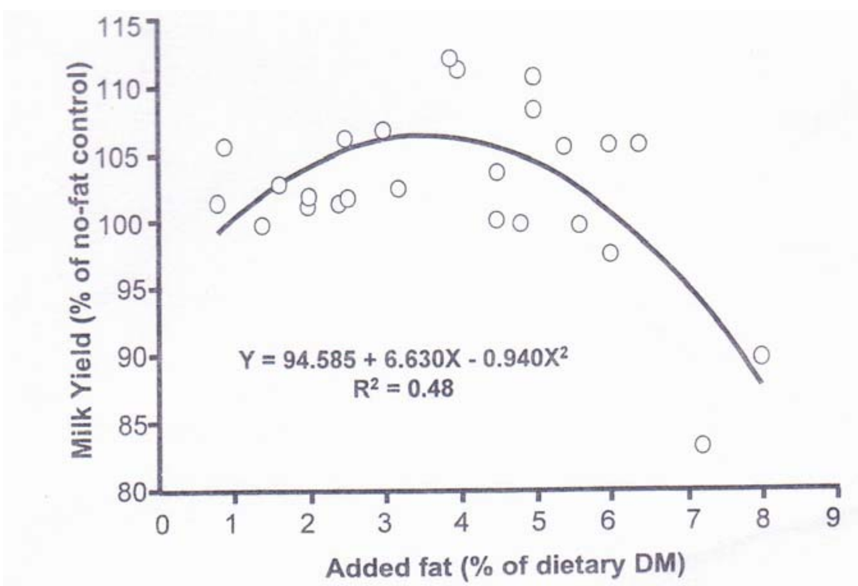

Figure 3. Response of milk yield (expressed as a percentage of the milk yield from cows fed a non-supplemented control diet) to increasing amounts of supplemental fat (expressed as a percentage of total dietary dry matter). Data are from 10 studies conducted at the University of Illinois (references 7, 8, 9, 11, 12, 17, 22, 23, 24, 25).

Although the fit of the curve is only moderate, the type of conceptual response described in Figure 2 can be seen these actual experimental data. The breakpoint in the response of milk production comes somewhere near to the 3% addition level.

This rule of thumb is, of course, only a guideline. The optimal amount may depend on the nature of the diet to which fat is added as well as the prevailing economic conditions of milk price and costs of fat and grains. Most of the data used to derive Figure 3 were from studies in which the forage base was a combination of corn silage and alfalfa silage. In situations where corn silage makes up more than 2/3 of the forage DM, we would recommend that supplemental fat be kept to 2.5% or less. This recommendation comes from our research demonstrating that addition of tallow at 2 or 4% of DM to a corn silage-based diet resulted in depressed milk fat percentage and alterations in rumen fermentation compared to supplementation of the same amount of fat to an alfalfa silage-based diet (Ruppert et al., 1996).

In western Canada where barley silage and grain are important feeds, the optimal supplementation level still may be at about the 3% level. Compared with corn and corn silage, barley has characteristics that would argue for both increased and decreased amounts of fat supplementation for optimal results. On one hand, barley starch ferments more rapidly in the rumen, which may make interference of fat with rumen fiber digestion more likely. On the other hand, barley contains considerably less fat than corn silage or grain. Consequently, milk production may respond to more *supplemental* fat until the amount of *total* fat in the diet reaches amounts similar to milk fat production, as proposed by Palmquist (1993).

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