

# Monitoring Feed Efficiency in Dairy Cows Using Fat-Corrected Milk per Unit Dry Matter Intake

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## Introduction

Anyone associated with the dairy industry is painfully aware of the rapid increases in feed costs that have occurred over the last three years. While the milk prices have gradually recovered from the crash of 2009, profitability has not returned as increased feed prices have consumed most of the increased producer income. There are many reasons for the increase in feed prices. Most certainly, the diversion of traditional livestock feeds such as corn into ethanol production along with increased demand for food following the global recession of 2009 are at the top of everyone's list. While feed costs have traditionally accounted for 50% of the cost of milk production, more recently that number has increased. Do you remember when you could feed the average lactating cow for \$3-4? That is certainly is not the case anymore and likely will not be the case unless there is a major change in the demand for feed grains.

In spite of the impact of feed prices on dairy profitability, the dairy industry is the only livestock industry in the U.S. that does not have a standard index of feed utilization efficiency. The beef feedlot, growing and finishing swine, and poultry broiler industries all use feed per gain as their standard index of feeding efficiency. Each industry has common benchmarks for feed efficiency that are used to evaluate farm or feed yard performance. Increased animal performance due to improved genetics, nutrition and management in these industries has resulted in improved feed efficiency over time. This improvement is largely a function of dilution of the growing animal's maintenance requirements in respect to their total feed requirements. A higher proportion of feed is used for growth and a lower proportion for maintenance.

While feed per gain can be used in growing dairy heifers, it is not appropriate for lactating cows. Recently, there has been interest in the use of fat-corrected milk (FCM) per unit feed dry matter intake (DMI) as an index of feed efficiency in dairy cows. I will refer to as FCM efficiency (FE) from here on. The use of FCM as the numerator in calculating FE makes sense in that it standardizes milk yield on an energy yield basis. It is easily calculated from the milk yield and fat content of a herd or a group within a herd. The most commonly suggested FE formula uses 3.5% FCM as the standard measure of milk production (the numerator) and DMI as the denominator where:

$$\text{FCM Efficiency} = \text{FCM} / \text{DMI} \quad [1]$$

Where: FCM = 3.5% fat corrected milk, kg/d (See Equation 5)  
DMI = Dry matter intake, kg/d

Most confinement dairies routinely monitor DMI, milk yield and milk composition. Therefore calculation of 3.5% FCM and FE is relatively straightforward. The real questions become: 1) What are the factors that affect FCM efficiency? and 2) Are there benchmarks that dairy producers and nutritionists can use as standards to compare FE in individual herds?

### **The Feed Efficiency Numerator: Fat-Corrected Milk**

Heats of combustion of milk were used by Gaines and Davidson to develop the standard formula for 4% fat-corrected milk (FCM) in 1923. The FCM formula was developed as means to standardize milk production records on an energy equivalent basis for use in genetic analysis. Milk fat normally accounts for 50% or more of the total energy content in milk and milk fat is by far the most variable of the major milk components both within and across breeds and within a cow's lactation (Sutton, 1989).

Usually referred to as the Gaines formula, FCM was derived from the caloric values of 4.09 and 9.28 kcal/g respectively for solids-non-fat and milk fat that had previously been determined by Stocking and Brew (1920). Gaines and Davidson (1923) found that milk fat could be used as a predictor of the heat of combustion [H] of milk. Remarkably, the caloric value they used for milk fat is nearly identical to the value (9.29 kcal/g) used by the NRC (2001). The use of a constant caloric value (4.09 kcal/g) for nonfat milk solids assumed that there was a constant ratio among individual nonfat solids components (protein, lactose, and ash). Ash has caloric value of 0, while lactose and crude protein have values of 3.95 and 5.45 kcal/kg, respectively (NRC, 2001). Based on these [H], a milk with an ash, lactose, and crude protein content of 0.70, 4.85, and 3.20%, respectively would have a [H] of 4.18 kcal/g. This value is slightly greater than the value of 4.09 kcal/g used in deriving the Gaines formula. In fact after deriving the FCM formula Gaines and Davidson (1923) found that the actual energy concentration predicted from their FCM equation under predicted milk energy by 3%.

While final derivation of the Gaines formula used milk energy values expressed as kcal/quart, I have converted their equations to kcal/kg to illustrate how the equation predicts the energy concentration in milk (M):

$$E \text{ (Mcal/kg)} = 109.21M (2.66 + f) \quad [2]$$

Where: E = heat of combustion of milk  
M = amount of milk produced  
f = milk fat%

For milk containing 4% fat:

$$\begin{aligned} E \text{ (Mcal/kg)} &= 109.21M(2.66 + 4.0) \\ &= 109.21M \times 6.66 \\ &= 727 \text{ kcal/kg} \\ &= 0.727 \text{ Mcal/kg} \end{aligned}$$

To standardize milk production to a constant energy value of milk with 4% fat:

$$\begin{aligned}
E' &= \frac{\text{total energy value of the entire quantity of milk}}{\text{energy value of 1 kg of 4 percent milk}} && [3] \\
&= \frac{109.21M(2.66 + f)}{109.21M(2.66 + 4)} = \frac{2.66M + Mf}{6.66} = \frac{2.66M + 100F}{6.66} \\
&= 0.3994M + 15.15F
\end{aligned}$$

Where: M = kg milk  
F = kg milk fat

After Gaines and Davidson (1923) did same exercise using milk energy equations developed by others and finding similar relationships, they decided round their coefficients to make life simpler such that the final equation for 4% FCM became:

$$4\% \text{ FCM} = 0.4M + 15F \quad [4]$$

The formula stuck! Since the coefficients were so easy to remember “FCM equals 0.4 times pounds of milk plus 15 times pounds of fat.”, the 4% FCM equation quickly became ubiquitous in the dairy science community and has been used for the last 90 years.

One item that I mentioned earlier was that Gaines and Davidson found that the predicted energy value of one unit of 4% milk predicted from Equation 4 was low. Realizing that their value was about 3% low compared with others (0.727 vs. 0.749 Mcal/kg), they assumed their number was wrong. So they increased (fudged) their number to conform with other results. Thus the [H] or net energy  $NE_1$  for one kilogram of 4% FCM became 0.749 (0.75) Mcal.

Later on as our dairy cows improved and milk production increased and correspondingly, average milk fat percent declined, someone (We don't know who?) decided that it would be more appropriate standardize records to 3.5% FCM. Derivation of the 3.5% FCM formula uses the same process:

$$\begin{aligned}
E' &= \frac{\text{total energy value of the entire quantity of milk}}{\text{energy value of 1 kg of 3.5 percent milk}} && [5] \\
&= \frac{109.21M(2.66 + f)}{109.21M(2.66 + 3.5)} = \frac{2.66M + Mf}{6.16} = \frac{2.66M + 100F}{6.16} \\
&= 0.4318M + 16.23F
\end{aligned}$$

In contrast to the 4% FCM formula the 3.5% FCM coefficients are not so easy to remember. To keep it straight, I have them posted on a tack board in front of my desk when I need them. Using Gaines and Davidson's (1923) 3% fudge factor, the net energy of one kilogram of 3.5% FCM would be 0.692 Mcal. For the most part the Gaines formula is adequate for predicting milk energy. However, one must remember that it does not account for changes in the proportions of milk lactose, protein, and ash as the energy contribution of those constituents

are indirectly predicted from milk fat content. This approach is probably appropriate for breed differences in nonfat milk solids but not among cows within breed or for the changes in milk protein and fat that occur during a lactation. Tyrrell and Reid found that the Gaines formula under predicted milk energy when milk fat was low (< 3%) and then developed a new solids corrected milk (SCM) equation with the same energy concentration (0.75 Mcal/kg) as the Gaines formula to overcome this problem. Similarly, DHIA uses energy corrected milk (ECM) derived from regression equations developed by Tyrrell and Reid (1965) to standardize lactation records. While somewhat better than the Gaines formula, these equations also use some of the same assumptions which create small but inherent errors. In the end, these formula have not gained the same usage that the 3.5% FCM formula has for calculating dairy feed efficiency.

### The Feed Efficiency Denominator: Dry Matter Intake Effects

Cows that eat more will give more milk and as intake and milk production increases FE increases. The reason for the improved FE is that a larger and larger portion of the cow's feed intake is being used for productive purposes and a smaller proportion for maintenance. The maintenance dilution effect is illustrated in Figure 1-A where the intake effects on diet digestibility has not been adjusted for feed intake. Each increment of feed above maintenance results in an equal increment in 3.5% FCM and FE increases from 1.23 to 1.96 as intake increases from 1X to 5X maintenance.

Unfortunately increasing feed intake also affects diet digestibility. In this case about the expected decline (NRC, 2001) is about 3 digestibility units or 0.03 Mcal/lb net energy for lactation (NE<sub>l</sub>) for each multiple of maintenance. This is illustrated both numerically and graphically in Figure 1-B. At 1X maintenance the diet has a NE<sub>l</sub> of 0.77 Mcal/lb while at 5X maintenance, the diet has an NE<sub>l</sub> of 0.64Mcal/lb. Each increment of feed above maintenance results in a smaller increase in 3.5% FCM. Here, FE increases from 1.12 to only 1.54 as intake increases from 1X to 5X maintenance. Note that there is little improvement in FE at greater than 4X maintenance feeding. This response illustrates why high milk production does not necessarily lead to huge increases in FE.

Figure 1. Unadjusted and adjusted 3.5% FCM production and 3.5% FCM/DMI in response to increasing feed intake from 1 to 5X multiples of maintenance<sup>1</sup>.

<b>A) Intake Unadjusted</b>	DMI, lb/d (X Maint)	13 (1)	26 (2)	39 (3)	52 (4)	65 (5)
	NE <sub>l</sub> Mcal(Mcal/lb)	10 (.77)	20 (.77)	30 (.77)	40 (.77)	50 (.77)
	3.5% FCM, lb/d	0	32	64	96	127
	FCM/DMI	--	1.23	1.64	1.84	1.96
<b>B) Intake Adjusted</b>	DMI, lb/d (X Maint)	13 (1)	26 (2)	39 (3)	52 (4)	65 (5)
	NE <sub>l</sub> Mcal(Mcal/lb)	10 (.77)	19.1 (.74)	27.4 (.700)	34.8 (.67)	41.3 (.64)
	3.5% FCM, lb/d	0	29	56	79	100
	FCM/DMI	--	1.12	1.43	1.53	1.54

<sup>1</sup>Assumes a 1375 lb consuming a diet with and 1X multiple of maintenance NE<sub>l</sub> value of 0.77 Mcal/l feed DM (NRC, 2001) where diet digestibility declines 3 percentage units per multiple of maintenance feeding.

## What are the Benchmarks for FE?

In order to establish benchmark FCM feed efficiencies, the published 50<sup>th</sup> percentile milk production data from 2009 DHIA summary for the Holstein and Jersey breeds (AIPL, 2010) were used. Lactation curves for milk, milk fat percent, and 3.5% FCM were generated for both breeds using Wood's (1969) formula with adjusted coefficients as reported by Dunlap et al. (2000) for Holsteins. These coefficients were also used for the Jersey breed since more recent coefficients specific to Jerseys are not available. Dry matter intake was predicted using the NRC (2001) intake prediction formula and along the lactation curve based on the predicted milk production and milk fat percent. The proportion first, second, and third or greater parity cows were assumed to be 34, 27, and 39%, with bodyweights (BW) of 536, 582, and 626 kg for Holsteins, respectively (Dunlap et al., 2000). The respective BW used for Jerseys were 395, 427, and 454 kg. Feed efficiency was then calculated as in Equation 1.

Figure 2 shows parity and days-in-milk (DIM) effects on FE in a 2009 50<sup>th</sup> percentile Holstein herd with a 305 day lactation average of 9820 kg (21,629 lb). By far that largest factor affecting FE is stage of lactation where FE declines from approximately 2.25 at the beginning of lactation to about 1.30 at the end of lactation. The rapid decline in FE with DIM is due to two factors: 1) Cows are in a negative energy balance at the beginning of lactation such that a portion of the milk produced is due to energy from tissue mobilization and not from feed; and 2) feed intake lags behind the lactation curve and peaks later on making the denominator (DMI) component of the FE equation larger and FE smaller. Once peak DMI is achieved, FE declines linearly at about 100 DIM. While there is a parity effect where mature cows have higher FE than first lactation cows, this is largely due to differences in milk production and to a lesser extent, the fact that first parity cows have “flatter” lactation curves.

Figure 3 shows parity and days-in-milk (DIM) effects on FE in a 2009 50<sup>th</sup> percentile Jersey herd with a 305 day lactation average of 6774 kg (14,920 lb). Similar to Holsteins, there is a rapid decline with DIM. Here the advantage of 3<sup>rd</sup> lactation vs. 2<sup>nd</sup> lactation is reversed. This may be more due to the effect of BW on predicted feed intake in the NRC 2001 equation rather than a real advantage with 2<sup>nd</sup> parity cows. Remember that the NRC (2001) was primarily based on Holstein cows. Just as with Holsteins, DIM is the most important factor affecting FE. In comparing the two breeds, average FE across a lactation for a 50<sup>th</sup> percentile Jersey herd was 1.45 as compared with 1.49 for the 50<sup>th</sup> percentile Holstein herd. Since the reduced Jersey effect is primarily due to disparity in the 3<sup>rd</sup> lactation, I doubt that there is a real breed effect as the values during the 1<sup>st</sup> and 2<sup>nd</sup> parities were similar.

Figure 2. Parity and days-in-milk effects on 3.5% FCM per dry matter intake in 2009 50<sup>th</sup> percentile Holstein herds with DHIA 305 day lactation averages of 8980 kg (21,769 lb) milk.

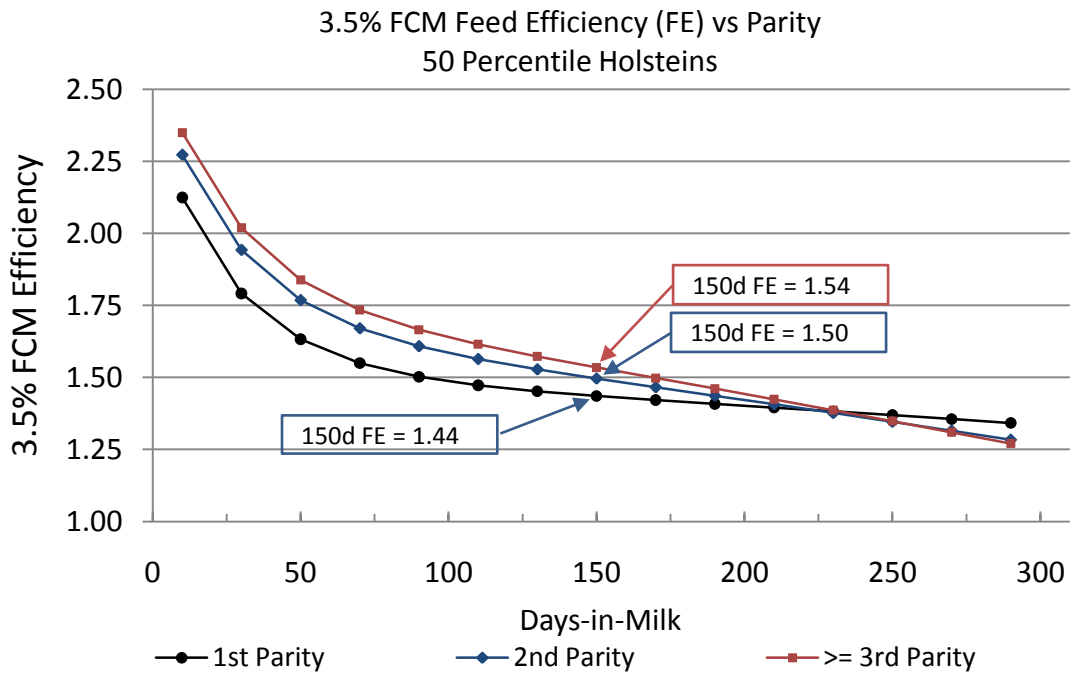
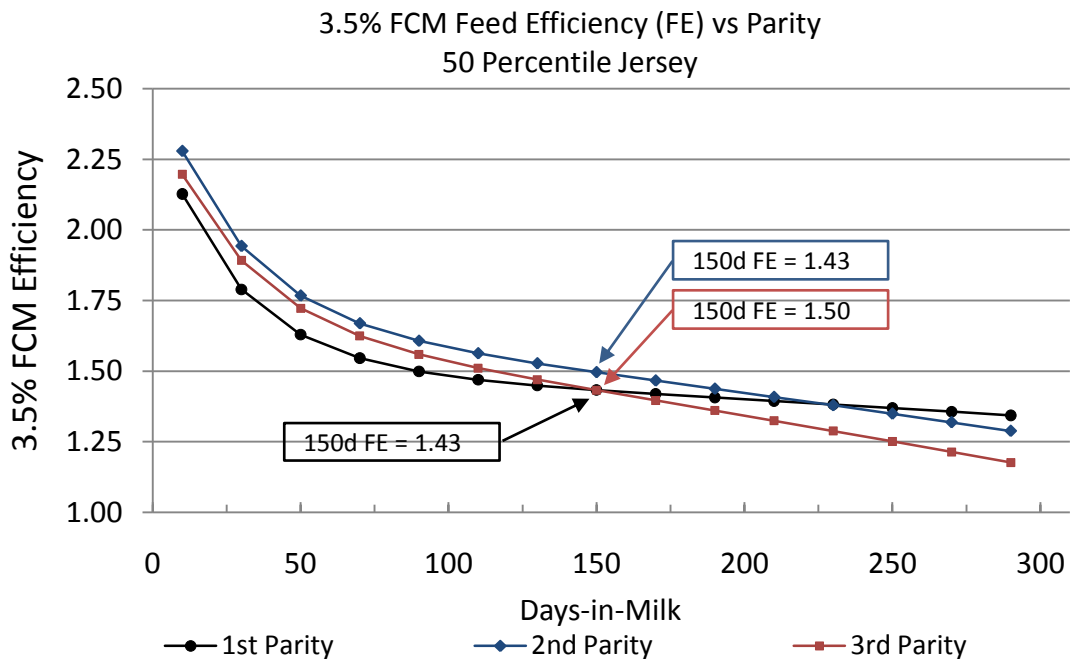


Figure 3. Parity and days-in-milk effects on 3.5% FCM per dry matter intake in 2009 50<sup>th</sup> percentile Jersey herds with DHIA 305 day lactation averages of 6774 kg (14,902 lb) milk.

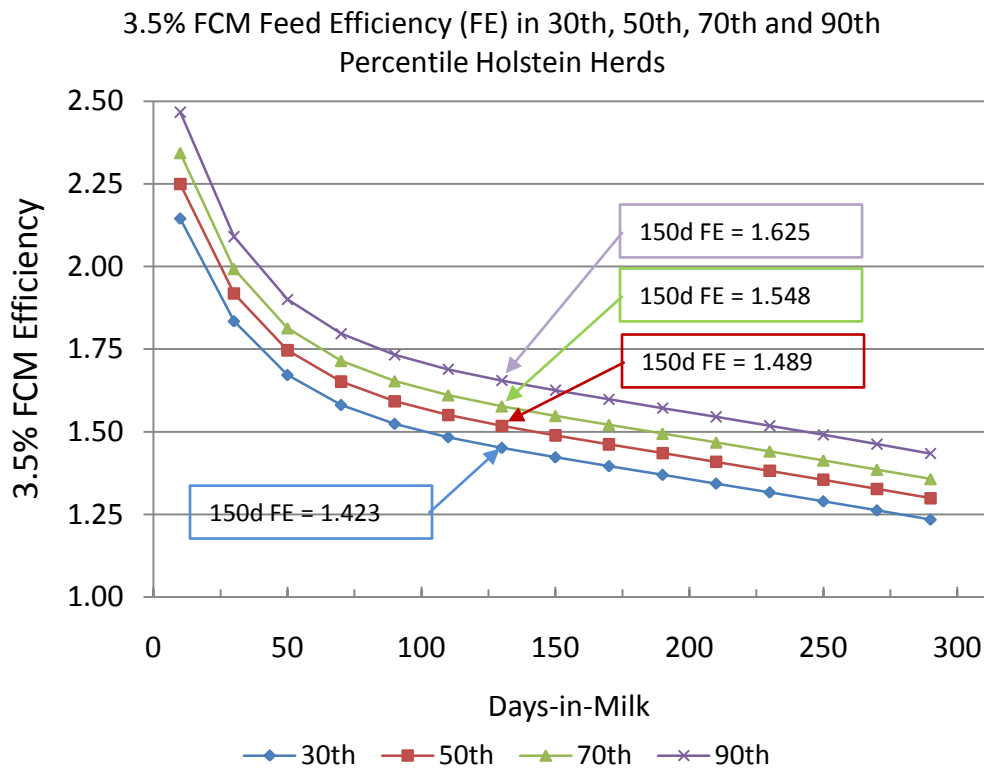


## Production Level Effects on FE

Figure 4 shows the effect of production level on FE using the 30<sup>th</sup> through 90<sup>th</sup> percentile Holstein herds from the AIPL (2009) summary. These herds had a range in 305 day lactation yields from 19,717 to 26,190 lb milk. The corresponding average daily 3.5% milk production in those herds would be approximately 66, 72.5, 78.6, and 87.5 lb per cow per day. Expected average feed intakes were respectively 45.1, 47.1, 49.1, and 51.9 lb. I would caution that the feed intake estimates may be low, especially at the higher end of production, since we assumed similar BW for all herds. Generally, herds with higher production also have larger cows which would increase feed consumption.

The FE at 150 DIM increased from 1.42 to 1.62 with increasing herd production. The curves showing the change in FE with DIM were nearly parallel suggesting a linear increase with increasing lactation yield. This suggests a standardized FE should be adjusted for level of milk production. In this example the change in FE was roughly a 0.01 FE units per lb 3.5% FCM meaning that comparisons of FE data from year-to-year should include an adjustment for milk production.

Figure 4. Milk production effects on 3.5% FCM per dry matter intake in 2009 30<sup>th</sup>, 50<sup>th</sup>, 70<sup>th</sup>, and 90<sup>th</sup> percentile Holstein herds with DHIA 305 day lactation averages of 8952, 9820, 10672, and 11890 kg (19,717, 21,629, 23,506, and 26,190 lb).



## 150 Day Feed Efficiency

Because of the rapid decline in FE with increasing DIM, evaluating overall FE in cows in very early lactation (< 60 DIM) probably has little meaning. So much of the high FE in early lactation is due to use of body tissue energy in support of milk production that FE at that stage of lactation may be a meaningless statistic. Also you would not necessarily want to have groups of early lactation cows that have an extremely high FE. That might reflect a greater loss of body condition resulting in poor feed intake and possibly subclinical or clinical ketosis.

As shown in Figures 2-4, once milk production and more importantly DMI peaks by 100 DIM, FE declines linearly for the remainder of lactation. This makes it possible to determine a DIM adjusted FE for a herd or group. DHIA calculates 150 day milk for comparing herd production on a month-to-month basis where daily milk production from individual cows is adjusted to a constant 150 DIM. This statistic is very useful for evaluating feeding and management changes in herd as it adjusts for the known effects of stage of lactation on milk production. Similarly a 3.5% FCM efficiency adjusted to a constant DIM would also be valuable in evaluating feeding changes that affect FE.

Using curve peeling techniques, it was found that the effect of DIM could be modeled well by an equation consisting of both linear and exponential decay components (model not shown). More importantly, it was also found that once the linear portion of the decline in FE occurred at 100 DIM, the percent decline was similar, about 0.1% per day. Conversion of actual FE to 150d FE is done by subtracting 150 from the actual DIM from 150 and correcting FE up or down by 0.1% per day.

Table 1 illustrates the correction to 150d FE for herds or groups of cows with varying DIM. Cows in Herd 1 averaging 125 DIM had the greatest measured FE (1.47) while those in Herd 4 at 200 DIM the lowest measured FE (1.43). When adjusted to a constant 150 DIM (150d FE) feed efficiency was actually greatest in Herd 4 at 200 DIM (1.502). In addition to the DIM adjustment, the expected 150d FE within a herd should also be adjusted for milk production. Herds with greater production should be expected to have a greater average FE. The suggested adjustment taken from above would be .01 FE units per lb 3.5% FCM production. Similar to the use of 150 day milk, 150 day FE could be used to evaluate feeding and management changes that affect feeding efficiency.

Table 1. Adjustment of measured FE (3.5% FCM/DMI) to a 150 day FE.

Herd	Days in Milk	Measured FE (3.5% FCM/DMI)	DIM minus 150	% Change (Difference *x 0.1)	Adjustment Factor	150d Adjusted FE
1	125	1.47	-25	-2.50	0.975	1.433
2	150	1.44	0	0.00	1.000	1.440
3	175	1.46	25	2.50	1.025	1.497
4	200	1.43	50	5.00	1.050	1.502

## Feed Effects on FCM Efficiency

There are numerous examples in the literature of feeding factors that can influence FE. On the dairy farm, effective management of feed resources may be one of the most important tools to improve feed utilization. Avoiding excessive handling of feeds and ensuring proper storage to reduce shrink losses improves farm FE. Proper silo management pays huge rewards in terms of silage storage losses. Proper feed bunk design and feeding management can reduce feed losses at the feeding row. Close attention to feed refusals such that they don't exceed 2-3% of the total amount fed reduces the loss of valuable dairy cow TMR. Even though cow feed refusals are typically fed to pregnant heifers so they are not a total loss, the cost of the dairy cow ration is considerably greater than that for the heifer ration. That said, I will focus on specific feeds and feed additives that can impact FE.

## Monensin Effects

Monensin has been used in the beef industry as a feed efficiency enhancer for 40 years. It was approved for use in lactating dairy cows in December 2005. In a meta-analysis of studies with lactating dairy cows Duffield et al. (2008) reported weighted mean monensin responses of -0.3 and +0.7kg/d for DMI and milk production, respectively. Unfortunately, FE was not reported nor was there sufficient information to calculate FE from that report. Perhaps the largest coordinated monensin experiment with lactating dairy cows involved 9 universities with 858 cows that was first reported by Symanoski et al. (1999). Feed efficiency as measured by 3.5% FCM/DMI increased from 1.50 to 1.56 at the highest level of monensin feeding. These responses would have been even greater had milk fat test been maintained with monensin feeding. Fat test has and continues to be a concern among dairy producers with monensin use. Anticipated FE responses would be about .06 units when feeding 300 mg/d monensin to dairy cows.

Table 2. Feed intake, milk production, and 3.5% FCM feed efficiency responses to monensin.

Monensin, g/ton: <sup>1</sup>	0	11	15	22
Dry matter intake, lb/d	43.9	43.4	42.8	42.3
Milk yield, lb/d	65.0	66.7	66.8	67.5
Milk fat, %	3.65	3.53	3.49	3.38
3.5% FCM milk (lb)	66.1	66.8	66.7	66.0
3.5% FCM/DMI	1.50	1.54	1.56	1.56
Energy efficiency (%)	--	+2.0	+2.5	+4.0

<sup>1</sup> Grams per ton of total mixed ration dry matter. Corresponding amounts of monensin using treatment means are: 0, 238, 321, and 465 mg per cow per day.

## Dietary Protein Effects

In the 1970's and 1980's there were a series of energy metabolism experiments conducted at both USDA-Beltsville and the University of New Hampshire on the effects of dietary crude protein (CP) on digestibility and milk production. In those studies increasing CP

increased digestibility and milk production, especially in diets containing less than 15% crude protein. These results were most likely due to deficiencies in rumen degradable protein required to optimize rumen microbial growth and rumen fermentation. More recently, Kalscheur et al. (2006) measured the production responses in cows fed diets ranging from 12.3 to 17.1% CP where rumen undegradable protein was held nearly constant (5.5 to 5.9%) and rumen degradable protein ranged from 6.8 to 11.2%. The results from that experiment and those of Holter et al. (1982) are shown in Table 1.

In both experiments, diets containing less than 15.5% CP had reduced FE. There was no consistent response in FE to feeding more than 15.5% CP. In the study by Holter et al. (1982) diet DM digestibility increased linearly from 57.2 to 68.2% with increasing CP. Holter et al. (1982) also reported the results of a 2<sup>nd</sup> experiment where dietary CP ranged from 13.8 to 20.9% of diet DM. Dry matter digestibility increased from 68.6 to 76.3% but there were no FE responses. I would conclude that protein effects on FE are apparent when diet RDP is less than required, particularly when less than 9% of diet DM. Expected FE responses would be on the order of 0.015 to 0.03 units per percentage unit CP up to 15.5% diet CP or 9% RDP in the ration DM.

Table 3. Summary of diet crude protein effects on 3.5% FCM feed efficiency

Study				
Kalscheur et al., (2006)				
Diet crude protein, %	12.3	13.9	15.5	17.1
Dry matter intake, kg/d	20.5	21	21.2	21.4
3.5% FCM, kg/d	32.9	33.4	34.9	35.9
FCM/DMI	1.604	1.592	1.649	1.679
Holter et al. (1982)				
Diet crude protein, %	11.0	13.7	15.7	19.2
Dry matter intake, kg/d	17.5	18.3	18.7	18.9
3.5% FCM, kg/d	22.8	28.2	31.2	30.3
FCM/DMI	1.309	1.543	1.670	1.601

### Dietary Fat Effects

Because of its increased energy density, dietary fat should improve FE in proportion to the difference between fat source NE<sub>1</sub> concentration and the NE<sub>1</sub> concentration the current diet being fed. Assuming that fat does not change the energy partition between tissue and milk production, the improvement in FE can occur in one of two scenarios: 1) Added fat maintains NE<sub>1</sub> intake and 3.5% FCM output while reducing DMI; or 2) Added fat maintains DMI while increasing NE<sub>1</sub> which is used to increase 3.5% FCM. Alternatively, the response could be a combination of Scenarios 1 and 2. Table 1 shows theoretical outcome of Scenarios 1 and 2 using the substitution of 2% additional dietary fat in a diet fed to mature Holstein cows producing 35 kg/d FCM, eating 23.6 kg/d DMI of a diet containing 1.55 Mcal NE<sub>1</sub> /kg DM and a baseline FE

of 1.48. The published NE<sub>1</sub> values of various fat sources from the NRC (2001) were used in the calculations.

If fat addition causes feed intake to decrease and milk production is constant (Scenario 1), FE increases by 0.06 to 0.07 units depending on the fat source and on a percentage basis, by 3.8 to 5.0 percentage units. However, if DMI is increased causing energy intake and milk production to increase (Scenario 2), FE is increased by 0.16 to 0.20 units and on a percentage basis, by 12 to 13 percentage units. The reality probably lies somewhere in the middle between no change in feed intake and no change in milk production. However, the addition of dietary fat theoretically could increase FE quite dramatically depending on its effect on DMI and milk production. The expected response to dietary fat would be on the order .03 to .10 FE units per percentage unit fat addition.

Table 4. Theoretical changes in 3.5% FCM feed efficiency with substitution of 2% fat in the diet.

Diet/Fat Source:	Basal Diet	Ca Soaps	Hydrolyzed Tallow	Tallow
3X NE <sub>1</sub> , Mcal/kg	1.55	5.02	5.41	4.53
<u>DMI ↓, NE<sub>1</sub> Intake ↔, 3.5% FCM ↔</u>				
FCM, kg/d	35.0	35.0	35.0	35.0
DMI, kg/d	23.6	22.6	22.5	22.7
3.5% FCM/kg DMI	1.48	1.55	1.56	1.54
Change in 3.5% FCM/kg DMI		0.07	0.07	0.06
% Change in 3.5% FCM/kg DMI		4.5	5.0	3.8
<u>DMI ↔, NE<sub>1</sub> Intake ↑, 3.5% FCM ↑</u>				
FCM, kg/d	35	39.3	39.7	38.7
DMI, kg/d	23.6	23.6	23.6	23.6
3.5% FCM/kg DMI	1.48	1.66	1.68	1.64
Change in 3.5% FCM/kg DMI		0.18	0.20	0.16
% Change in 3.5% FCM/kg DMI		12.2	13.4	10.7

### Dietary Cation Anion Difference (DCAD) Effects

Ruminants typically are fed diets with dietary cation anion differences (DCAD) ranging from 250 to 450 meq/kg DM. Most of the active cation is potassium as forages are a rich source of this element. Added sodium typically comes from sodium bicarbonate (Salt, NaCl is cation anion neutral). Hu and Murphy (2004) summarized the literature responses to increasing DCAD in dairy cows and found maximal DMI and 4% FCM at 400 and 490 meq/kg diet DM, respectively. We reported responses to added potassium (Erdman et al., 2008) in an experiment with 45 Holstein cows during the first 20 weeks postpartum. This experiment was designed to examine the effects of mineral supplementation in corn silage based diets as compared to 50:50 alfalfa hay-corn silage diets. In that study, potassium carbonate and calcium carbonate were added to a corn silage (corn silage + DCAD) diet to match the potassium and calcium

concentrations in the alfalfa hay-corn silage diets. We found a 0.14 unit increase in FE with potassium addition that raised the dietary DCAD in the corn silage based diet from 251 to 336 meq/kg DM (Table 4). White et al. (2008) reported similar results in a study which raised the DCAD from 250 to 420 meq/kg using potassium carbonate. Using the equations for DMI and FCM responses to dietary DCAD from the meta-analysis of Hu and Murphy (2004), the calculated FE by increasing DCAD from 250 to 400 meq/kg DM was increased from 1.31 to 1.36.

Using principal components analysis on the dataset of Hu and Murphy (2004), we (Erdman unpublished, 2010) found that FCM increases in response to DCAD using either sodium (bicarbonate) or potassium (carbonate or bicarbonate). With sodium the increase in FCM was associated with an increase in feed intake. However, with potassium, the increase in FCM was not associated with increased feed intake. This suggests that potassium is potentially stimulating a change in digestibility which may correspond to the marked improvement in FE with potassium supplementation (Erdman et al., 2008; White et al., 2008). The expected response to dietary potassium would be on the order of 0.07 to 0.15 FE units depending on the basal DCAD concentration.

Table 4. DCAD Effects on FE in corn silage based diets (Adapted from Erdman et al., 2008)

Item	Alfalfa Hay-		Corn Silage	SEM	P-value
	Corn Silage	Corn Silage	+ DCAD		
DCAD, meq/kg DM	281	251	336	---	---
DMI, kg/d	22.0	22.7	20.7	0.52	0.395
Milk					
kg/d	35.6	35.5	37.8	1.25	0.325
Fat, %	3.91	4.32	4.08	0.113	0.044
3.5% FCM, kg/d	37.9	40.4	41.4	1.45	0.197
FCM / DMI	1.76	1.80	1.94	0.050	0.029

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