Feed Efficiency in Lactating Dairy Cows

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Efficient utilization of resources is an important economic component of any business operation. On dairy farms, feed is the largest single cost of production; therefore, the efficient conversion of home-grown and purchased feed nutrients into saleable milk directly affects the profitability of a dairy. Feed efficiency (FE) as a measure of converting nutrients into animal product has been used in the beef, swine and poultry industry for several years, but only recently has the dairy industry started evaluating FE of lactating cows. Good FE is not only of economic importance, but also is a monitor of nutrient management on farms. As FE increases, more nutrients are directed into milk production with less manure and nutrients excreted.

MEASURING FEED EFFICIENCY

Adjusting for milk fat content puts all dairy cows on an energy output equivalent basis allowing for a more accurate comparison of feed DM (energy) used for production. Use of 3.5% FCM is necessary for comparison of FE between breeds of cattle, cows at different stages of lactation, and cows and/or herds with high or low fat tests. When milk production is corrected to 3.5% FCM, FE should be the abbreviation used for feed efficiency. When milk is not corrected for fat content, the conversion of DM into milk should be referred to as dairy efficiency (DE). In this paper, an abbreviation of FE will represent feed efficiency for milk standardized to 3.5% fat and conversion of DM into milk uncorrected for fat content will be denoted as DE. Knowing whether or not milk has been corrected for fat content is important in the evaluation of feed efficiency. In a study by Britt et al. (2003) on the efficiency of converting DM to milk in 13 Holstein herds, the average DE value across the 13 herds was not different at 1.36 compared to 1.40 for FE. However, the difference between DE and FE within a herd was as great as 0.12. In an analysis of 476 treatment observations in a data set compiled by Agri-King, Inc. from published articles in the scientific literature, the difference between FE and DE across studies ranged from -0.28 to 0.41 with an average difference across all studies of 0.07. The need to use 3.5% FCM in calculating a feed efficiency value is more clearly illustrated in the following example of a cow producing 36.3 kg of milk and consuming 22.7 kg of DM per day:

Fat %	DE	FE
3.0	1.60	1.47
3.5	1.60	1.60
4.0	1.60	1.73

The DE is 1.6 for all milk fat percentages whereas correcting milk to 3.5% FCM changed FE 0.26 across the 1% unit change in milk fat content. The data base from the scientific literature indicates a 1% change in milk fat percent will generally result in a 0.25 change in FE.

FACTORS AFFECTING FEED EFFICIENCY

Feed efficiency can vary from 1.0 to nearly 2.0 during the lactation of a cow or across farms. Several factors influence FE measurement besides milk fat content and need to be considered when interpreting and comparing FE.

Body weight. Body weight (BW) is of particular importance in evaluating FE between cows in different stages of lactation and between breeds. Veerkamp (1998) pointed out in a paper on selection for economic efficiency that if two cows of equal BW are compared, the cow with 25% more milk production will have a 10 to 15% higher FE. Conversely, two cows at equal milk production, the cow with 25% less BW will have a 10 to 12% higher FE. An example of how BW affects FE at equal milk production is shown in Table 1. Cows with lower BW have a higher FE.

High milk production. High producing cows are more energetically efficient because more of the consumed energy goes to milk production than maintenance. Stated differently, maintenance becomes a smaller proportion of the total energy intake; therefore, more product output per unit of energy intake is achieved, which increases FE. High producing cows are always more efficient than low producing cows even though they consume more feed. But, are they more efficient in using energy or feed DM consumed above maintenance for milk production than lower producing cows? If the amount of feed DM needed for maintenance is subtracted from total DM intake, the effect of BW on FE is removed and the remaining feed DM is primarily used for milk production. An example of how FE can change when only DM intake above maintenance is used to calculate FE is shown in Table 2.

Body weight change. Before 60 days in milk (DIM), a high FE value may reflect the loss of BW to support milk production. Because BW, or more correctly the energy in BW loss, is unaccounted for in FE calculations, cows losing BW energy to support milk production will always have a higher FE than cows gaining BW. Between 100 and 200 DIM, cows should not be gaining or losing substantial amounts of BW and should be in the period of lactation where BW change has the least affect on FE. After 200 DIM, cows will begin to gain body weight and FE will decrease as feed is partitioned into weight gain and not milk production.

Body condition score (BCS). Because BCS is easier to obtain on farms than BW, consideration was given to the possible use of change in BCS as an indicator for adjusting feed intake for gain or loss in body tissue (weight). A 30-day change in BCS could be obtained and the energy corresponding to the loss or gain in BCS could be credited either negatively or positively to milk production. By converting BCS gain or loss into milk equivalents, FE of early and late lactation cows can be compared. An example of how converting BCS change into milk production equivalents changes the comparison of FE between early and late lactation cows is in Table 3. Correcting for BCS change indicates cows in late lactation and early lactation have similar efficiencies in converting feed to milk (Table 3). Because replenishing energy reserves (BW) is an essential function of cows in late lactation, feed utilized for BW gain should not be considered as an inefficiency. On the contrary, BW loss is a normal and important function of early lactation cows. However, excessive losses should not be given credit as efficient feed utilization. A BCS corrected FE of 1.5 should be a good target for conversion of feed to milk across all DIM.

Days in milk (DIM). Figure 1 shows farm DE data from 686 pens of lactating Holstein cows by DIM. The average DE across DIM was 1.56 with the lowest DE occurring in late lactation and the highest DE occurring in very early lactation. The differences in DE between early and late DIM are reflections of BW being lost or gained.

In early lactation, a high FE (>1.8) could indicate significant amounts of BW are being mobilized to support milk production, in which case cows often become ketotic and body reserves are depleted to a point where both milk production and reproduction are negatively affected. A very low FE (<1.2) in early lactation can signal health problems such as acidosis or, if healthy, a very poor producing animal.

A 1.5 to 1.6 FE is a reasonable target for cows or herds 150 to 200 DIM. For cows greater than 250 DIM, a FE below 1.4 should be expected. The lower FE is a result of lower energy diets being fed and the sifting of nutrient intake from milk production to BW gain, replenishment of body condition and support of pregnancy. The decrease in FE during late lactation is from a decrease in milk production without a proportional decrease in feed intake.

Changes in maintenance requirement. Anything that increases the maintenance requirement will lower FE. Cows on pasture or cows required to walk long distances to and from a parlor will have a lower FE than tie-stall housed cows. Tennessee researchers (Britt et al., 2003) reported DE was higher when temperatures were below 21º C than when temperatures were above 21º C. An increase in maintenance associated with heat stress and a subsequent decrease in milk production were attributed to the lowering of DE. Extended periods of standing such as during periods of heat stress also will decrease DE.

Genetics. Genetics ultimately determines how nutrients are partitioned between maintenance, milk production and other metabolic functions. Gibson (1986) compared DE between high and low milk production genetic lines of British Friesians and Jerseys. Friesians had a higher DE but when milk was corrected for fat content there was no difference in FE. High milk genetic lines were more efficient than low genetic lines in both breeds.

Feed digestibility. Increasing the digestibility of feeds means more nutrients will be available for milk production. Some common ways of increasing DM digestibility include: proper processing of corn silage and grain, feeding high quality forages with high NDF digestibility and balancing rations to meet nutrient requirements.

Cows require amounts of digestible nutrients to produce milk and not percentages or concentrations of nutrients in the diet DM. Although digestibility as a percent of the diet decreases with increasing DM intake, the quantity of digested nutrients available to an animal increases with increasing intake. The 2001 Dairy NRC takes this into consideration when calculating the energy content of a diet and has a formula to apply a variable discount to the TDN content of the diet as DM intake increases. Gabel et al. (2003) demonstrated this effect by feeding the same diet to lactating dairy cows at 1.4, 2.7 and 4.6 times maintenance energy requirements. The DM digestibility of the diet decreased linearly from 74.8% to 72.3% to 67.2% as diet DM intake increased. Digestibility of energy decreased 4.1% per multiple increase of maintenance energy intake; a very similar value was reported in the 2001 Dairy NRC. Neutral detergent fiber (NDF) is less digestible than nonfiber carbohydrates (starch and sugar). If digestibility is related to FE, then as the percentage of NDF in the diet increases, particularly from forages, FE should decrease. A summary of studies published in the Journal of Dairy Science from 2002 to 2004 showed a decrease in FE from 1.7 to 1.4 as total NDF in the diet DM increased from 25 to 35%.

Maximizing both the digestibility of nutrients and DM intake will result in the highest milk production. When both diet digestibility and DM intake are maximized, FE may not be the highest, but economic returns from milk production should be optimal. Growth and reproduction. Young cows will generally have a lower milk production as they partition some nutrients into growth. This will result in a lower FE than second or later lactation cows at the same DM intake. Pregnant cows may have a decreased FE because of fetal energy requirements; however, requirements are very minimal until the third trimester of gestation. Nutrient imbalance. Overfeeding or underfeeding of nutrients may adversely affect FE.
University of Illinois research (Ipharraguerre, 2005) has shown both the amount and source of crude protein (CP) in the diet affects FE (Table 4). As dietary CP increased (14.8, 16.8 and 18.7%), FE only increased slightly. Substituting a higher rumen undegradable protein source of animal-marine protein for soybean meal increased FE with increasing dietary protein level. Efficiency of converting CP into milk protein was highest when low protein diets were fed.

ON-FARM FEED EFFICIENCY

As previously discussed, a variety of factors (BW, DIM, genetics, environment, activity, nutrient imbalances, etc.) can affect FE on-farm. When FE is calculated taking these factors into consideration, it is considered an adjusted feed efficiency (AFE) value. To compare FE with AFE we conducted a field trial using nine dairy farms in Western Wisconsin, and Northwest and Southeast Minnesota. Three farms utilized tie-stall facilities and 6 farms free-stalls. Milking herd size ranged from 63 to 740 cows. Data was collected twice on each farm; once each during the summer of 2005 and winter/spring of 2006. An AFE value was calculated using the Feed Efficiency Determinator (FED) program developed by Zinpro Corporation, Eden Prairie, MN. Information required by the FED program included: average DM intake and milk yield, DIM, BW, fat %, protein %, temperature, relative humidity, wind speed, sunlight, and walking distance. Feed efficiency and AFE are calculated on energy corrected milk (ECM) in this program rather than 3.5% FCM.

Results are shown in Table 5. Across all farms, FE was within a range (1.3 to 1.8) expected for herds between 158 and 231 DIM. An exception was Farm 3 during the winter/spring measurement period where

FE was very high at 2.2. After the data collection period on this farm, it was discovered the weigh scales on the mixer wagon were incorrectly weighing feed amounts. The AFE was higher than FE for 16 out of the 18 data recordings indicating that on all farms, feed is being utilized for functions other than milk production. The large variation in FE and AFE across farms shows why there should not be a single target for FE and why a comparison of FE for benchmarking across farms is difficult. The best utilization of FE for management purposes is within a farm, and for monitoring changes in feeds and the feeding program on the farm.

PROTEIN EFFICIENCY

Increasing protein efficiency, or the conversion of dietary protein to milk protein, is economically and environmentally desirable. Protein is a major fraction and a major cost in dairy rations; as more of the protein consumed is converted to milk protein, less N is excreted into the environment. Using 131 studies from the Journal of Dairy Science (primarily 2000- 2006) we conducted a meta-analysis to determine the relationship between dietary crude protein (CP) and 1) milk yield, 2) milk protein yield, and 3) protein efficiency. In addition, the relationship between the CP:energy ratio in diets on protein utilization was determined. A positive relationship between dietary CP concentration and milk yield ($R2=0.17$; $P<0.001$) was found (Figure 2a). However, this relationship was only modest due to the large amount of variation in milk yield at similar CP concentrations. For example, cows fed diets with a CP concentration of approximately 18% produced milk ranging from 31 to 40 kg/d. Likewise, the effect of dietary CP on milk protein yield was variable and weakly ($R2=0.16$; $P<0.001$) related (Figure 2b).

The positive relationship between dietary CP concentration and milk yield has probably stimulated the use of high-CP rations to improve milk production. However, as milk yield increases, milk protein concentration generally decreases resulting in a negative association between efficiency of protein utilization (EPU), defined as milk protein yield divided by crude protein intake, and CP concentration of the diet (Figure 3a). Based on our meta analysis, a 1 percentage unit increase in CP concentration of the diet decreased the EPU by 1.52 percentage units. Interesting to note is the low efficiency of protein use (maximum of about 35%) unlike FE where efficiencies are 120 to 180%. For most dairy farms, an EPU between 25 to 30% should be expected with anything above 30% considered excellent.

Van Straalen et al. (1994) indicated that energy status of the animal plays an important role in determining the response to absorbed protein. These authors found a strong negative correlation between the ratio of absorbed protein:energy intake and efficiency of protein utilization. Similarly, as shown in Figure 3b, our meta-analysis also found a strong relationship between the dietary protein:energy ratio and EPU ($R2 = 0.44$; $P<0.001$). In this model, energy was expressed as Mcal/kg of NEL and CP concentration was divided by 10 to transform its units close to those of NEL. Therefore, the relationship that was found indicates that to maximize EPU, the ratio between CP / 10 and net energy concentration (Mcal/kg DM) should be as close to 0.80 as possible. In other words, for a ration with an energy density of 1.7 Mcal/kg, the optimum CP content to maximize EPU should be about 13.6%.

Potential ways to improve protein utilization by dairy cows include balancing diets for lower protein and higher carbohydrates decreasing the protein:energy ratio of the diet. More research on the forms of carbohydrates, their digestibility and their interaction with amounts and forms of protein in diets is needed before a specific protein:energy ratio can be utilized in the formulation of dairy cattle diets. In addition, increasing our understanding of amino acid balancing in diets will be crucial. As indicated by the NRC (2001), dietary protein utilization improves when the essential amino acid profile absorbed more closely meets the animal’s essential amino acids requirement. Feeding diets that meet amino acid requirements of dairy cattle should reduce wastage of dietary protein, increase efficiency of protein utilization for milk synthesis, and allow for decreased CP levels in diets.

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Table 1. Impact of body weight on feed efficiency[a]

Body weight, kg	DM[b], kg/day	FE
544	22.3	1.55
635	23.7	1.46
726	25.0	1.38
816	26.2	1.32

[a] Milk production is 34 kg at 3.6% fat/day for all BW.
[b] DM intake from 2001 Dairy NRC.

Table 2. Effect of BW on FE of cows producing 36.3 kg/day of 3.5% FCM.

Body weight, kg	590	680
DM intake, kg/day	24.4	25.6
Feed efficiency	1.49	1.42
Maintenance DM intake, kg/day	11.6	12.8
DM intake above maintenance for milk, kg/day	12.9	12.9
Feed efficiency above maintenance	2.81	2.81

Table 3. Impact of correcting for body condition score (BCS) change on feed efficiency (FE) measurements of early and late lactation cows[a].

Item	Early	Late
Days in milk	45	265
DM intake, kg/day	22.7	20.0
Milk – 3.5% FCM, kg/day	40.8	20.4
Unadjusted FE - 3.5%FCM/DM intake, kg	1.80	1.02
Body condition score change/30 days	-0.5	+0.5
Milk equivalent to BCS change/day, kg/day	9.0	11.4
Milk adjusted for BCS change, kg/day	31.8	31.8
Adjusted FE – 3.5%FCM/DM intake, kg	1.40	1.59

[a] Assumptions used to calculate milk equivalency to BCS change were as follows:

Early lactation cows started at BCS of 3 and lost 0.5 BCS during a 30-day period.

A decrease of 0.5 BCS equals 200 Mcals of NE_L or 6.6 Mcals of NE_L/day over 30 days.

Milk NE_L requirement is 0.73 Mcal/kg; therefore, a loss of 6.6 Mcals/day supports 9.0 kg of milk/day. In late lactation cows, a gain of 0.5 BCS from 3.0 to 3.5 in 30 days requires 250 Mcals of NE_L or 8.3 Mcal/day (250 Mcals/30 days) of energy goes to BCS gain. Milk equivalency is 11.4 kg/day (8.3 Mcal per day to BCS/0.73 Mcal for milk).

Table 4. Feed efficiency of cows fed two sources, animal-marine protein blend (AMP) or soybean meal (SBM) at three dietary concentrations (14.8, 16.8 or 18.7%) of crude protein.

	14.8% CP		16.8% CP		18.7% CP	
	SBM	AMP	SBM	AMP	SBM	AMP
Feed efficiency (3.5% FCM, kg/DM intake, kg)						
15 to 112 days in milk	1.59	1.64	1.58	1.65	1.61	1.68
15 to 210 days in milk	1.46	1.49	1.43	1.52	1.50	1.57
Feed efficiency by milk production						
Average 45.6 kg/day	1.62	1.73	1.63	1.64	1.65	1.72
Average 37.9 kg/day	1.53	1.58	1.55	1.61	1.54	1.64
Milk nitrogen/intake nitrogen						
Nitrogen efficiency, %	30.1	33.0	28.5	27.5	25.6	25.1

Table 5. Feed efficiency (FE) and adjusted feed efficiency (AFE) of 10 Wisconsin or Minnesota dairy farms taken during the summer of 2005 or winter of 2006.

	Summer 2005				Winter/Spring 2006			
Farm	DIM	FE[a]	AFE[b]	AFE-FE	DIM	FE[a]	AFE[b]	AFE-FE
1	187	1.85	1.95	+0.10	213	1.66	1.70	+0.17
2	194	1.40	1.47	+0.07	190	1.57	1.64	+0.07
3	178	1.76	1.82	+0.06	197	2.20	2.35	+0.15
4	186	1.49	1.69	+0.20	189	1.59	1.63	+0.04
5		1.29	1.43	+0.14	175	1.45	1.55	+0.10
6	231	1.47	1.58	+0.11	149	1.41	1.42	+0.01
7	195	1.74	1.82	+0.08	203	1.30	1.89	+0.59
8	191	1.76	1.86	+0.10	215	1.46	1.44	-0.02
9	201	1.66	1.76	+0.10	158	1.77	1.75	-0.02

[a] FE = Feed efficiency (ECM, kg/DMI, kg).

[b] AFE = Adjusted feed efficiency (ECM, kg/DMI, kg); calculated using the FED program by Zinpro Corporation, Eden Prairie, MN.

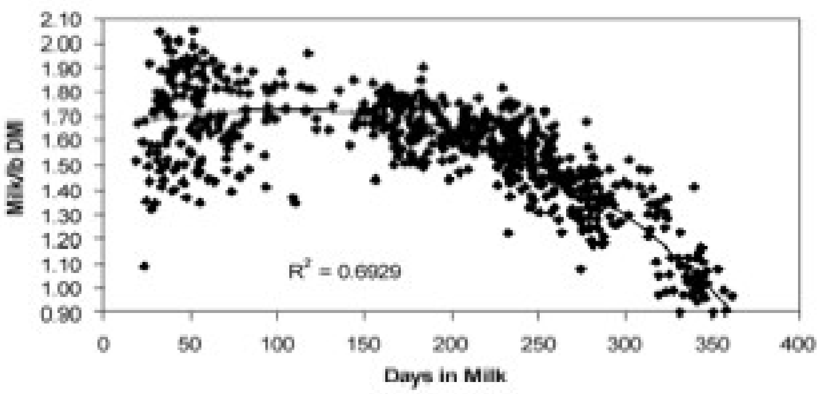

Figure 1. Relationship between dairy efficiency (milk/DM intake) and days in milk.

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