Managing Measures of Feed Costs: Benchmarking Physical and Economic Feed Efficiency

Normand St-Pierre[1]
Department of Animal Sciences
The Ohio State University

Abstract

Problems associated with the measurement and monitoring of physical feed efficiency are reviewed. We propose targets for gross feed efficiency based on milk production and stage of lactation and present elements to diagnose possible causes when actual results depart from the proposed targets. This is followed by the development of a meaningful benchmark of economic feed efficiency based on market prices for milk components, amounts of major nutrients required for the production of these milk components, and market prices of these nutrients derived from market prices of all feeds traded in a given market. The resulting index, the **Cow-Jones Index**, is used as a proxy to a benchmark of income-over-feed-costs with the clear benefits that: (1) it doesn't use a specific benchmark diet, (2) it uses market information for both milk components and feeds, and thus, can be regionalized, and (3) it can be easily calculated for different levels of target milk production.

Introduction

Feed costs have always been a dominant portion of the cost of producing milk in the United States (St-Pierre et al., 2000). The unprecedented rise in market prices of all feedstuffs that has occurred in the U.S. over the last 18 months has stimulated much interest in feed management and measures of the economic efficiency of feed use (i.e., dietary nutrients) on dairy farms. Physical efficiency is embedded and is a vital component of economic efficiency. Feed costs management and monitoring must ensure: (1) cost-efficient feeds are grown and purchased to make up the diets, (2) diets made of these feeds are nutritionally balanced for the targeted milk production, (3) of all possible balanced diets that could be used, the one formulated is close to an economic optimum, (4) that the formulated diets are those actually fed to the animals, and with minimum wastage, and (5) the costs and measurements used are accurate. The identification of under-priced and over-priced feedstuffs using a multiple regression approach has been presented at this Conference (St-Pierre, 2000) and will not be repeated here. A nutritionally balanced diet should perform according to nutritional expectations. That is, the conversion of feeds into milk should be done with an efficiency that is predictable and does not violate the laws of thermodynamics. Thus, we first address the monitoring of physical feed efficiency before we move on to monitoring the economic efficiency of the nutrition program on a dairy farm.

Physical Feed Efficiency

During the 1990's, it was often stated that the first objective of nutrition management and feed formulation was to maximize feed intake of lactating dairy cows. This dogma was derived from the strong association (correlation) between daily dry matter intake **(DMI)** and milk production. Of course, this interpretation was incorrect because a

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[1] Contact at: 2029 Fyffe Court, 221 Animal Science Bldg., Columbus, OH-43210-1995, (614) 292-6507, FAX: (614) 292-1515, Email: st-pierre.8 @osu.edu

correlation (or simple regression) does not imply a cause and effect. Over time, field observations of DMI that were disproportionately high to milk production levels were being reported, raising concerns about the validity of the "maximize DMI" dogma. The author remembers all too well visiting a herd where apparent daily DMI exceeded daily milk production. Gradually, this dogma was replaced by one based on gross feed efficiency **(GFE)**, which at first was simply expressed as units of milk per unit of DMI and later was replaced by slightly more complex measures such as pounds of 3.5% fat-corrected milk or energy-corrected milk per pound of DMI. Unless one is facing a situation of milk production with abnormally low or high fat content, the use of any of these energy-corrected feed ratios generally leads to the same (and sometimes erroneous) conclusions as the simple GFE based on raw milk production.

There are some problems associated with the interpretation of the GFE.

Effect of stage of lactation on GFE

Figure 1a presents theoretical lactation and DMI curves for a 1,500 lb cow in her third parity, producing 22,000 lb of milk in 330 days of lactation with average fat and true protein concentrations of 3.60 and 3.10%, respectively. The curve was generated using the well-known gamma (a.k.a., Wood) function (Kellogg et al., 1977):

$$\text{Milk (lb/day)} = 17.01\ t^{0.345}\ e^{-0.00702\,t} \qquad [1]$$

where t is time post-calving (days). On each day, expected DMI was calculated using the NRC (2001) equation. Milk production peaked at 101 lb/day at 50 days in milk **(DIM)**, while DMI peaked at 58.5 lb/day at 80 DIM.

Figure 1b shows the calculated GFE over the course of the lactation. Predictably, GFE is the highest in early lactation (2.21 in the first month), decreasing monotonically over the lactation cycle to reach a value of 0.78 in the eleventh month. After the third month of lactation, the decline in GFE over time is nearly linear, dropping 0.11 unit per month of lactation (0.0037 unit per day). Over the entire lactation, GFE averages approximately 1.4, a value about equal to the GFE at 150 DIM. Because of the significant effect of DIM on GFE, it seems important that the benchmark be adjusted for DIM in herds that do not have uniform calvings throughout the year. Essentially, the benchmark should be reduced by 0.11 units for each month that the average DIM exceeds 150 days.

Effect of milk production level on GFE

In theory, increased productivity should be associated with increased GFE due to the dilution of maintenance. In Figure 2, we calculated the GFE over a lactation cycle at three levels of production: 16,000, 22,000, and 28,000 lb/lactation (330 days). The average GFE over the lactation cycle drops from approximately 1.6 to 1.4 when production is reduced from 28,000 to 22,000 lb/year, and to 1.15 when production is further reduced to 16,000 lb/year. Animal production has a profound effect on the expected GFE. If GFE is to be used as some sort of efficiency benchmark, it is clear that the target must be adjusted for the level of production in a herd. Whether the actual level of production is optimal is a very different question than whether the animals are converting feeds according to nutritional (physical) expectations.

The relationship between milk production and GFE is illustrated in Figure 3, where we calculated DMI at 90 DIM for a 1,500 lb cow producing milk at 3.6% fat, 3.1% protein, and 5.7% other solids (i.e., 4.8% lactose). Estimates were based on NRC (2001). The relationship between daily milk production and DMI is a straight line crossing the X-axis at a value of 26.6 lb of DMI and with a slope of 2.98 (i.e., a change of ~ 3 lbs in production is associated with a change of ~ 1 lb in

DMI). In this figure, the slope of a line connecting any point on the milk production – DMI curve to the (0, 0) origin is in fact the GFE at that level of daily production. Hence, it is easy to see how GFE rises as production increases. It is also easy to see how each additional unit of production increases GFE at a decreasing rate. For example, GFE rises from 1.0 to 1.5 (a 0.5 unit change) when production is increased from 40 to 80 lb/day, but only rises from 1.5 to 1.8 (a 0.3 unit change) when production is increased from 80 to 120 lb/day. In fact, GFE converges towards an asymptote of 2.98 – its maximum value for milk with this composition.

Effects of ration energy density

The calculations done so far assume that the diets are formulated according to NRC requirements and estimated DMI. For example, a 1,500 cow producing 75 lb/day of milk at 3.6% fat, 3.1% protein, and 5.7% other solids has a total NE_L requirement of 34.7 Mcal/day and is expected to consume 51.8 lb/day of DMI, thus requiring a diet with an energy density of 0.67 Mcal/lb to attain a zero energy balance. Changing the energy density of the diet would likely alter DMI. Assuming that the animal and the diet are in a state where physiological factors are the predominant drivers of feed intake (Conrad et al., 1964), we can calculate the expected GFE for diets of different energy densities (Table 1). Over a range of reasonable diet NE_L densities (0.65 to 0.74 Mcal/lb), GFE varies by nearly 0.2 units. In Table 1, calculations are based on energy density being increased by the addition of grains to the diet, but the same could be done using digestible fats. Depending on the relative costs of grains, forages, and fats, increasing the energy density above the implied energy density "requirement" does improve GFE, but this may lead to reduced income. The important point here is to remember that the objective should not be to maximize GFE but to achieve a GFE in line with the expectations derived from the model used to formulate the diet.

Setting up meaningful GFE benchmarks

In Table 2, we propose target GFE for Holstein cows at different levels of milk production. If milk production is expressed in pounds of milk per cow per day (i.e., milk production for a herd - or for a pen - is at a given point in time), then the target GFE is read directly from the table. For example, a pen of cows milking 80 lb of milk has a GFE benchmark of 1.54. If milk production is expressed as rolling herd average or other forms of annual production, then the benchmark GFE must be adjusted based on the current average days in milk of the herd (or pen) as explained previously. For example, a herd with a 22,000 lb RHA at 180 DIM would have a target GFE of 1.4 (from the table) – 0.11 (to account for the month deviation in DIM from 150 days) = 1.29. In either case, because measurements of both production and DMI are subject to errors, deviations of actual GFE from target GFE of less than 0.05 unit should be ignored, while deviations of less than 0.10 unit should probably not be of any great concern. Of course, monitoring GFE is a worthless activity unless one ensures relatively accurate and precise measurements of both milk production and DMI.

Diagnostics and interventions

<u>Measured GFE is greater than target GFE (feed efficiency seems too good to be true)</u>:

1. Some dietary components may have an actual energy concentration greater than the value used in feed formulation. You may consider gradually replacing some of the more expensive, energy dense ingredients by cheaper and less energy dense feeds.

2. Are the cows loosing an excessive amount of weight and condition score? If so, you'll be paying back later with much added interest. Physical factors such as rumen fill or other management factors could be limiting intake.

The digestibility of the diet and/or its energy density may need to be raised.

3. Verify the numbers. Forage moisture may in fact be less than values used for diet formulation. Also, ensure that the correct head count was used to calculate DMI.

4. Verify the feed (mixer) scale.

Measured GFE is less than target GFE (feed efficiency seems bad):

1. Are the cows gaining an excessive amount of weight and body condition? If so, this indicates a fundamental problem with the diet or the management of the animals. Somebody needs to intervene.

2. Some dietary components may in fact have a lower energy concentration than the one used for balancing the diet. For example, forages may not be as digestible as calculated. Try increasing the ration energy density if at all possible.

3. Verify the numbers. Forage moisture may be greater than the value used for balancing the diet. Verify the head count used for calculating DMI. Ensure that intake is solely for lactating dairy cows and does not include dry cows, pre-fresh cows, shortly fresh cows, or even replacement heifers. Sometimes, DMI is based on the amount of feed offered and has not been corrected for feed refusal and wastage.

Economic Feed Efficiency

Whereas physical feed efficiency tries to answer the question "are the cows processing (digesting) the diet in line with what should be expected?", economic feed efficiency attempts at answering "is the feeding program economically optimal; is it competitive?". It is important to note here that the objective should *never* be to minimize feed costs per hundredweight of milk. This has been discussed at length previously (St-Pierre, 1998), and the arguments will not be repeated here. Although not quite correct, the maximization of income-over-feed-costs **(IOFC)** acts as a reasonable proxy to profit maximization in the short term – certainly so when decisions regarding feeding programs are concerned. The IOFC measures the difference between milk revenues and feed costs and can be represented algebraically as:

$$IOFC = M\,P_m - E\,F_i\,P_{Fi} \qquad [2]$$

where IOFC is income-over-feed-costs ($/cow/day), M is milk production level (lb/cow/day), P_m is the price of milk ($/lb), E is a symbol representing the sum over all the feedstuffs in the diet, F_i is the amount of feedstuff i (there are i = 1 to m feeds used) in the diet (lb/cow/day), and P_{Fi} is the unit price of feedstuff i ($/lb). With the Federal Milk Marketing Order **(FMMO)** reform of the late 1990's, $M\,P_m$ is now the sum of the value of milk components produced and their pricing, that is:

$$M\,P_m = F\,P_f + P\,P_p + O\,P_o \qquad [3]$$

where F is fat production (lb/cow/day), P_f is the price paid for fat ($/lb), P is true protein production (lb/cow/day), P_p is the price paid for protein, O is other solids production (lactose and ash; lb/cow/day), and P_o is the price paid for other solids ($/lb). Thus, [2] becomes:

$$IOFC = (F\,P_f + P\,P_p + O\,P_o) - E\,F_i\,P_{Fi} \qquad [4]$$

We are all aware of the striking gyrations of milk prices in the U.S. over the last decade. Figure 4 shows adjusted Class III milk prices in FMMO from January 2005 through February 2008. Milk prices averaged $15.29/cwt, with a minimum of $11.17/cwt in May of 2006 and a maximum of $22.00/cwt in July 2007. What is often forgotten is that in most FMMO, milk is now component priced. That is, most of the mailbox price is in fact determined by prices and milk composition for fat, protein, and other solids **(OS)**. Figure 5 reports the evolution of fat, protein, and OS prices over the same period of January 2005 through February 2008. This figure makes evident that much of the substantial increases in milk prices experienced in 2007 were due to sharp increases in milk protein prices and to a lesser extent to OS prices.

The pricing structure of milk in FMMO allows for an exact quantification of P_f, P_p, and P_o in [4]. But, if we truly want to optimize [4], we must recognize that F, P, and O are functions of the F_i. That is, *the production of fat, protein, and other solids is dependent of what is being fed*. From a nutritional science standpoint, it is much more correct to state that F, P, and O are functions of the nutrients being fed, which themselves are function of the feeds being consumed. Nutrition models, such as the NRC (2001) model, have achieved remarkable progress in their ability to forecast the delivery of nutrients to an animal in a stated physiological status. Practically speaking, this means that we can now estimate reasonably well the delivery of NE_L, metabolizable protein **(MP)**, and other nutrients of production importance if we know the characteristic of the animals (weight, milk production, and milk composition) and the identity, nutritional characteristics, and amounts of each feed in the diet. So, we can mathematically translate quite readily a diet (a mixture of feeds) into an array of nutrients. We have, however, made little progress in translating a given delivery of nutrients into a prediction of milk component production. There are two reasons for that. First, the models that have been developed are essentially requirements models; milk production and composition are inputs into such models. Milk production serves to calculate expected DMI, which itself is used to calculate nutrient delivery. In the end, these models can assess the adequacy of a diet for a given level of milk production (i.e., can the nutrients delivered support the given milk input?), but they fail miserably at predicting what happens to milk component production if nutrients are not delivered according to "requirements". This is the realm of response models as opposed to requirement models. The second reason for the lack of progress in the development of response models is that they are fundamentally much more complex than requirement models. Research in the 1970's at U.C. Davis produced a computerized response model to net energy (Bath and Bennett, 1980). The model, however required an arbitrary input for a milk production asymptote, thus implicitly resulting in an infinite set of optimal solutions solely dependant on the user's own biases. Empirically, production of milk and milk components always show a declining, nonlinear response to dietary inputs (Roffler et al., 1986). Curnow (1973) did propose a statistical mechanism for transforming a single nutrient requirement function for individual animals into a response function for groups. We greatly expanded the method, allowing for the simultaneous response to multiple nutrients as well as accounting for uncertainty in the requirement functions and feedstuffs composition (St-Pierre and Thraen, 1999). This mathematic approach is; however, very messy, and a closed functional form and solution cannot be derived. So although the question of what level of production would be optimal for a given group of animals under a given set of feed and milk prices is economically important, we are currently in no position to answer this question with any degree of accuracy. Thus, for the rest of this paper, we will assume that the level of milk component production is a given.

For a long time, the USDA has tracked a measure of economic efficiency using the milk-to-feed **(MTF)** ratio, essentially the ratio of the price of a hundredweight of milk (numerator) to the cost of 50 lb of corn, 8 lb of whole soybeans, and 41 lb of hay (denominator). For some reason, economists like to bring almost everything into a ratio. The MTF fails to be a reliable benchmark of profitability for many reasons, most importantly because it is a *ratio* of two entities, whereas profitability and its proxy IOFC are *differences* between two entities. Ken Bailey at Penn State University has proposed using a measure of IOFC for a benchmark, but feed costs are calculated using either a naïve diet, or a complex diet using constant proportions of feeds. The benchmark diet doesn't change based on the relative economics of available feedstuffs. We have proposed a different approach where the benchmark is completely dissociated from any specific diet. Our approach is as follows:

Determination of nutrient requirements based on milk components production

We know reasonably well the nutrient requirements for a cow of a given weight, producing a given amount of milk of a given composition (NRC, 2001). These can be calculated easily using the following equations:

$$\mathrm{DMI} = 0.1102\ \mathrm{MBW} + 5.361\ F + 2.499\ O \quad [5]$$

$$\mathrm{NE_L} = 0.0444\ \mathrm{MBW} + 4.245\ F + 2.551\ P + 1.542\ O \quad [6]$$

$$\mathrm{MP} = 0.004353\ \mathrm{MBW} + 0.1665\ F + 1.4935\ P + 0.07746\ O \quad [7]$$

$$\mathrm{RDP} = 0.01248\ \mathrm{MBW} + 0.4687\ F - 0.0160\ P + 0.2245\ O \quad [8]$$

$$\mathrm{RUP} = -0.003581\ \mathrm{MBW} - 0.1320\ F + 1.7935\ P - 0.0626\ O \quad [9]$$

$$\text{e-NDF} = 0.0231\ \mathrm{MBW} + 1.1258\ F + 0.5248\ O \quad [10]$$

$$\text{ne-NDF} = 0.00771\ \mathrm{MBW} + 0.3753\ F + 0.1749\ O \quad [11]$$

where MBW is the metabolic body weight (i.e., $W^{0.75}$, in lb), F, P, and O are as defined in [3], $\mathrm{NE_L}$ is net energy for lactation requirement (Mcal/cow/day), MP is metabolizable protein requirements (lbs/cow per d), RDP is rumen degradable protein requirement (lb/cow/day), RUP is rumen undegradable protein requirement (lb/cow/day), e-NDF is effective NDF requirement (assumed at 21% of DMI; lb/cow/day), and ne-NDF is non-effective NDF requirement (assumed at 7% of DMI; lb/cow/day). Of course, there is redundancy in [5] to [11]: one should use either one of the two following sets: (a): [6], [7], [10], and [11], or (b): [6], [8], [9], [10], and [11]. In our experience, either approach yields about the same results. Set (a) will be used for the remainder of this paper.

Determination of unit costs of nutrients

The software *Sesame*™ (available at wwww.sesamesoft.com) uses the prices and composition of all feeds traded in a given market to calculate the implicit costs of nutrients (St-Pierre and Glamocic, 2000). Although this software can be used to compare the relative economic values of various feeds, the primary objective during its development was to extract the prices of nutrients from prices of commodities. Details on the method used were presented at this Conference (St-Pierre, 2000) and have been published (St-Pierre and Glamocic, 2000). In short, the method is based on a multiple regression approach which, under reasonable assumptions, produces maximum likelihood estimates of unit costs of nutrients. *Sesame* does *not* use a diet approach; and in fact, there are no nutrient requirements either explicitly or implicitly stated or embedded. Feed markets (prices) solely determine the calculated values.

Figure 6 shows the evolution of unit costs for $\mathrm{NE_L}$, MP, and e-NDF during the period of May 2005 through February 2008 for central OH (ne-NDF costs are not presented because they didn't vary much during this period of time). From this Figure 6, it is evident that the rises in feed prices experienced over the last 18 months have translated, as expected, into increased unit costs of nutrients, although nutrients have shown different patterns over time.

Calculating the benchmarks

Table 3 shows in detail how the economic efficiency benchmark is calculated, using price and cost figures for February 2008. A spreadsheet to assist making these calculations (Cow-Jones-Index.xls) can be downloaded at http://dairy.osu.edu. In addition, results for OH are regularly posted on the same web site.

There are two outcomes resulting from these calculations. First, we get an index of the average costs of providing the nutrients required by a cow with known production characteristics. We call this the nutrient costs index **(NCI)**. Of course, this index moves up and down with the feed markets, but it is also adjusted based on levels of production and milk composition. The second outcome is an index representing the difference between milk revenues and the NCI. This essentially is an index of income over nutrient costs – which we have facetiously named the *Cow-Jones Index* **(CJI)**. Just as people can track the performance of their stock investments by comparing their returns to the Dow-Jones Index, dairy producers and their nutritionists can now compare over time their nutrition costs and milk revenues to an index that summarizes the movement of both the milk and the feed markets. The calculated index is shown in Figure 7 for theh period of May 2005 to February 2008.

Diagnostics and intervention

When a herd's IOFC deviates substantially from the CJI, the following questions must be addressed:

1. Are you growing or buying the right feeds? *Sesame* can be used to answer this question.
2. Are you buying competitively (i.e., Are you a good buyer)?
3. Are you assembling the correct diet? Are feeds put in the right combination?
4. What DMI are you using, the one on the feeding chart or the one actually consumed?
5. Who pays for feed refusals? Who pays for feed shrink?
6. What costs are you using? Are forages priced based on their total costs of production (including storage) or just variable costs?
7. Are feeds converted to milk as expected (i.e., Is the GFE near its target)?

Conclusions

Managing feed costs is substantially more complicated than buying cheap feeds or just being cheap. One must ensure that the efficiency of converting feeds to milk follows expectations. Ultimately, the whole process must ensure that the farm is competitive with its peers. The proposed methods and indexes can assist producers and their advisors in assessing and monitoring the physical and economic feed efficiency on dairy farms.

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Table 1. Effect on ration net energy for lactation (NE_L) density on target gross feed efficiency (GFE) for Holstein cows producing 75 lb/day of milk at 3.6% fat, 3.1% protein, and 5.7% other solids.

NE_L (Mcal/lb)	DMI (lb/day)	Target GFE	Forage (% of DMI)[1]	Forage (lb/day)	Grain (lb/day)
0.65	53.4	1.40	66.7	35.6	17.8
0.66	52.6	1.43	63.3	33.3	19.3
0.67	**51.8**	**1.45**	**60.0**	**31.1**	**20.7**
0.68	51.0	1.47	56.7	28.9	22.1
0.69	50.3	1.49	53.3	26.8	23.5
0.70	49.6	1.51	50.0	24.8	24.8
0.71	48.9	1.53	46.7	22.8	26.1
0.72	48.2	1.56	43.3	20.9	27.3
0.73	47.5	1.58	40.0	19.0	28.5
0.74	46.9	1.60	36.7	17.2	29.7

[1] Forage and grain amounts are calculated assuming an NE_L of 0.55 Mcal/lb for forage and 0.85 Mcal/lb for grain. Bolded cells are according to NRC (2001).

Table 2. Target gross feed efficiency (GFE) for Holstein herds at various levels of milk production expressed either as rolling herd average (RHA) or average daily milk production.

RHA milk (lb/year)	Target GFE	Milk production (lb/cow/day)	Target GFE
16,000	1.16	55.0	1.25
17,000	1.20	57.5	1.28
18,000	1.24	60.0	1.32
19,000	1.29	62.5	1.35
20,000	1.32	65.0	1.38
21,000	1.36	67.5	1.41
22,000	1.40	70.0	1.44
23,000	1.43	72.5	1.46
24,000	1.47	75.0	1.49
25,000	1.50	77.5	1.51
26,000	1.53	80.0	1.54
27,000	1.56	82.5	1.56
28,000	1.58	85.0	1.58
29,000	1.61	87.5	1.60
30,000	1.63	90.0	1.63
31,000	1.65	92.5	1.64
32,000	1.68	95.0	1.66

Table 3. An example of the calculation of the Cow-Jones Index (a.k.a., income over nutrient costs) for February 2008.

Animal Inputs		
Cow weight (lb)	1500	
Milk (lb/day)	75	
Fat (%)	3.6	
Protein (%)	3.1	
Other solids (%)	5.7	
Milk component prices input		
Fat ($/lb)	$1.3010	
Protein ($/lb)	$4.0180	
Other solids ($/lb)	$0.0803	
Nutrient unit costs inputs		
NE_L ($/Mcal)	$0.1330	
Metabolizable protein ($/lb)	$0.2922	
Effective NDF ($/lb)	$0.0732	
Non-effective NDF ($/lb)	$(0.0906)	
Nutrient requirements		
NE_L (Mcal)	34.70	
Metabolizable protein (lb)	5.30	
Effective NDF (lb)	10.85	
Non-effective NDF (lb)	3.62	
Milk income		
Fat ($/cow/day)	$3.51	
Protein ($/cow/day)	$9.34	
Other solids ($/cow/day)	$0.34	
TOTAL		$13.20
Nutrient Costs		
NE_L ($/cow/day)	$4.61	
Metabolizable protein ($/cow/day)	$1.55	
Effective NDF ($/cow/day)	$0.79	
Non-effective NDF ($/cow/day)	$(0.33)	
TOTAL		$6.63
Income over nutrient costs		
The Cow-Jones Index		**$6.57**

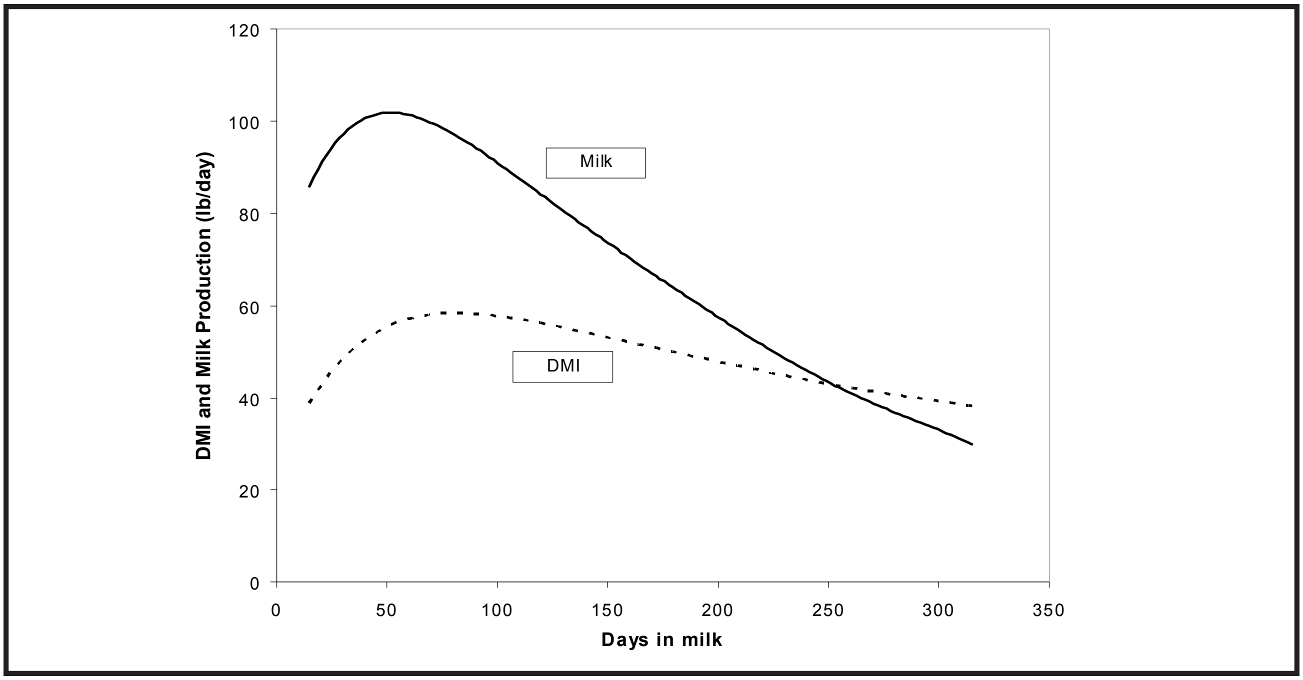

Figure 1a. Daily dry matter intake (DMI) and milk production of a third parity cow producing 22,000 lb of milk in 330 days. The lactation curve was calculated using a gamma function (Kellogg et al., 1977); DMI was estimated according to NRC (2001).

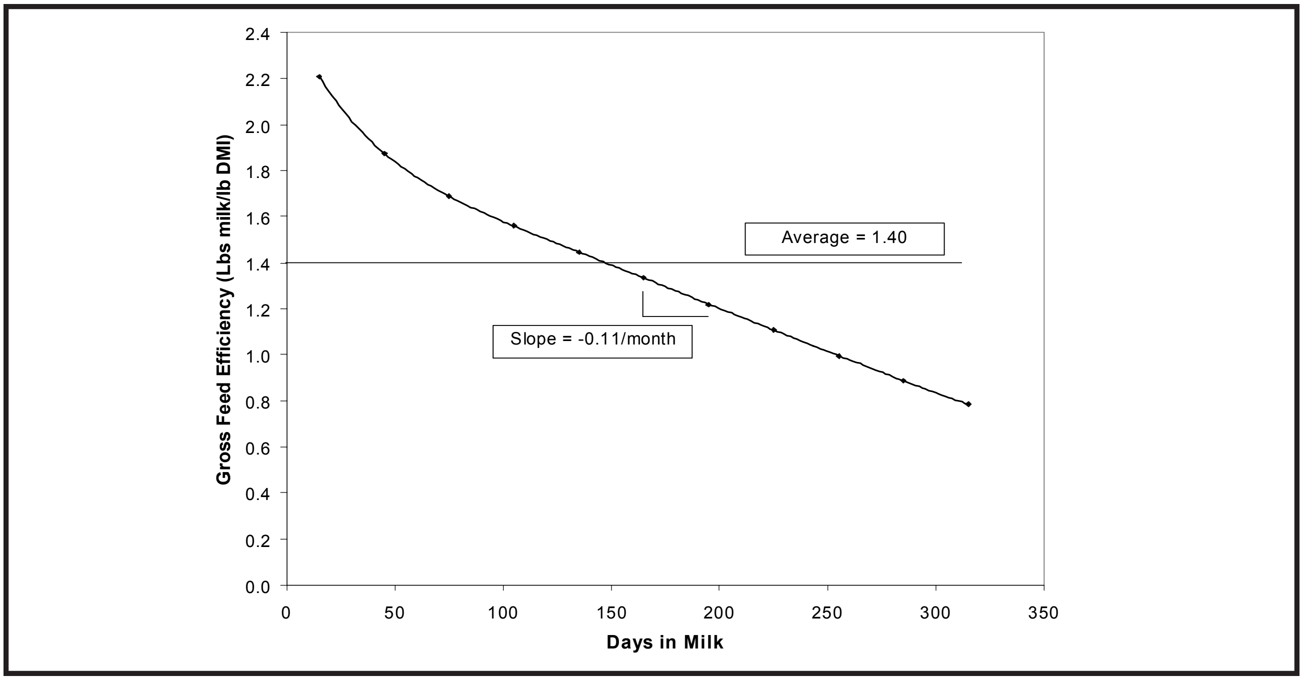

Figure 1b. Instantaneous gross feed efficiency across a lactation cycle for a cow with production and intake characteristics reported in Figure 1a (DMI = dry matter intake).

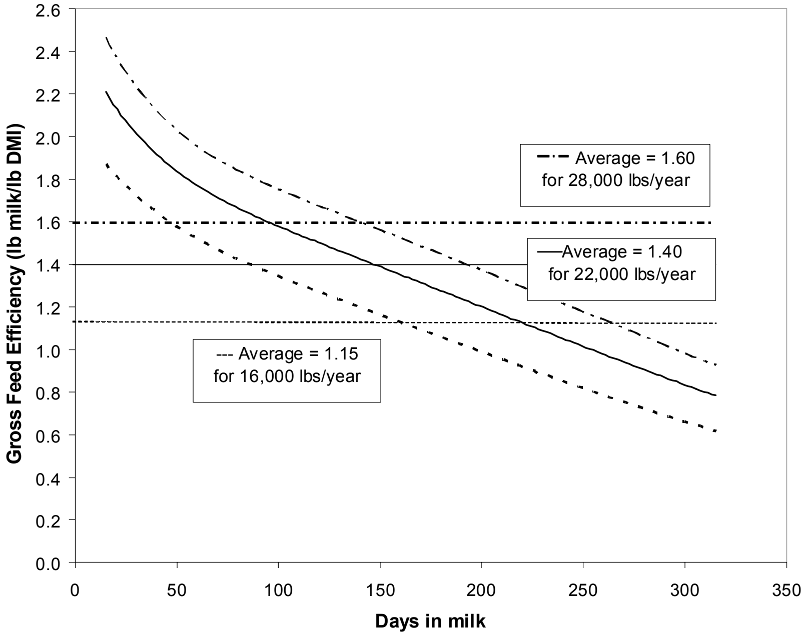

Figure 2. Comparative gross feed efficiency across a lactation cycle for a cow producing 16,000 (---), 22,000 (–) and 28,000 (- . -) lb of milk in a 330 day lactation (DMI = dry matter intake).

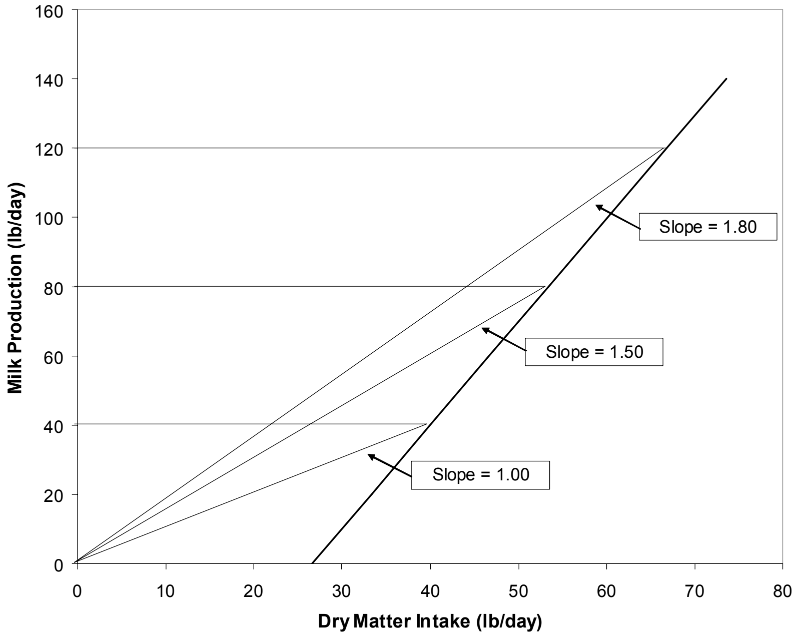

Figure 3. Relationship between milk production, dry matter intake (DMI), and gross feed efficiency (GFE) in a 1,500 lb cow producing milk at 3.6% fat, 3.1% protein, and 5.7% other solids; GFE is simply the slope of the line connecting a point on the milk production – DMI curve with the (0, 0) origin.

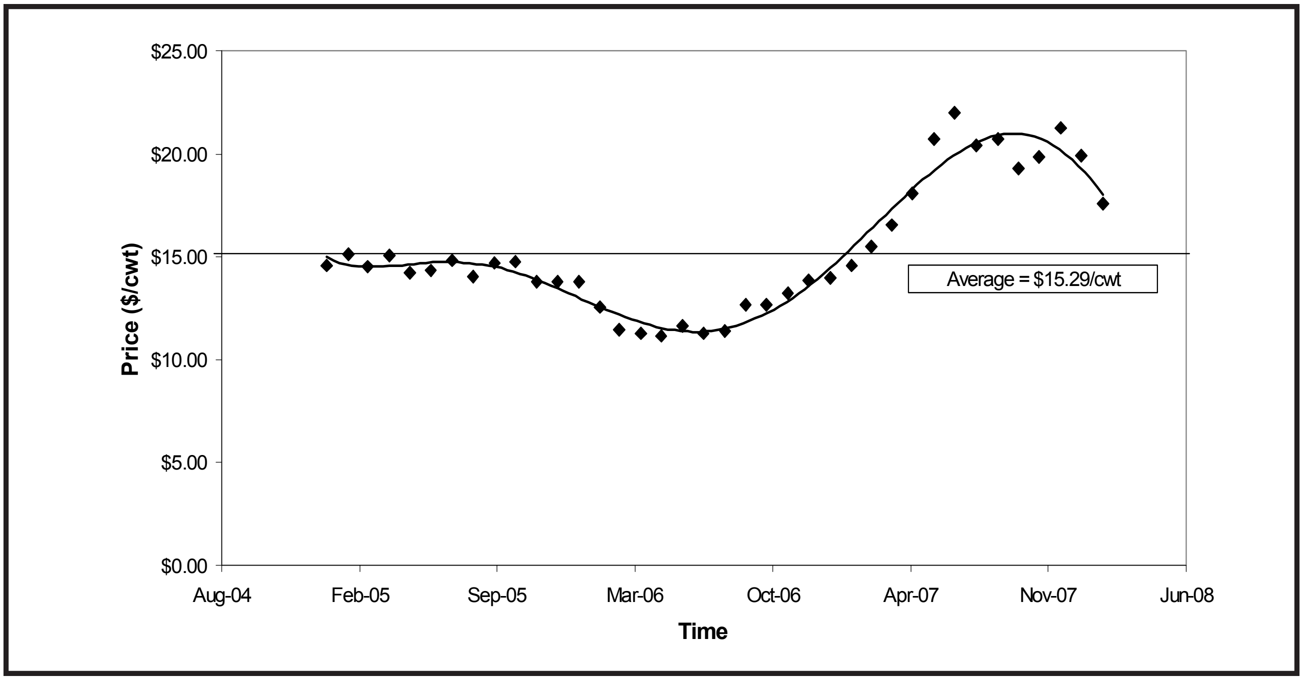

Figure 4. Uniform milk prices in Federal Orders from January 2005 through February 2008.

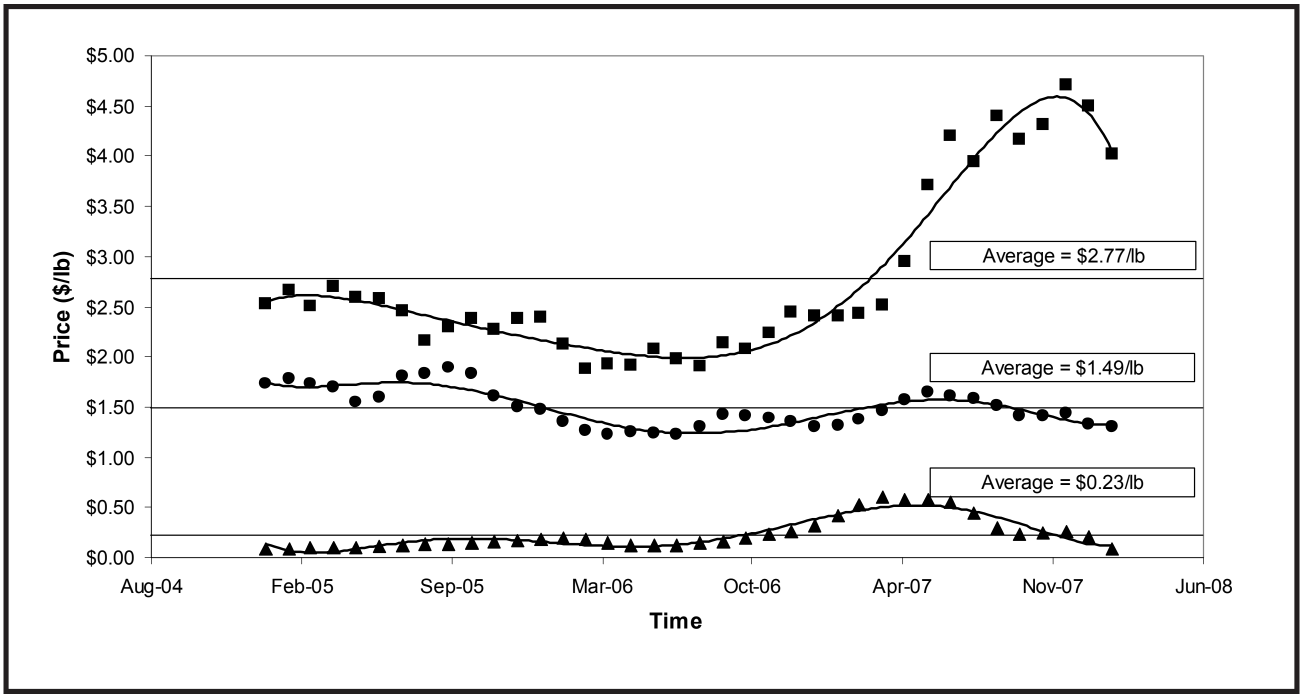

Figure 5. Milk component prices in Federal Orders from January 2005 through February 2008; ■ = protein ($/lb), ● = fat ($/lb), and ▲= other solids ($/lb).

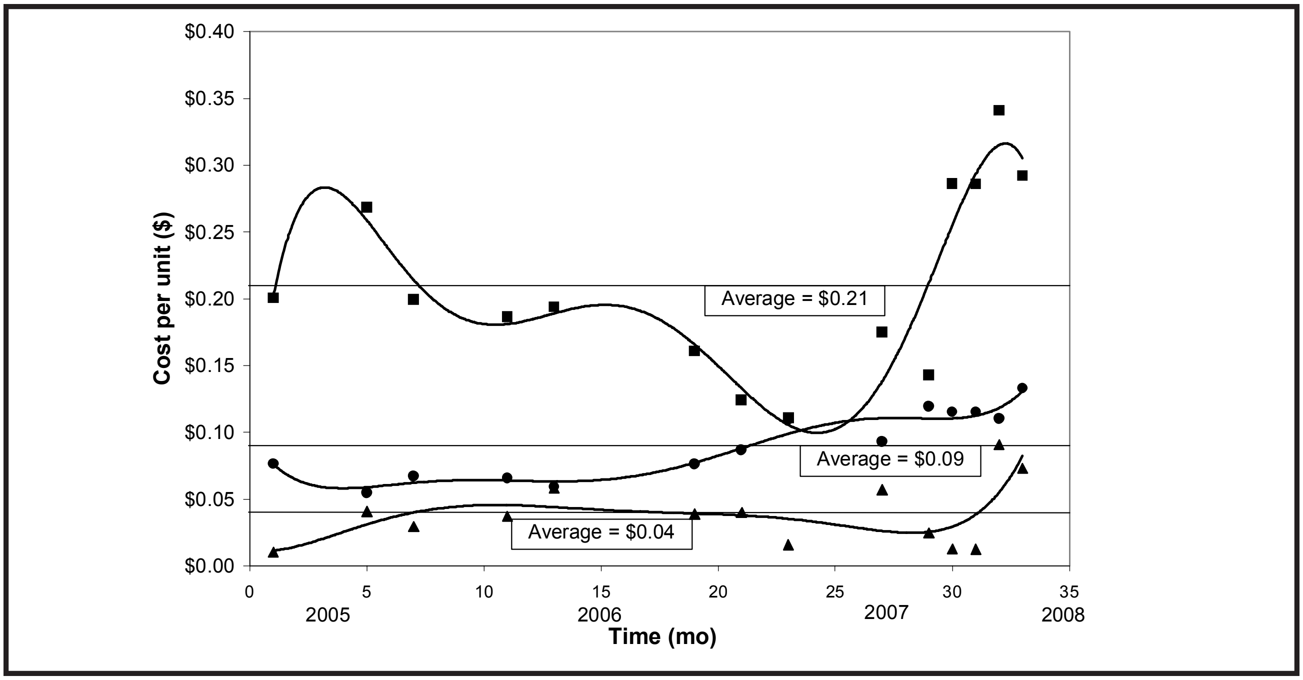

Figure 6. Costs of nutrients between May 2005 and February 2008; ■ = cost of metabolizable protein ($/lb), ● = cost of net energy for lactation ($/Mcal), ▲ = cost of effective NDF ($/lb). Results are from *Sesame*, using central OH prices (St-Pierre and Glamocic, 2000).

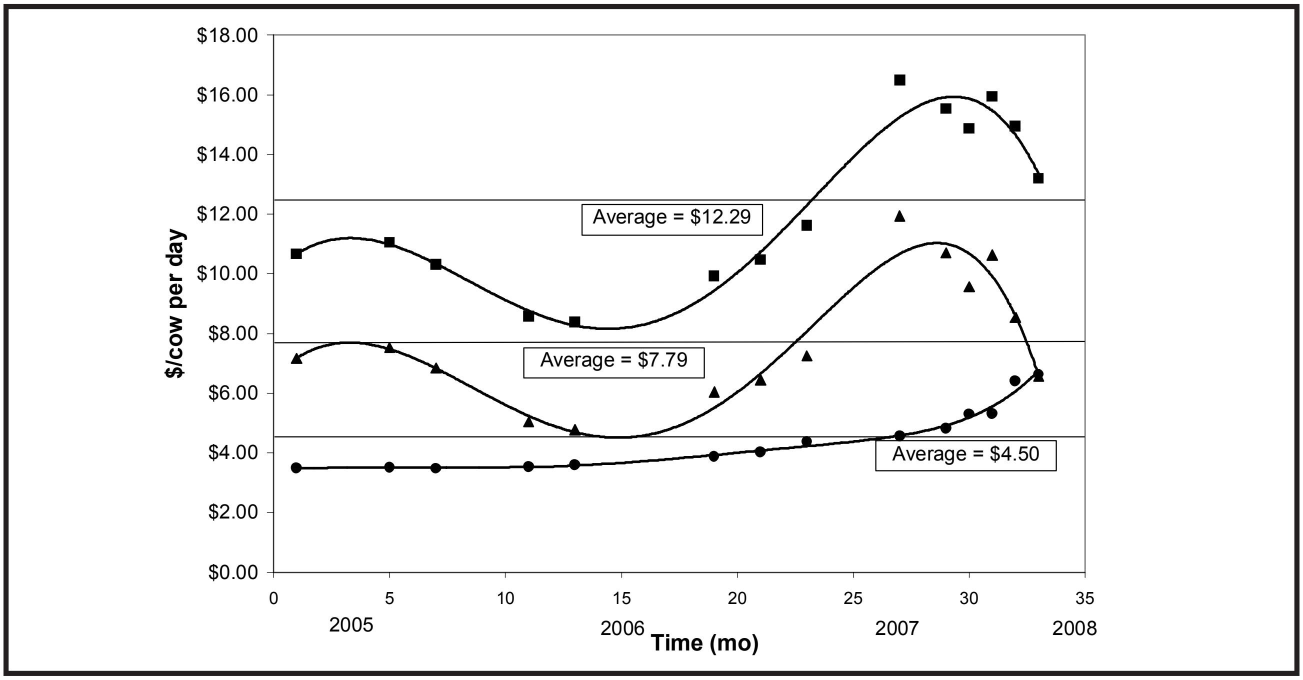

Figure 7. Milk revenues (■), nutrient costs (●), and income-over-nutrient-costs (▲ – the Cow-Jones Index) between May 2005 and February 2008.