Feed Efficiency: What is it and How to Calculate it

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INTRODUCTION

Certainly not news to anyone, operating in the current dairy economy remains difficult. The milk to feed ratio has been at historic lows since mid- 2007. July 2009 settled at 1.65; a mere 0.2 point increase from June 2009, but still lagging far behind the suggested profitable level of greater than 3.0. Increased global competition, rising cost of production and falling milk prices have forced dairy producers to increase efficiency in order to sustain profitability or, as is the case for many producers recently, minimize losses. One factor having a profound effect on dairy profitability is conversion of feed to milk. For example, improving feed efficiency (FE) from 1.4 to 1.5, while maintaining milk production increases profitability of a 1000 cow dairy by $131,400/year (Table 1). However, obtaining an accurate estimate of FE is difficult due to confounding factors such as energy required for temperature maintenance, variability in milk composition and body weight (BW) loss and gain as lactation progresses. This paper will review factors to consider when estimating FE and measures producers can implement to improve FE.

CALCULATING A MORE ACCURATE ESTIMATE OF FE

Observed FE is the amount of milk produced per lb of dry matter intake (DMI). This measure of FE has also been previously titled Dairy Efficiency by Hutjens (2005). Recently, from August 2007 through August 2008, Zinpro Corporation monitored monthly observed and actual FE (using Zinpro FED™ software) on 7 Holstein dairy herds in the Western United States (Figure 1, J.M. DeFrain et al., personal communication) and found that as milk production increased there was a trend toward higher FE. Of particular interest is the number of observations with similar levels of milk production but markedly different FE. For example, in this summary, there are two herds (denoted by red highlights in Figure 1 as Herds A and B) producing approximately 73 lb/d milk (not corrected for milk composition), but Herd A is producing 1.44 lb of milk per lb dry matter (DM) and Herd B is producing 1.29 lb milk per lb DM. For these two herds, if one assumes an equal cost/lb of DM ($0.12/lb) and milk price ($10/cwt.), the herd with the higher FE yields $0.71/cow/d greater income over feed costs. For a 1000 cow dairy, this increase in profitability translates to $259,150 per year! While these differences in FE are great, there are several questions one must ask before concluding that Herd A is more efficient at converting feed to milk than Herd B.

1. ***Is there a difference in milk composition between these two herds?***

   Fat and protein content of milk are the primary determinants of milk energy content. For this reason, milk energy output should be corrected to a standard fat and protein concentration. The equation used to calculate milk energy content is as follows (NRC, 2001):

   Milk energy content (Mcal/kg) = 0.192 + (0.0929 × fat %) + (0.0563 × true protein %)

In comparing the two herds highlighted in Figure 1, Herd A produces milk containing 3.32% fat and 3.12% true protein which translates into 0.676 Mcal/kg, while Herd B produces milk containing 3.72% fat and 3.05% true protein translating into 0.709 Mcal/kg. In other words, a cow in Herd A producing 35 kg/d (77.1 lb/d) of milk containing 3.3% fat and 3.1% true protein would produce as much milk energy as a cow in Herd B producing 33.4 kg/d (73.7 lb/d) of milk containing 3.7% fat and 3.0% protein.

2. Is Herd B heat stressed/cold stressed while Herd A is under thermo neutral conditions?

Reduced milk production due to heat stress is attributed to both an increase in energy required for maintenance and reduced dry matter intake. Arizona researchers observed that when cows under thermal neutral conditions (temperature humidity index [THI], 64^{o}F for 24 h) were offered a similar amount of DM as cows under heat stress conditions (THI, 80^{o}F for 16 h) were consuming, cows under thermal neutral conditions produced approximately 14 lb/d more milk. This illustrates the increased diversion of nutrients from milk production to maintenance when cows are heat stressed (Rhoads et al., 2009). Heat stress has been reported to increase maintenance requirements by 7 to 25% (NRC, 2001). For a 1400 lb cow this equates to 0.71 to 2.96 Mcal of additional NE_L/d. Increased maintenance requirements result from an increase in respiration rate to dissipate heat. The impact of heat stress on maintenance requirements can be calculated using the following equation by Fox and Tylutki (1998):

Increased energy requirements due to heat stress (Mcal) = 1.09857 – (0.01343 × CETI) + (0.000457 × CETI^2)

Where CETI = 27.88 – (0.456 × mean daily temperature, ºC) + (0.010754 × (mean daily temperature, ºC)^2) – (0.4905 × % relative humidity) + (0.00088 × (% relative humidity)^2) + (1.1507 × wind speed, m/s) – (0.126447 × (wind speed, m/s)^2) + 0.019876 × mean daily temperature, ºC × % relative humidity) – (0.046313 × mean daily temperature × wind speed, m/s) + (0.4167 × hours per day in direct sunlight)

Cold stress also appears to affect FE by both reducing DM digestibility and diverting nutrients to heat generation. Young (1976) reported that cold stress reduces DM digestibility by 1.8% for each 50º F reduction in temperature below 68º F. Much of the cold stress reduction in digestibility is attributed to increased passage rate of feed through the digestive tract (Kennedy et al., 1976). In addition, maintenance requirements have been estimated to be 51% higher at -4° F as compared to 64° F for a 1323 lb cow producing 60 lb of milk containing 3.7% fat (NRC, 1981). However, cold stress adjustments for dairy cattle in the NRC (1981) appear to be based upon limited data.

The two herds highlighted in Figure 1 were experiencing only slightly different environmental conditions. Actual high and low temperature and relative humidity for

Herd A averaged 84° F, 45° F and 35%, while Herd B averaged 78° F, 49° F and 57%, respectively, and were both experiencing mild heat stress. Therefore, using the aforementioned Fox and Tylutki (1998) equation to account for heat/cold stress, Zinpro FED^{TM} estimated Herd A was losing the energy equivalent of 0.46 lb/cow/d of energy-corrected milk (ECM, 3.5% fat and 3.0% protein) while Herd B was losing 0.31 lb/cow/d.

3. Is Herd B walking excess distances to and from the milking center?

The facility layout and milking frequencies greater than twice per day on many dairies requires that cows walk considerable distances from their pen or paddock to the milking center. The energy diverted from milk production to walking must be taken into account in order to obtain a true measure of FE. Energy expenditure for walking can be calculated as follows (NRC, 2001):

Energy for walking (Mcal) = 0.00045 × body weight, kg × distance walked, m (NRC, 2001).

Relative to the two herds under discussion from Figure 1, it was determined that cows in Herd A (680 kg; 1500 lb BW) walked 1,861 m (6,104 ft) from the middle of the pen to the milking center compared to 2,193 m (7,196 ft) for Herd B (635 kg; 1400 lb BW). Therefore, it was estimated that Herd A required the energy equivalent of 1.8 lb/d of ECM while Herd B required 2.0 lb/d of ECM to walk to and from the milking center.

4. Lastly, are cows in Herd A primarily in early lactation while cows in Herd B are primarily in mid- to late lactation?

Additional factors that should be considered in order to ascertain the true FE of dairy cattle are energy expenditure for continued growth of first lactation heifers and BW loss and gain with lactation progression. From a data set of 17,087 cow wk (5962 first lactation cow wk, 11,125 multiparous cow wk), it was estimated that first lactation heifers lost the BW equivalent of 1.17 Mcal/d in the first 40 d in milk (DIM) and gained the BW equivalent of 1.44 Mcal/d from 41 DIM through the end of their first lactation (J. G. Linn, University of Minnesota, personal communication; W. P. Weiss, The Ohio State University, personal communication). Mature cows lost the BW equivalent of 3.323 Mcal/d in the first 40 DIM and gained the BW equivalent of 1.442 Mcal/d from 106 DIM until the end of lactation. There was minimal change in BW of mature cows between 41 and 105 DIM.

Therefore, prior to 40 DIM first lactation heifers and mature cows are deriving an energy equivalent of 3.8 and 10.7 lb ECM/d from body stores, respectively. After 105 DIM, the first calf heifer and mature cow are diverting the energy equivalent of 4.6 lb ECM/d towards tissue accretion. It is noteworthy that the first calf heifer derives less energy from tissue reserves in early lactation than mature cows. Once cows begin regaining BW, first calf heifers divert the same amount of energy towards tissue accretion on a daily basis as mature cows, but have more days of tissue accretion reflecting continued growth of first calf heifers.

Distribution of first lactation heifers and mature cows by DIM for Herds A and B from Figure 1 are shown below in Table 2. At first glance (using observed FE), Herd A has a 0.15 point greater FE than Herd B. However, Herd A is producing milk with a lower milk fat and protein content, has roughly half as many first lactation cows and is walking less distance to and from the milking center. After adjusting FE for milk composition, energy expenditure for walking distance, temperature stress, growth and BW loss and gain with progression of lactation, the difference in FE is between these herds narrows (0.09 points) versus the original difference noted in observed FE (0.15 points).

In summary, adjusting for these factors allows nutritionists to obtain a better estimate of the true conversion of feed to productive purposes such as tissue accretion, activity and milk production. In addition, monitoring the true FE over time within a herd provides the ability to assess the value of various feeds, evaluate the true profitability of diet changes and determine the cost effectiveness of new technologies.

WHAT IS THE VALUE OF USING FE IN YOUR FEEDING PROGRAM?

Several metrics are available for use in evaluating the impact of feeding changes on profitability; each with its advantages and disadvantages. Feed cost per cow per day does not reflect milk yield, stage of lactation or nutrient requirements. However, this value can provide insight into determining if costs are optimal for herd production and local feed costs. Feed cost per pound of dry matter can be useful only when comparing similar regions, breeds and levels of milk production. Feed cost per cwt standardizes milk yield to allow for the comparison among groups of cows and farms within a region. Income over feed costs (IOFC) is a popular benchmark for herds or groups of cows reflecting profitability, current feed prices and milk prices. Providing one has accounted for fixed and variable costs, IOFC is useful in determining breakeven prices, dry off time and culling strategies. Marginal milk is any milk yielded after maintenance and fixed costs have been covered by previous production levels. All of these measurements are useful; however, since feed costs typically represents well in excess of 50% of the cost of producing milk, one must ultimately optimize FE: either produce more milk per pound of DM or get the same milk production at a lower DM intake to improve profitability.

Generally, as milk production declines, FE declines due to maintenance requirements comprising a greater portion of nutrient requirements. An example comparing the FE of a cow producing 70 lb of milk versus a cow producing 95 lb of milk is shown in Table 3. Assuming that BW of both cows are static, 30.8% of dietary energy is devoted to maintenance requirements in the cow producing 70 lb of milk while 24.7% of dietary energy is diverted to maintenance in a cow producing 95 lb of milk. Using NRC (2001) predicted dry matter intake (DMI), FE for the cow producing 70 lb of milk is 1.41, while the FE of the cow producing 95 lb of milk is 1.63. Thus dairy producers restricting DMI in an attempt to improve FE may not obtain desired results if milk production is compromised.

According to Rodriguez and DeFrain (2009), the value or return from monitoring and improving FE is a decrease in feed cost/cwt and an improvement in profitability. Holstein herds with a FE of approximately 1.10 had a feed cost/cwt of $7.0 while herds with FE nearing 1.50 had feed costs/cwt between $5.0 and $6.0 in 2006, increasing by

$1.0 for both low and high FE herds in 2007. This data set was recently updated with 2008 data by L.A. Rodriguez (Zinpro Corporation, personal communication). Figure 2 shows the relationship between feed cost/cwt and FE for approximately 130 Holstein herds in CA from 2006-2008. Relative to 2006 and 2007, feed cost/cwt again increased nearly $2/cwt for all herds during 2008; however the same trend exists in that herds with higher FE had lower feed cost/cwt. The higher FE and lower feed cost/cwt contributed to greater milk income as shown in Figure 3. Clearly as FE increases, milk income/cwt increases regardless of year, increasing the likelihood of achieving a milk income of breakeven or greater. Therefore, FE should be among the key performance indicators used to determine the net impact of changes in nutrition or management factors.

HOW TO IMPROVE FE

Additional measures that can be taken to improve FE include:

1. **Minimize feed wastage at the feed bunk.**
2. **Minimize bird, rodent and parasite infestations.**
3. **Minimize illness and disease**. Elevated immune system activity decreases the amount of nutrients available for milk production, activity, and tissue accretion. "Most immune responses to pathogens are accompanied by a systemic acute phase protein response, which is characterized by decreased appetite and a shift in nutrient use away from skeletal muscle accretion towards hepatic secretion of acute phase proteins" (Klasing, 2001). Research has shown that under normal conditions, 1.17% of Lys consumed by young chicks is utilized for immune processes (Klasing, 2001). However, when activity of the immune system was stimulated through lipopolysaccharide administration, 6.71% of Lys consumed by the chicks was used for immune processes. Thus, improving animal health improves FE.
4. **Minimize the inclusion of low digestibility and spoiled feeds in the diet**. Dry matter digestibility has been reported as a major factor affecting FE of lactating dairy cows (Casper et al., 2004). Casper et al. (2004) evaluated the relationship between milk production, milk composition, ration energy concentration, fecal energy concentration and DMI of cows from six dairy farms. Their findings indicated that diet digestibility was the most significant ($P < 0.01$) predictor of FE (FE = 0.032 + 0.02 * DMD; $R^2 = 0.59$). This study also indicated that as FE increased, DMI decreased. Similarly, Linn et al. (2005) showed a linear improvement in FE (1.31 – 1.78) as *in vivo* DM digestibility increased from 50 to 78%. The 2001 Dairy NRC takes these changes in FE into consideration when calculating dietary energy content as discounts are applied to TDN content as DMI increases.

   Similarly, offering spoiled feed can compromise FE due to reduced DM digestibility. Kansas State researchers found that increasing the inclusion of spoiled corn silage from 0 to 16.0% of DM, in diets of beef steers, reduced organic matter (OM) digestibility from 75.6% to 67.8%, reduced crude protein digestibility from 74.6% to 62.8%, reduced NDF digestibility from 63.2% to 52.3%, and reduced ADF digestibility from 56.1% to 40.5% (Whitlock et al., 2000). The decrease in nutrient digestibility was largest when the amount of spoiled silage in the diet was increased from 0 to 5.4% of DM and the drop in nutrient digestibility was larger than anticipated. Inclusion of spoiled corn silage may have affected digestibility of other ingredients in the diet as well as affecting rate of passage as researchers observed that the forage mat was destroyed in the rumen of steers fed spoiled corn silage (Whitlock et al., 2000).

Clearly following good silage making practices such as harvesting forages at the correct moisture content, proper particle length, adequate packing and prompt covering can reduce silage spoilage and improve FE. Use of silage inoculants can also improve silage quality and FE. In a summary of four comparisons, addition of silage inoculants to harvested forages increased lb milk produced per lb DM from 1.63 to 1.66 (Kung et al., 1993; Stokes, 1992).

5. **Proper feed processing to optimize rumen pH and the site and extent of starch digestion.** Risk factors for acidosis and the negative effects of acidosis on nutrient digestion and animal health have been extensively reviewed in the literature. Briefly, rapid fermentation of diets in the rumen results in rapid production of volatile fatty acids (VFA; Beauchemin et al., 2006). When VFA production exceeds the ability of the rumen environment to neutralize or absorb them, subacute ruminal acidosis occurs (Beauchemin et al., 2006). Decreased FE as a result of subclinical acidosis is attributed to reduced absorption of nutrients from the rumen due to excessive keratinization of ruminal epithelium and decreased fiber digestion as a consequence of inhibited growth of cellulolytic ruminal bacteria (Beauchemin et al., 2006).

Recently, Canadian researchers found that reducing particle size of corn silage from 1.13 in. to 0.19 in., decreased lb of ECM produced per lb DM from 1.42 to 1.32 (Yang and Beauchemin, 2006). Corn silage, harvested at 60% moisture with a kernel processor set at 2 mm, was the sole forage source and comprised 45.8% of diet DM. While ECM production tended to decline with decreasing particle size, milk fat content and mean rumen pH (5.99 to 6.08) did not vary between treatments. However, rumen pH of cows fed corn silage chopped at 0.19 in. was below 5.5, 1.2 h/d longer than rumen pH of cows fed corn silage chopped at 1.13 in. Results of this study illustrate that even minor rumen acidosis can reduce FE.

Grain processing also impacts FE as it affects site and extent of starch digestion. In a summary of studies evaluating effect of corn processing on site and extent of nutrient digestion and lactation performance, Firkins et al. (2001) found that increased ruminal starch digestion with increased grain processing generally accompanied a decrease in ruminal NDF digestibility. In addition, the effect of decreased ruminal starch digestibility was mitigated by increased starch digestion in the lower tract. Hence total tract OM digestion only differed a few percentage points between different processing methods and production benefits obtained from different processing methods were less than predicted (Firkins, 2006). It should be noted that corn content of treatment diets were held constant and that benefits of increased corn processing may have been more evident had the amount of corn in treatment diets decreased with increased processing (Firkins, 2006).

On commercial dairies, advantages of increased grain processing can be more fully exploited if diets are balanced to insure adequate amounts of physically effective NDF, and dietary starch levels are adjusted for grain processing, thus minimizing the negative effects of increased ruminal starch digestion on digestion of other dietary nutrients (Firkins, 2006).

6. **Grouping heifers separate from cows.** Spanish research found that heifers grouped separate from mature cows consumed 1.2 lb/d less DM, produced 1.6 lb/d more ECM and had a 5.8% improvement in FE as compared to heifers housed with mature cows (Bach et al., 2006). The primary contributor to reduced ECM yield was a 0.31-percentage unit decrease in milk fat content for heifers housed with mature cows as compared to heifers grouped separately. Reduced milk fat content may be a consequence of reduced rumen pH. Although rumen pH was not monitored in this study, heifers housed separate from mature cows had more visits to the feed trough (4.91 vs. 4.02 visits/d), and thus would have had smaller meal sizes and a smaller drop in rumen pH following a meal. It should be noted that in this study, there were approximately 1.78 cows per feeding stall. Thus, when housed together, heifers were competing with mature cows for limited feeding stalls. Magnitude of improvement in FE for grouping heifers separate from mature cows may have been smaller if additional feeding stalls were provided.
7. **Extended day lighting.** A summary of 6 studies conducted at laboratories located 39 to 53^{o}N latitude showed that ECM production increased 5 lb/d when the photoperiod was extended from less than 13 h to 18 h using artificial lighting (Dahl et al., 2000). Dry matter intake did not increase to the same extent as ECM production, resulting in increased FE. While the exact mechanism has not been fully elucidated, the current theory is extended photoperiods increase ECM yield and hence FE by increasing circulating prolactin, growth hormone, and/or IGF-I concentrations (Dahl et al., 2000).
8. **Balancing diets for amino acids.** Sloan (2006) summarized seven studies in which early lactation cows were either fed a control diet or a treatment diet balanced for Lys (6.83 to 7.09% of metabolizable protein (MP)) and Met (2.13 to 2.30% of MP). The Lys to Met ratio of 3.1 to 1 was respected with ratios ranging from 2.97 to 3.32. Cows fed the diet balanced for Lys and Met produced 5.7 lb/d more ECM while consuming only 1.1 lb more DM, resulting in a 4.3% improvement in FE.

   Improved FE resulting from balancing diets for Lys and Met can be attributed to both an increase in milk production and improved utilization of dietary N, reducing energy required for excretion of surplus amino acids through urea. It is estimated that the process of urea synthesis requires 4.4 kcal of NE_L per g of N converted (Tyrrell et al., 1970).

   Improvements in N utilization and increased milk production may explain the 18.0% advantage in FE for herds feeding two or more diets to lactating cows in comparison to herds feeding only one diet to lactating dairy cows (Castillo, 2006). In a survey of 51 California dairies, production of 3.5% fat-corrected milk (FCM) increased approximately 4 lb for each additional diet fed to lactating cows. Dairies feeding one diet to lactating cows averaged 60 lb/d FCM while herds feeding five diets to lactating cows averaged 75 lb/d FCM (Castillo, 2006). Increasing the number of diets fed to lactating dairy cows also allows nutritionists to formulate diets to more closely meet the MP requirements of cows. Not surprising, the efficiency of dietary N utilization was 12.5% higher for herds feeding two or more diets to lactating dairy cows in contrast to herds feeding one diet to lactating dairy cows.

9. **Feeding monensin.** In a summary of nine trials, researchers found that increasing the amount of rumensin from 0 to 22 g/ton DM increased the efficiency of ECM production by 3.8% (Thomas et al., 2004). Improvements in FE is a consequence of monensin shifting the microbial population in the rumen, by promoting growth of more efficient bacteria involved in carbohydrate metabolism (Aguilar, 2005).

10. **Improving trace mineral status.** Trace minerals are essential for maintaining optimal health and performance of animals. Zinc, Mn, Cu, Co, I and Se impact the activity and efficiency of key enzyme systems responsible for energy and protein metabolism, cellular repair and integrity, immune system functionality, fertility, and claw health and maintenance.

    The impact of trace minerals and trace mineral status on FE is clearly illustrated in a trial conducted by Engle et al. (1997). In this trial, calves that received a diet with no supplemental Zn (diet contained 17 ppm Zn) for 28 d had a 50% decrease in FE as compared to calves that received a diet containing 40 ppm Zn (23 ppm supplemental Zn from $ZnSO_4$). The decrease in FE for the calves receiving no supplemental Zn was attributed to both a 46% decrease in ADG and a 6.7% increase in DMI. During the 14 d repletion phase, calves receiving zinc methionine (ZINPRO®) returned to control FE levels 3X faster than calves receiving $ZnSO_4$.

    Increasing Co supplementation of lactating dairy cattle above current NRC (2001) requirements has been shown to improve FE. In a series of studies conducted at Washington State University, adding approximately 10 to 25 mg of supplemental Co from Co glucoheptonate to diets of multiparous cows increased FCM yield (Kincaid et al., 2003; Kincaid and Socha, 2006). In addition, FE improved 2.56 and 7.37% when cows received approximately 10 and 20 mg of supplemental Co. The control diet in both studies exceeded NRC (2001) requirements for Co. The hypothesis that NRC (2001) requirements for Co may be inadequate for maximizing performance of lactating dairy cattle is supported by results of a study recently reported by Girard and Matte (2005). In the study, first calf heifers in early lactation receiving diets supplemented with 0.66 ppm Co produced more ECM when given weekly injections of 10 mg vitamin B_{12}.

    Increased FE due to increased Co supplementation may be attributed to several factors including increased fiber digestion and vitamin B_{12} synthesis. In an *in vitro* study conducted at the University of Minnesota, fiber digestion and bacterial production of vitamin B_{12} increased when dietary Co concentrations increased from 0 to 10 ppm (Allen, 1986). It should be noted that vitamin B_{12} synthesis was lower in a 40% forage diet as compared to a 70% forage diet (Allen, 1986). In a follow-up study, Allen (1986) observed that replacing $CoSO_4$ with Co glucoheptonate increased bacterial production of vitamin B_{12} and numerically increased fiber digestion. Due to improved fiber digestion and production of vitamin B_{12}, improving Co availability to rumen microbes should improve animal performance under conditions such as reduced intakes, feeding high concentrate diets and feeding high forage diets.

Lastly, improving the status of zinc, manganese, copper and cobalt can improve reproductive performance, indirectly improving FE. In a summary of 12 trials (Kellogg et al., 2003) found feeding a combination of cobalt glucoheptonate and specific amino acid complexes of zinc, manganese and copper to decrease days to first service by 7 d and decrease days open by 16 d which would ultimately decrease herd DIM. Recently, St-Pierre (2009) reported that for each month conception is delayed, therefore increasing DIM, the herd can lose 0.11 point of FE.

Other factors that may potentially affect efficiency of ECM production include use of rbST, feeding yeast culture and improving cow comfort. Peel et al. (1989) noted that FE improved by 2.7 to 9.3% when cows were administered rbST. Improved FE is due partially to dilution of maintenance requirements, resulting in a greater percentage of dietary nutrients being used for milk production.

Conclusion

Feed efficiency is becoming an increasingly important performance measure as dairy management becomes more refined. However, to effectively evaluate FE, it must be standardized for milk composition, changes in BW, environmental factors and exercise. Feed efficiency can be enhanced by improving feed digestibility, increasing milk production and optimizing trace mineral status. Trace minerals have critical roles in maximizing FE as trace minerals are in involved in nutrient capture and utilization and maintaining animal health.

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Table 1. Effect of FE on dairy profitability.

Herd Size, cows	Milk Yield, lb/d	Dry Matter Intake, lb/d	Feed Cost, $/lb DM	Feed Efficiency	Feed Cost, $/Year
1000	75	53.6	$0.10	1.40	$1,956,400
1000	75	50.0	$0.10	1.50	$1,825,000

Table 2. Effect of correcting observed FE for milk composition, excess walking, body weight loss and gain and increased maintenance costs due to heat stress.

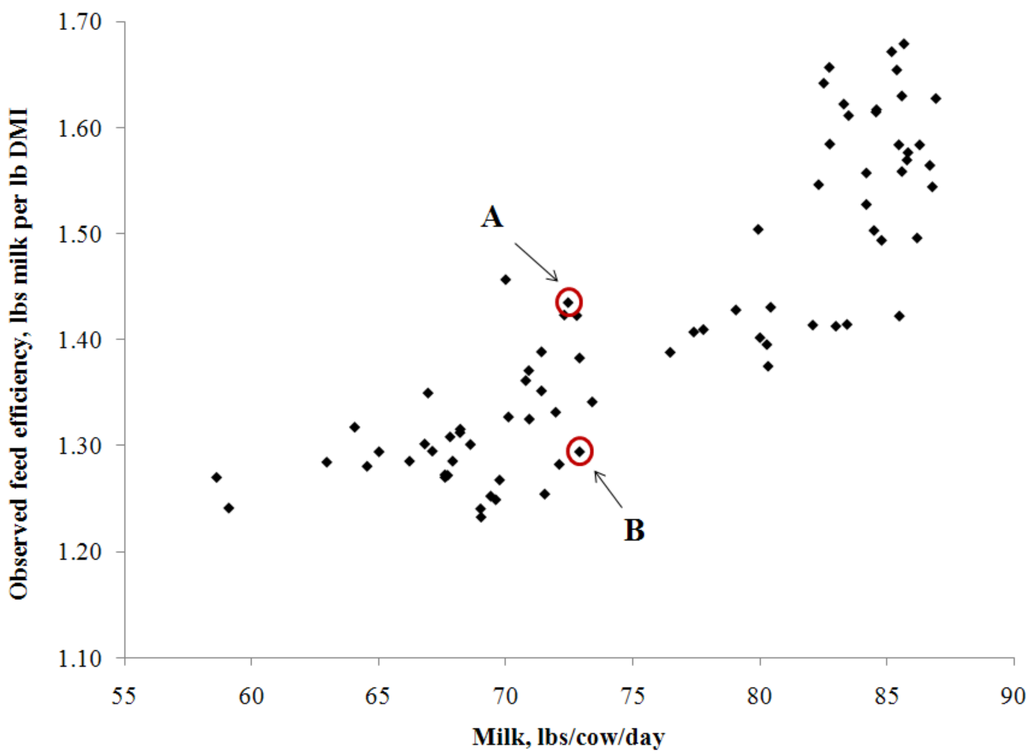
Item	Herd A	Herd B
Milk production, lb/d	72.5	72.9
Milk fat, %	3.32	3.72
Milk protein, %	3.12	3.05
Dry matter intake, lb/d	50.5	56.3
Observed feed efficiency (milk/DMI)	1.44	1.29
Energy corrected milk (ECM): 3.5% fat, 3.0% true protein	71.5	75.4
Cow body weight, lb	1500	1400
Walking distance, ft	6104	7196
Milkings/d	2	2.2
Average daily high temperature, degrees F	84	78
Relative humidity, %	35	57
Wind speed, mph	1	14
Hours in direct sunlight	1	8
% first calf heifers ≤ 40 days in milk	9.3	5.7
% first calf heifers ≥ 40 days in milk	20.7	39.4
% cows ≤ 40 days in milk	4.5	5.4
% cows 41 to 105 days in milk	7.3	10.7
% cows > 105 days in milk	58.2	38.8
ECM lost due to growth, lb/d	0.61	1.61
ECM lost due to temperature stress, lb/d	0.46	0.31
ECM lost due to excess walking, lb/d	1.83	2.01
ECM adjustment for stage of lactation and parity	2.83	2.83
Adjusted ECM, lb/d	76.7	80.5
Adjusted feed conversion	1.52	1.43

Table 3. Portion of dietary nutrients utilized for maintenance in cows producing 70 lb of milk versus 95 lb of milk (NRC, 2001).

Body Weight, lb	Milk Yield, lb/d[a]	Maintenance Requirement, Mcal	Production Requirement, Mcal	% of Energy Requirement Used For Maintenance	NRC (2001) Estimated DMI, lb/d	Feed Efficiency
1400	70	10.1	22.7	30.8%	49.8	1.41
1400	95	10.1	30.8	24.7%	58.4	1.63

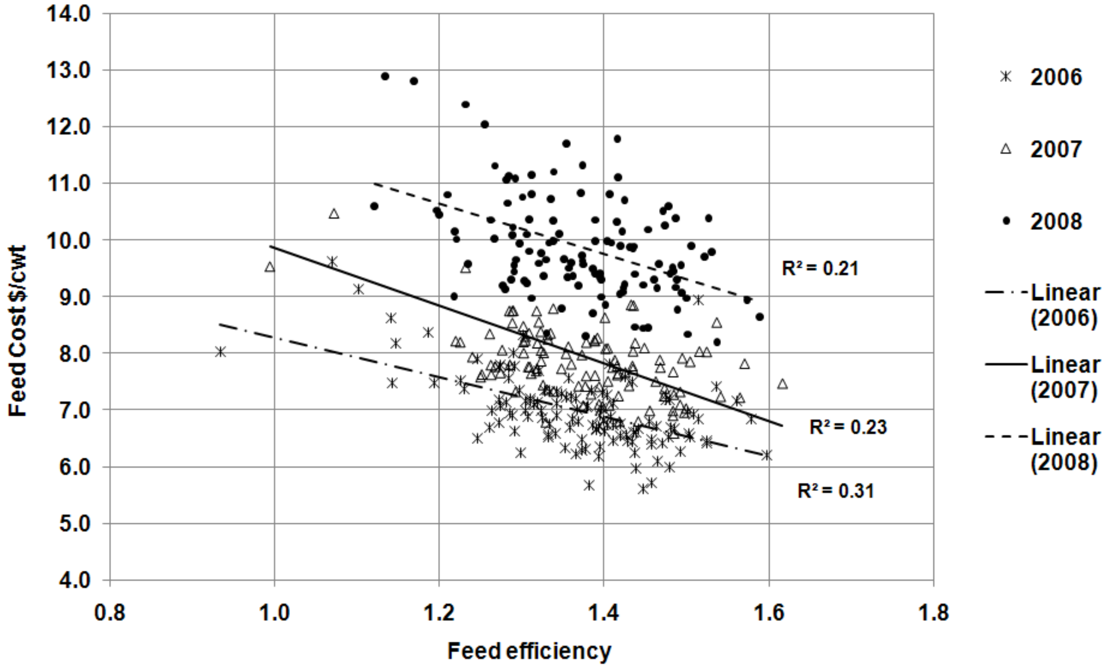
[a] Contains 3.7% fat and 3.1% protein.

Figure 1. Relationship between observed feed efficiency and milk production[a]



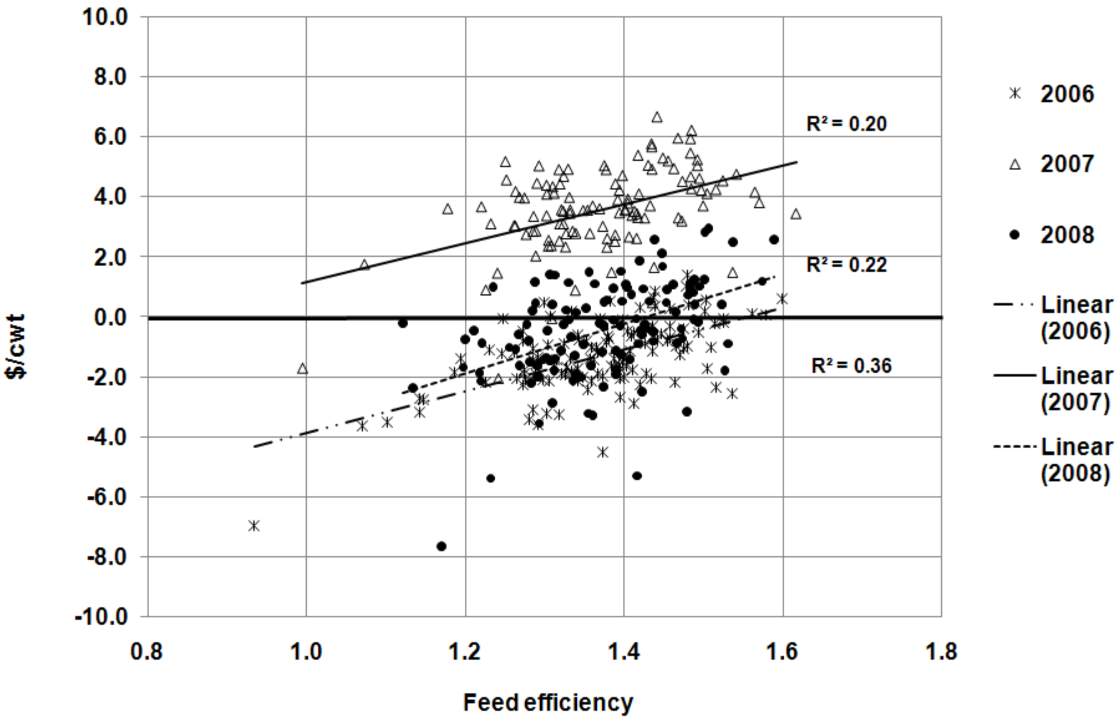
[a] 7 Western United States Holstein dairy herds, evaluated monthly from Aug 2007-Aug 2008 by Zinpro Corporation

Figure 2. Relationship between feed cost/cwt and feed efficiency in California Holstein herds during 2006 to 2008[a]



[a] Rodriguez, Zinpro Corporation, personal communication

Figure 3. Relationship between milk income/cwt and feed efficiency in California Holstein herds during 2006 to 2008[a]



[a] Rodriguez, Zinpro Corporation, personal communication. Milk income is defined as the mailbox price paid to each dairy less the total cost of producing milk (feed cost [forage, concentrate and supplements], labor, herd replacement [value of cows entering the herd less the total receipts for the same number of cows culled and dead], operating [utilities, supplies, veterinarian, nutritionist, medicine, outside services, repairs/maintenance, bedding, manure haul, fuel/oil, insurance, taxes, depreciation and miscellaneous] and milk marketing).