Factors Affecting Feed Efficiency of Dairy Cows

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Abstract

Feed efficiency **(FE)** is a concept that has gained popularity in recent years in the dairy industry. Monitoring FE is becoming a more common benchmark for monitoring the profitability of milk production relative to dry matter **(DM)** intake. In today's markets, feeds and commodities are becoming more costly, which is driving the requirement for more efficient utilization to maintain profitability. The goal of the dairy operation should be to maximize the efficiency of converting feed into milk, which adds the caveat of reducing manure production as well. How efficiently a dairy cow converts feed into milk can affect the dairy operation's bottom line, which during tough economic conditions, can be the difference between producing milk at a profit or a loss. Other livestock industries have used FE as a benchmark for profitability. Many articles have been written on what FE is, how to measure and calculate FE, and what factors influence FE. This presentation will be to focus the discussion on those biological mechanisms that control the efficient utilization of feeds by the dairy cow, especially DM and fiber digestibility. The understanding of these fundamental mechanisms will enable management decisions on the dairy operation to be implemented that will further improve or enhance FE.

Introduction

Feed efficiency or dairy efficiency **(DE)** has been a popular topic of observation and discussion on dairy farms the past few years. Many articles, both scientific and popular press, along with several conference proceedings (Britt et al., 2003; Casper et al., 2003, 2004; Britt and Hall, 2004; Linn et al., 2004; Hinders, 2005; Hutjens, 2005, 2006, 2007; Atwell, 2006a, 2006b) have been written on what FE is, how to measure and calculate FE, and factors affecting FE on the farm. In this presentation to keep things simple, FE will be defined as a unit of milk produced per unit of DM consumed.

Other livestock industries, such as the poultry, swine and beef industries, have used FE as a benchmark for profitability. Many examples have been published demonstrating the economics of FE (Casper et al. 2003; Hutjens 2005, 2007). The interest in FE is due to it's relationship of reducing feed cost while increasing the profitability of milk production. Table 1 provides a simple example of how improving FE can impact profitability. Both herds produced the same amount of milk, but the cows in Herd B consumed 7 lb less DM than cows in Herd A. Assuming today that feed costs are $0.10/lb of DM (probably conservative), Herd B had a lower feed cost of $0.70/cow/day compared to Herd A to get the same amount of milk. This $0.70 would be additional profit to the dairy operation. Thus, improving the FE will result in lower feed costs per unit of milk production while increasing profitability.

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In addition, Figure 1 demonstrates the reductions in feed costs on a per cow per day basis as FE increases, assuming constant milk production and a cost of $0.10/lb of DM. What is interesting about this graph is that the slope of this relationship in not linear but curvilinear. Thus, the biggest savings in feed costs can be realized by improving FE from 1.2 to 1.4, than improving FE from 1.6 to 1.8 ($0.83 vs. 0.63), respectively; however, remember these savings would be additive if FE could be improved from 1.2 to 1.8. During periods of low milk prices, finding ways to improve the FE or maintaining a high FE can be the difference between producing milk at a profit or a loss.

The range in FE observed in the field or the scientific literature can be quite large. Table 2 contains a summary of 422 treatment means summarized from feeding studies conducted with Holstein dairy cows published in the scientific literature. Milk production across these treatment means averaged 72.9 lb, but ranged from 41.0 to 103.0 lb/day, while DM intake averaged 48.6 lb/day with a range of 30.0 to 67.9 lb/day. The calculated FE observed in this data set averaged 1.51, but it ranged from a low of 0.86 to a high of 2.30. Understanding why FE varies this dramatically across feeding studies will allow for management decisions to be made that can enhance FE in the future.

Agri-King has been monitoring FE for approximately 15 years because of our focus on improving the profitability of the dairy operations that we work with. Our first experience (Casper et al., 2003) with increasing FE occurred when dairy herds were having high milk production on lower than expected DM intakes. Evaluating these dairy herds in depth indicated that the apparent reason(s) for these dairy cows achieving higher milk production on lower than expected DM intakes appeared to be related to the feeding of extremely highly digestible forages.

Many authors have published excellent reviews on factors influencing FE, such as days in milk, age, body weight, etc. (Linn et al., 2004; Hutjens, 2005, 2006, 2007; Atwell, 2006a, 2006b). However, our work (Casper et al., 2003, 2004; Casper and Mertens, 2007) has focused on identifying those basic fundamental factors that can be measured, manipulated, and managed to increase FE. This presentation will address what we believe to be some of the fundamental factor(s) influencing FE and that is the digestibility of nutrients from the feeds and forages fed to lactating dairy cows.

Digestibility

The National Research Council (2001) demonstrates the greatest factor affecting energy availability to the lactating dairy cow is digestibility. In a small field study, Casper et al. (2004) reported that nutrient digestibility had a direct effect on FE. Six dairy farms feeding a total mixed ration **(TMR)** were used to collect samples of TMR and manure samples, along with data on milk production, milk composition, and intake of DM. Nutrient composition of TMR and manure samples were measured and nutrient digestibilities were calculated using acid insoluble acid **(AIA)** as an internal digestibility marker. Figure 2 shows that the FE responses of these dairy cows were directly related to the DM digestibility **(DMD)** of the ration ($FE = 0.032 + 0.02 * DMD$, $R^2 = 0.59$, $P < 0.01$). In addition, Figure 3 demonstrates that as the FE increases, the intake of DM was lower for these dairy cows. Indirectly, FE can be used as an indicator of ration digestibility, i.e. if FE is low, then digestibility of the ration may be poor. Figure 3 demonstrates that dairy cows do not need to consume large amounts of DM in order to have high milk production. Supplying the required amounts of digestible nutrients in the ration is crucial to achieving high milk production. If that supply can be achieved by consuming less DM that is more digestible, then milk production and FE should be improved.

Within this study, the range in digestibility of the forages explained most of the variation observed in digestibility of the ration by the lactating dairy cows. Thus, in most feeding situations, forages usually comprise the largest portion of the ration compared to other feed ingredients. Forages have much more variability in digestibility than grains or commodities. Therefore, forage quality and digestibility is going to have a major impact on FE. Tables 3, 4, and 5 demonstrate the ranges in forage quality and digestibility observed from samples submitted to our laboratory. As these tables demonstrate, the range in nutrient concentrations and the digestibility on a DM or NDF basis can be very large between samples within these forage categories. Submitting forage samples for measurement of digestibility of DM and NDF would be the first step towards improving FE on the dairy operation**.**

Energy Metabolism Database

If FE is directly related to nutrient digestibility, then it follows that FE would be directly related to dietary energy density. One of the biggest databases in the world measuring the energy density of the ration is the Energy Metabolism Database from the Energy Metabolism Unit **(EMU)** of the United States Department of Agriculture – Agriculture Research Service **(USDA-ARS)**. The EMU database, which was compiled by Casper and Mertens (2007), represents more than 40 years of studies measuring the energy and protein digestibility of dairy cattle fed diets that varied in forage types, grain sources, protein sources, and fat supplements. Of the 3,018 individual energy and N digestion trials, only 1351 individual trials used lactating dairy cows of different breeds and stages of lactation.

The initial analysis of the EMU database indicated that ruminal acidosis may have occurred in many of the individual balance trials, which negatively affected nutrient digestibility. Thus, digestion trials conducted on lactating dairy cows having inverted fat and protein ration (acidosis criteria) were removed from the data analysis, which resulted in the final data set having 495 observations relating FE and nutrient digestion. These energy balance trials demonstrated that FE was directly related to the amount of absorbed DM consumed by the lactating dairy cow (Figure 4; FE = 0.383 + 0.074 * DM absorbed, g/day; $R^2 = 0.44$, $P < 0.01$). Therefore, lactating dairy cows having higher FE are those cows that are consuming rations containing more digestible DM.

Because dietary energy density is directly related to ration digestibility, it becomes apparent that FE is directly related to the net energy **(NE)** density of the diet (Figure 5; FE = -0.01 + 1.25 * NE, Mcal/kg DM; $R^2 = 0.60$, $P < 0.01$). Since, absorbed DM is a function of both digestibility of the ration and intake of DM by the lactating dairy cow, it becomes apparent that improving DM digestibility has the potential to reduce the amount of DM needed to meet her nutrient requirements. Pushing dairy cows for maximum intake of DM may not always result in maximal or optimal milk production. Why push cows for high intakes of DM to get 80 lb of milk when the same milk yield can be achieved with 50 pounds of DM? The extra feed cost is lost profit to the dairy operation.

Acidosis

In the EMU database, feeding diets that resulted in lactating dairy cows having inverted fat and protein ratios (acidosis criteria) certainly had a negative effect on FE. Acidosis dramatically reduced the relationship of FE to absorbed DM (FE = 0.40 + 0.10 * DM absorbed, kg/day; $R^2 = 0.28$, $P < 0.01$). Acidosis, as expected, caused reductions in the digestibility of ADF and cellulose, which are the fiber fractions of the diet. Casper and Mertens (2007) also reported that acidosis increased the amount of heat produced per unit of digestible energy (51.4 vs. 54.6%), which resulted in a poorer conversion of digestible energy into net energy available for productive purposes. Acidosis negatively influences the energy metabolism of the lactating dairy cow along with affecting the health of the cow in a negative manner.

These data demonstrate that the biggest factor affecting energy availability to the lactating dairy cow is ration digestibility. This database analysis also demonstrates that by improving ration digestibility, the FE of the lactating dairy cow will increase as well. The corollary from an environmental standpoint is that improving ration digestibility will reduce manure output. In this data set, fecal energy output ranged from a low of 20% to more than 60% of gross energy intake. The data demonstrate that improving the nutrient digestibility of the diet to improve FE should result in more energetic efficient cows. Also, it stands to reason that using the best management practices of forage production to produce the highest quality forages or using feed additives that improve nutrient digestion, while preventing acidosis, have the greatest potential for improving FE.

Silage Additives

Forages represent a major portion of the diet and the digestibility/quality of these forages will have a major impact on ration digestibility (Casper et al., 2004; Casper and Mertens, 2007). In this author's opinion, forage quality cannot be too good. Thus, producing or purchasing forages having the highest digestibility is going to result in the highest FE and the most economical milk production. The use of silage inoculants or silage fermentation aids during the ensiling process has increased in recent years to enhance the production of lactic acid plus other benefits for the long term storage of forages.

The use of specific silage inoculants or silage fermentation aids (products) during the forage harvesting process that have been formulated with specific features and benefits have the potential to improve the digestibility of nutrients in ensiled forages. For example, we conducted a study (Ayangbile et al., 2001) evaluating the addition of a silage additive (Silo-King®, Agri-King, Inc., Fulton, IL) during the ensiling process at increasing rates to determine if the digestibility of alfalfa haylage could be enhanced. The additive was applied to alfalfa haylage at increasing applications rates (0.33, 0.67, and 1 lb/ton of alfalfa forage) at the time of ensiling. The ensiled alfalfa haylage was allowed to proceed through the ensiling process and was stored (> 60 days) before being fed to growing wethers. The experimental design was a replicated 4 x 4 latin square design using metabolism crates to measure the digestion and absorption of nutrients. Figures 6 and 7 demonstrated that application of the additive at increasing application rates resulted in increasing ($P < 0.05$) the digestion and absorption of DM and NDF. Thus, improvements in DM and fiber **(NDF)** digestibilities can be achieved by treating forages during the ensiling process. These improvements have the potential to improve the FE of lactating dairy cows through improvements in the digestibility of forages by the animal.

Direct Fed Microbials (DFM) and Enzymes

This is an exciting area of research and product development being undertaken by several companies that holds great promise for improving FE by lactating dairy cows. Schingoethe et al. (2004) demonstrated that feeding enzymes resulted in an improvement in milk production. The stage of lactation and the cows' energy requirement will dictate the type of responses observed in FE.

For example, we have developed a product based on the combination of DFM and enzyme technologies (Ru-Max®, Agri-King, Inc., Fulton, IL) that was evaluated using 1000 dairy cows split into 2 groups using a switchback trial design. Milk production (Figure 8) was similar ($P > 0.10$) for both groups of cows, but the improvements in ration digestibility resulted in a 5.3 lb decrease in intake of

DM. Therefore, feeding the product resulted in an improvement in FE of 0.16 units (1.57 versus 1.73 for Control and Product, respectively). This resulted in a return on investment of 4.2 for every $1 spent. These types of products hold promise in improving the FE of lactating dairy cows and the economics of producing milk

Yeast and Yeast Cultures

Yeast and yeast cultures have been fed to dairy cattle for more than 60 years. Yeast culture has improved intake of DM and milk production in controlled studies (Miller-Webster et al., 2002; Schingoethe et al., 2004; White et al., 2008). Schingoethe et al. (2004) reported an increase in FE of 0.1 unit ($P < 0.04$) when cows where fed yeast. This was the result of numerically greater ($P > 0.10$) milk production and lower intake of DM. It is interesting to note that milk fat was numerically increased due to feeding yeast which would be hypothesized to occur from greater DM and fiber digestion. Miller-Webster et al. (2002) reported increases in DM digestibility of 2.4 and 5.0 percentage units when yeast products were evaluated using a continuous culture system. White et al. (2008) demonstrated a 3.2 percentage unit improvement in NDF digestibility by feeding cows yeast culture compared to cows receiving the same diet without yeast culture. Using yeast as a feed additive has the potential to improve FE by approximately 0.1 units by improving rumen function and nutrient digestion.

It is the authors' field experience that reductions in intake of DM sometimes do not occur until cows are in a positive energy balance or gaining body weight. It is interesting to note that in the study by Schingoethe et al. (2004) that a numerical increase in body condition scores was observed with the reduction in DMI for cows fed the yeast containing ration.

Conclusions

The greatest factor affecting nutrient availability to the lactating dairy cows is the digestibility of the ration. The FE potential of the dairy herd is directly related to the DM digestibility and energy density of the forages and feeds used in ration formulation. Producing or obtaining forages with the highest digestibility possible represents the greatest potential for improving FE and reducing the cost to produce 100 lb of milk. Proper ration balancing to maximize fiber digestion and eliminating acidosis will improve FE and energetic efficiency of the dairy cow. The use of forage inoculants and feed additives (yeast cultures, live yeast, DFM, and enzymes) that improve ration digestibility can be used to further improve FE; however, these improvements are not as dramatic as improving forage quality. Improving FE can increase the income over feed costs and reduce the cost to produce 100 lb of milk. Tracking and improving FE on your dairy operation using those nutritional technologies that enhance digestibility and FE will improve profitability in good times and can be the difference between profit and loss in times of low milk prices.

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Table 1. Impact on feed costs in two herds with different feed efficiencies.

Measurement	Herd A	Herd B
Milk, lb/day	80	80
DM intake, lb/day	57	50
Feed efficiency	1.40	1.60
Milk income @ $16/cwt	$ 12.80	$ 12.80
Feed costs @ $0.10/lb DM	$ 5.70	$ 5.00
Income over feed costs	$ 7.10	$ 7.80
Cost to produce 100 lb milk	$ 7.13	$ 6.25

Table 2. Milk production and composition, dry matter intake (DMI), and feed efficiency summarized from 422 treatment means published in the scientific literature.

Measurement	Average	Minimum	Maximum
Milk, lb/day	72.9	41.0	103.0
Milk fat, %	3.59	2.37	4.84
Milk protein, %	3.16	2.61	3.74
DMI, lb/day	48.6	30.0	67.9
Feed efficiency, Milk/DMI	1.51	0.86	2.30

Table 3. Nutrient concentrations (% of DM), neutral detergent fiber digestibility (or cell wall digestibility; CWD, %), and dry matter digestibility (DMD, %) of corn silage samples when ranked by DMD.[1]

Item	CP	ADF	NDF	CWD	Lignin	Oil	NFC	Starch	DMD
Poor	8.0	30.8	51.1	46.8	3.29	1.94	21.1	22.2	55.5
Fair	8.5	29.3	50.1	50.1	3.06	2.29	36.4	22.9	67.8
Medium	8.4	24.5	42.9	52.0	2.44	2.70	43.8	30.4	72.7
Good	8.6	20.9	37.4	54.1	2.01	2.96	39.2	36.2	76.5
Excellent	9.0	16.5	30.7	55.2	1.58	3.25	55.8	43.9	80.9
Average	8.5	24.4	42.7	52.0	2.44	2.69	43.9	30.6	73.0

[1]CP = Crude protein, ADF = acid detergent fiber, NDF = neutral detergent fiber, and NFC = nonfiber carbohydrates.

Table 4. Nutrient concentrations (% of DM), neutral detergent fiber digestibility (or cell wall digestibility; CWD, %), and dry matter digestibility (DMD, %) of ensiled haylage samples when ranked by DMD.[1]

Item	CP	ADF	NDF	CWD	Lignin	NFC	DMD
Bad	12.3	47.5	66.0	46.0	12.2	17.5	43.2
Poor	13.9	42.7	61.6	52.3	8.5	19.6	56.6
Fair	18.3	36.1	50.9	57.6	6.9	23.8	66.4
Medium	21.1	31.4	43.7	60.0	5.9	27.2	72.4
Good	22.7	27.7	38.6	61.9	5.2	29.8	76.8
Excellent	24.3	23.8	33.3	65.2	4.4	32.8	81.5
Average	19.8	33.2	46.6	59.0	6.33	25.9	69.8

[1]CP = Crude protein, ADF = acid detergent fiber, NDF = neutral detergent fiber, and NFC = nonfiber carbohydrates.

Table 5. Nutrient concentrations (% of DM) , neutral detergent fiber digestibility (or cell wall digestibility, CWD, %), and dry matter digestibility (DMD, %) of hay samples when ranked by DMD.[1]

Item	CP	ADF	NDF	CWD	Lignin	NFC	DMD
Bad	8.71	45.9	71.7	41.6	7.2	15.9	45.9
Poor	12.2	40.6	63.8	48.8	6.3	19.9	55.7
Fair	18.1	34.9	51.7	54.4	6.5	24.8	65.7
Medium	21.3	29.8	42.3	57.1	6.0	29.5	72.4
Good	23.2	25.8	35.4	58.5	5.3	33.1	76.9
Excellent	24.9	21.8	29.2	62.1	4.6	36.2	81.4
Average	18.7	33.2	48.8	54.6	6.14	26.5	67.4

[1]CP = Crude protein, ADF = acid detergent fiber, NDF = neutral detergent fiber, and NFC = nonfiber carbohydrates.

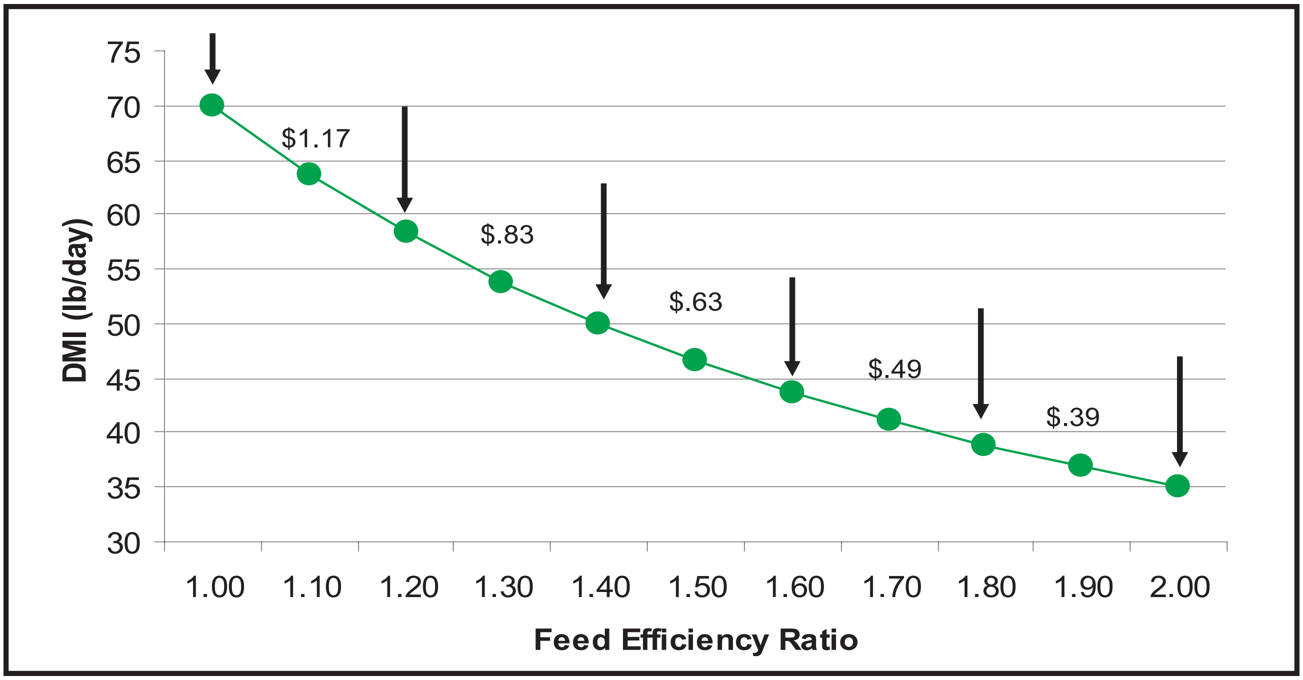

Figure 1. Change in feed costs as the feed efficiency ratio improves and dry matter intake (DMI) declines for producing 70 lb of milk at a cost of $0.10/lb of DM.

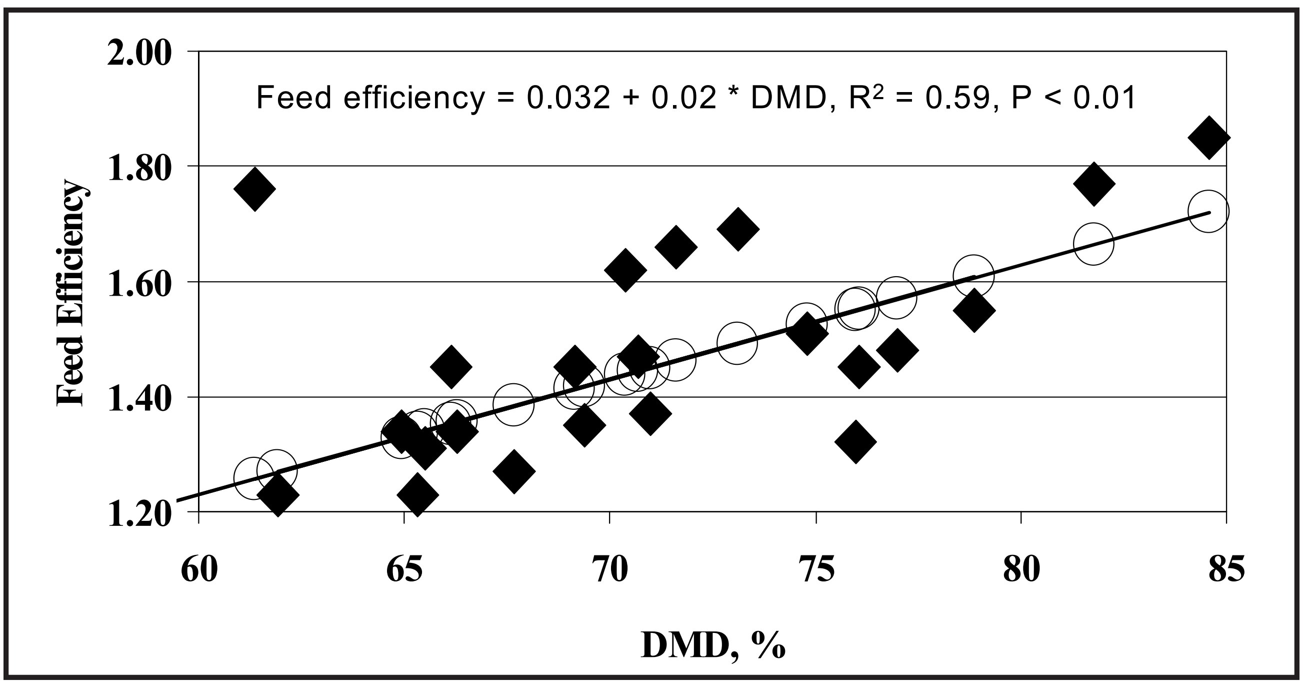

Figure 2. The relationship between feed efficiency and ration dry matter digestibility (DMD) by lactating dairy cows (Casper et al., 2004).

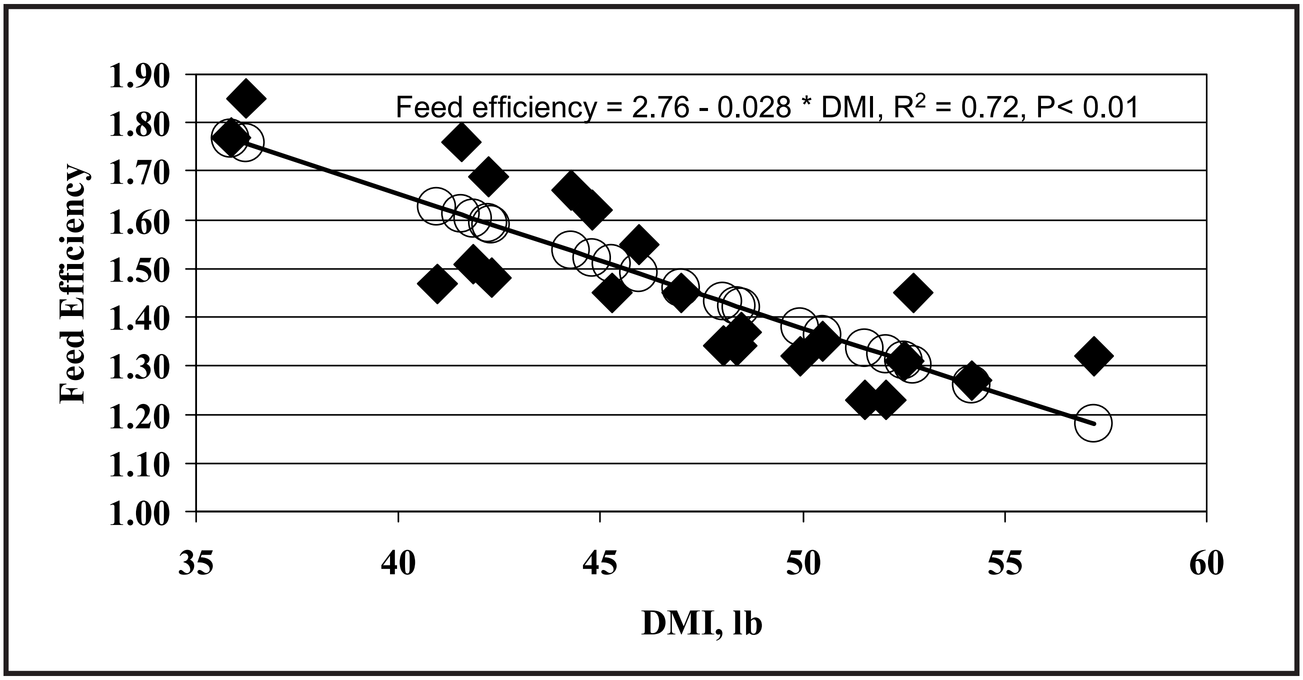

Figure 3. The relationship between feed efficiency and dry matter intake (DMI) by lactating dairy cows.

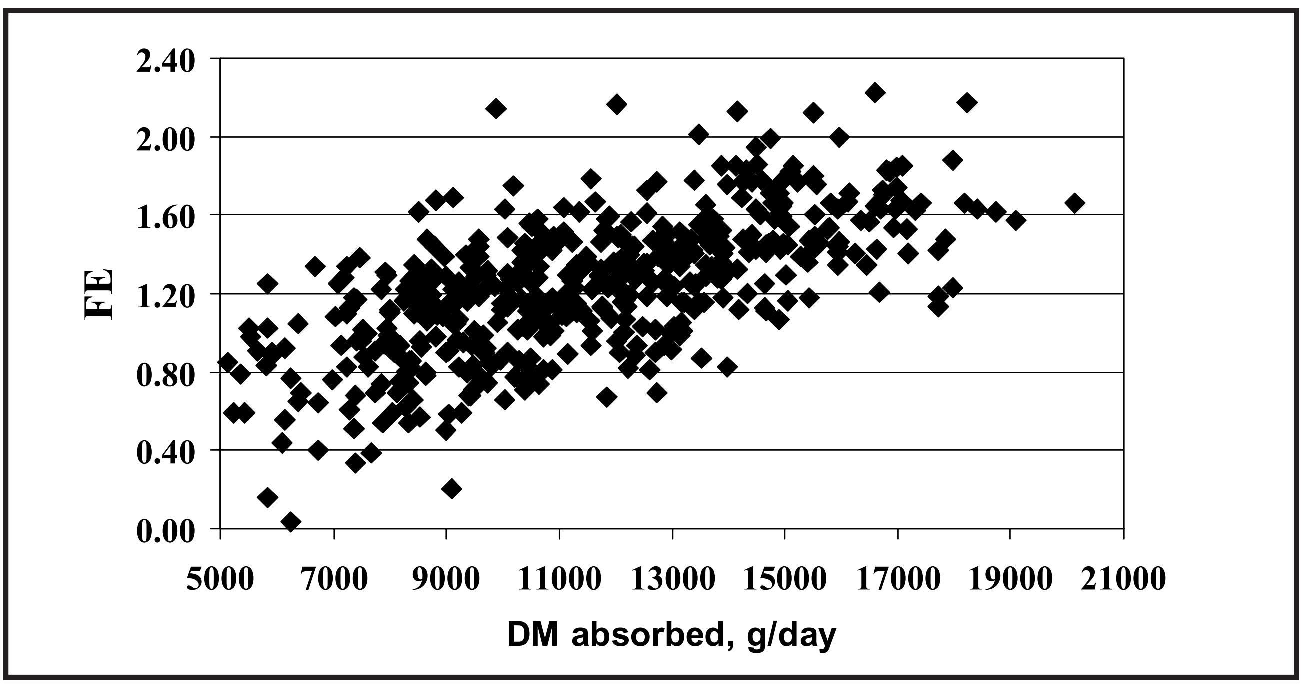

Figure 4. The relationship of feed efficiency (FE) to the amount of dry matter (DM) absorbed by lactating dairy cows.

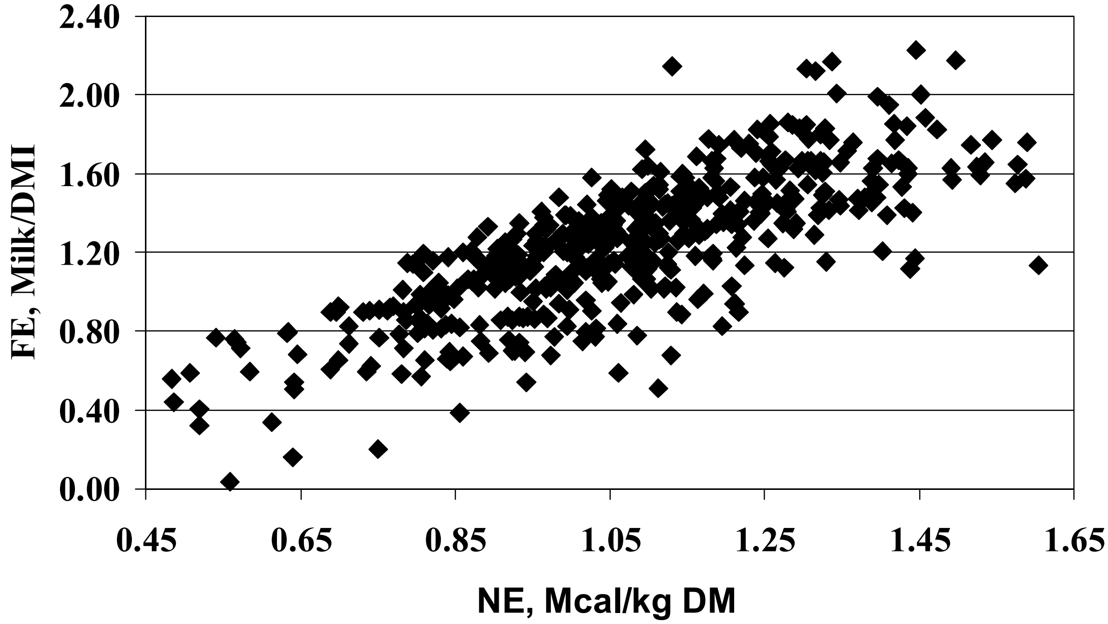

Figure 5. The relationship of feed efficiency (FE) to the net energy content (NE) of the diet fed to lactating dairy cows (DMI = dry matter intake).

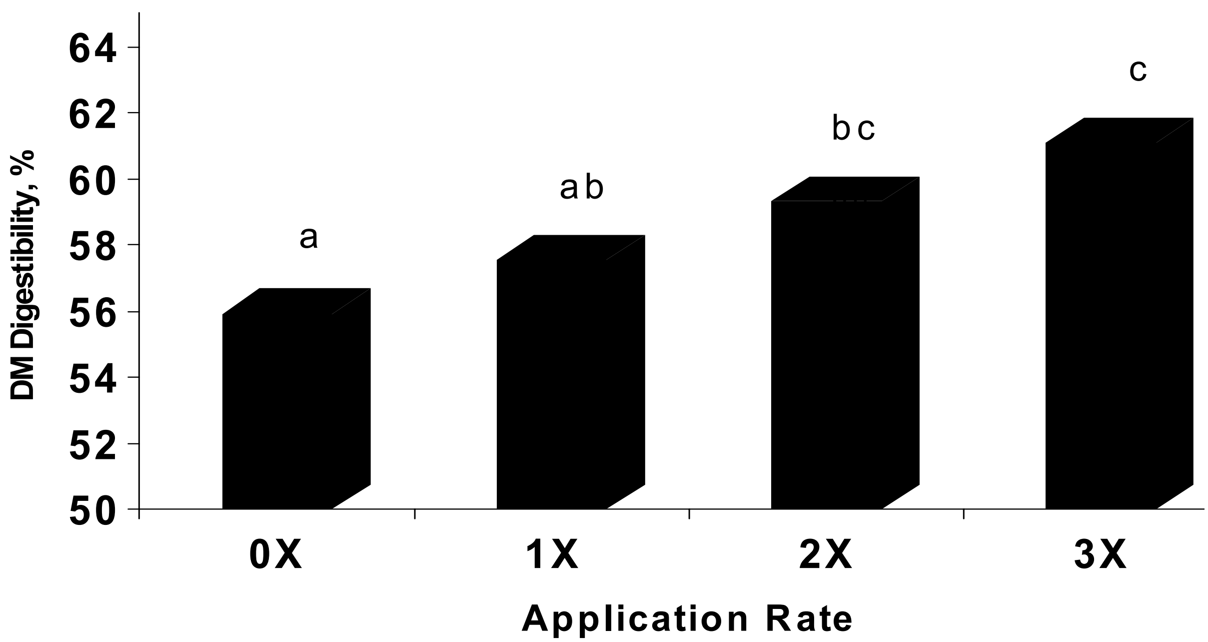

Figure 6. Effect of Silo-King® (Agri-King, Inc., Fulton, IL) application rate on dry matter (DM) digestibility of alfalfa haylage by growing wethers (Ayangbile et al., 2001; [abc]Means differ, $P < 0.05$).

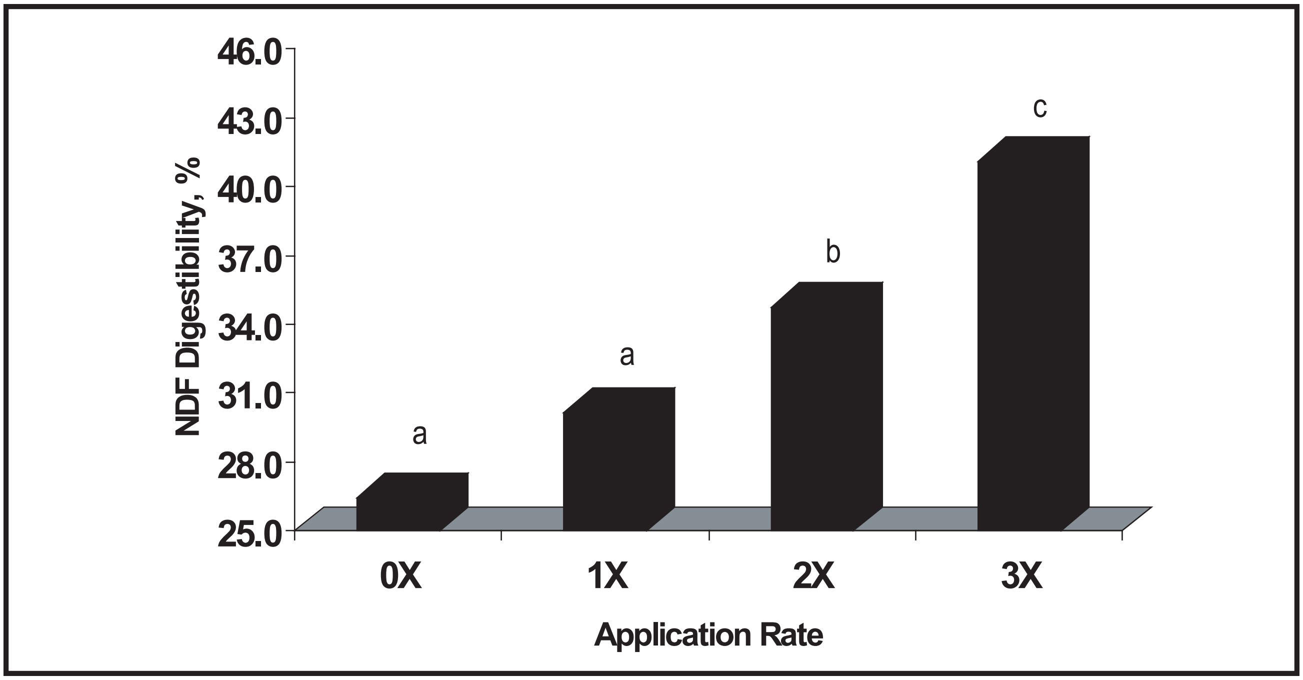

Figure 7. Effect of Silo-King® (Agri-King, Inc., Fulton, IL) application rate on neutral detergent fiber (NDF) digestibility of alfalfa haylage by growing wethers (Ayangbile et al., 2001; [abc]Means differ, $P < 0.05$).

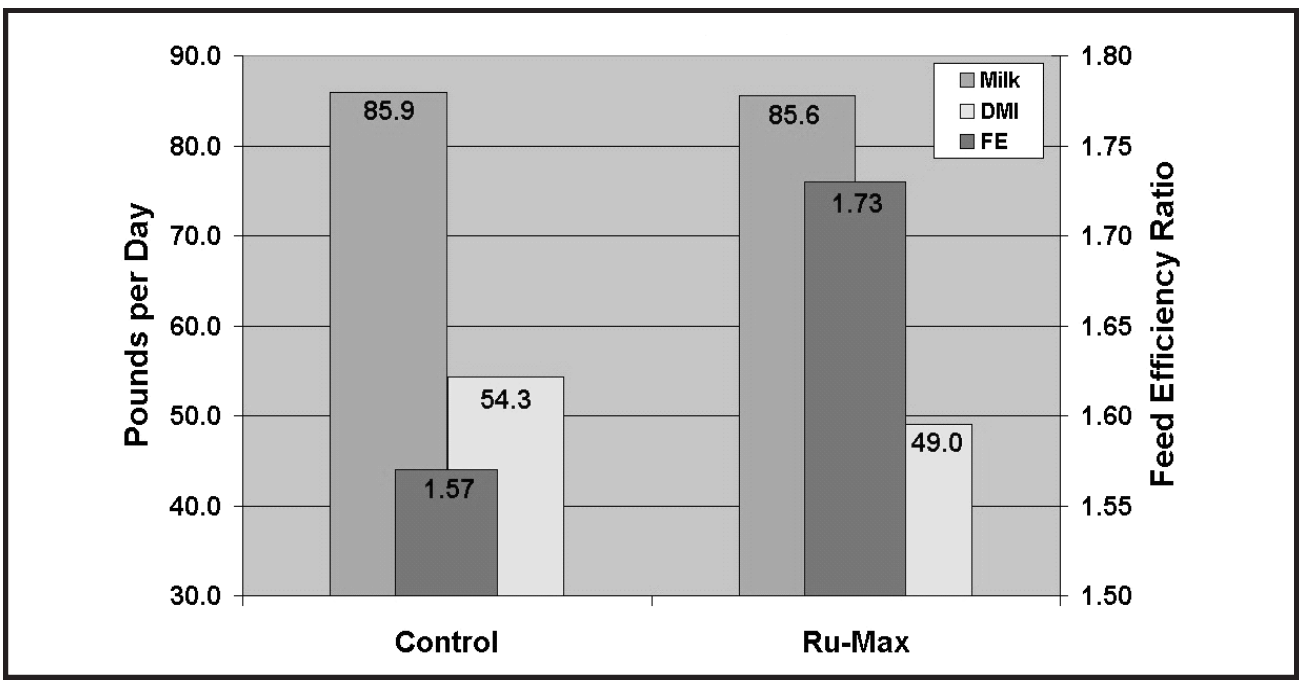

Figure 8. Milk production, dry matter intake (DMI), and feed efficiency ratio when lactating dairy cows were fed the same ration without (Control) or with Ru-Max (Agri-King, Inc., Fulton, IL).