Increasing Efficiency of Nutrient Use to Enhance Profit and Environmental Stewardship

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The efficiency of converting feed to milk in the US has doubled over the past 60 years (VandeHaar and St-Pierre, 2006). With increasing efficiency, we have decreased the amount of greenhouse gasses produced per pound of milk and the amount of wasted protein. Further improvement is essential to feeding a human population that is expected to increase from 6 to 9 billion in the next 40 years while at the same time reducing our environmental footprint and keeping farms profitable. Few Americans today understand how food is produced and the synergy between productivity, efficiency, stewardship of resources, reduction of waste, and profitability. Those of us in agriculture must do a better job of helping others to understand our industry so that technological innovations can continue to improve efficiency and environmental stewardship.

Productivity and Feed Efficiency

Feed efficiency can be considered many ways. The simplest would be pounds of milk per pound of feed, but this does not give adequate consideration to the value of forage and fiber in dairy nutrition. In addition, feed use impacts not only current production and efficiency but also health and longevity. Moreover, one might argue that we should consider all inputs and outputs of energy and nutrients on a global scale. Such a global view would consider the efficiency of using human-edible inputs, the efficiency of using land, and the inputs and outputs of fuels and greenhouse gasses. In this paper, I will discuss mostly energetic efficiency.

Gross energy (**GE**) is the combustible energy of a feed and is independent of how efficiently the cow uses it. I will define *energetic efficiency* as ***gross efficiency***, the total milk and body tissue energy captured per unit of GE consumed. Major factors that *affect gross feed efficiency on farms* include: a) cow body weight (**BW**), b) milk yield per cow, c) longevity and the percentage of lifetime a cow spends in lactation, d) nutritional accuracy in feeding, and e) the cows' net efficiency of converting feed to milk.

Not all GE is useful because some of it is not digested but is lost as fecal energy. Some of the digested energy (**DE**) is lost as gaseous energy, primarily methane produced during fermentation, and as urinary energy, primarily urea produced during protein breakdown. The remaining energy is metabolized energy (**ME**). About one-third of ME is lost as heat associated with the work of fermenting, digesting, and metabolizing

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nutrients. The remaining energy is known as net energy (**NE**), which represents the chemical energy of secreted milk and accreted body tissues and conceptus and the chemical energy that is converted to heat in support of maintenance functions. In dairy cows, the efficiency of converting ME to NE is about the same whether the ME is used for maintenance or for milk production, and thus we discuss NE for lactation (**NEL)**.

For the typical US Holstein cow, the first 10 Mcal of NEL/day (equivalent to ~25 Mcal of GE and 14 pounds of feed) is used for maintenance. At this level of intake, gross efficiency is 0% as no milk is produced. Additional feed that is consumed can be converted to milk or body tissues. If the cow eats twice as much feed, 20 Mcal NEL or 2X maintenance, then only half of her feed would be used for maintenance and half would be used for production. As she eats more feed, the portion used for maintenance becomes a smaller fraction of total feed intake; this phenomenon is referred to as "***dilution of maintenance***" and it is the reason that greater productivity leads to greater efficiency.

Theoretically, if the cow's maintenance requirement is constant and the net efficiency of converting feed to milk were constant, gross efficiency would continue to increase as maintenance accounted for a smaller portion of total feed intake. However, the increase in gross efficiency is less going from 3X to 4X maintenance than from 2X to 3X, and progressively less thereafter (solid line, Figure 1). This is true whether the increase in multiple of maintenance is caused by increased production at fixed BW or by reduced BW at fixed production. However, this projection is overly optimistic, because as cows eat more feed per day, feed digestion is depressed. Eventually, as productivity increases, this depressed digestive efficiency becomes more important than the dilution of maintenance and gross efficiency may decline (dotted line, Figure 1; NRC, 2001). This digestibility depression is not well quantified for cows consuming >4X maintenance (VandeHaar, 1998; Casper and Mertens, 2008; Huhtanen et al., 2008), and the NRC (2001) likely depresses digestibility too much at high intakes. The best estimate for gross efficiency would be a curve that is between the two curves of Figure 1. I believe a digestibility discount that diminishes with each successive multiple of maintenance is more logical and equally supported by the literature; this discount method was described in VandeHaar (1998) and is the basis for most of my discussions of efficiency.

Regardless of the discount used, the depression in digestibility at high intakes clearly does occur, and elite cows are already near, at, or possibly above the optimal multiple of maintenance for maximal efficiency. In the past 100 years, feed efficiency has increased considerably, largely as a byproduct of selection and management for increased productivity. As production increases to high levels, the digestibility depression becomes more important in determining gross feed efficiency than does the dilution of maintenance. We are not likely to continue to make major advances in feed efficiency in the US simply by increasing productivity. We must specifically focus more on how to get more milk from each unit of feed.

Productivity and Profitability

Because feed accounts for about half of all costs on a dairy farm, trying to cut feed costs is very tempting, especially when feed prices are high. However, feed for lactating cows is obviously not a frivolous expense but an investment. As already discussed, increasing productivity leads to increased feed efficiency, and increased feed efficiency leads to greater net profits. Many factors affect profitability and can mask effects of productivity on profitability; thus, some studies have shown virtually no relationship between production per cow and profit per cow across farms. However, within a farm this relationship is clearer, and, when full-cost accounting is used, profitability and milk production per cow are positively correlated. This positive relationship is largely due to two factors: 1) the biological dilution of maintenance, which increases cow feed efficiency, and 2) the economic dilution of fixed costs, which increases efficiency of farm capital and labor use. Opposed to this is the fact that feeds generally become more expensive on a per unit energy basis as cows are fed for higher production, which can increase the marginal cost of feeds per unit of milk.

As shown in Figure 2, increasing production from 15,000 to 25,000 lb/cow, has a major impact on efficiency, which is at least partly why such an increase would generally increase profitability. However, unless major improvements occur in the ability of cows to digest feed, or unless our predictions of feed digestion at high intake are very inaccurate, some farms in the US may now be approaching the predicted maximum lifetime feed energetic efficiency of ~25%. Despite the projection that efficiency may not increase as milk production surpasses ~35,000 lb/cow/year, profitability should continue to increase with higher production, even after considering that more expensive feeds may be required. Over the production range shown in Figure 2, the dilution of nonfeed fixed costs compensates for the increase in marginal feed costs and lack of improved feed efficiency. At some point, the marginal profitability (i.e., the increase in net income from one additional kg of milk) will become negative, but increased productivity will continue to enhance profitability on most farms for the foreseeable future. Furthermore, expected increases in environmental regulations will increase capital requirements per cow, putting an even greater emphasis on capital efficiency, and further favoring increased productivity.

Although increased productivity usually increases profitability, formulating diets to achieve maximum milk production is likely not the most profitable, feed costs do matter! With increasing the nutritional quality and cost of a diet, each successive increase in nutrient intake and cost generally results in less milk response, so that production responses follow the law of diminishing returns (Figure 3). Thus, there is usually an optimal nutrient intake or density for maximizing the efficiency and profitability of milk production, and the optimums for efficiency and profits are usually at different points in the milk response curve. For most nutrients except energy, it generally pays to increase the dietary concentration of the nutrient above that at which efficiency is maximized as long as the return from the last unit added exceeds its costs. Some nutrition programs attempt to formulate diets using a mathematical model for profit maximization. However, in real life, it is virtually impossible to accurately predict how a diet will affect appetite, nutrient partitioning, and milk yield and components. Thus, monitoring the actual response is essential for optimal farm management. High milk production is almost always more important for high profitability than is low feed cost, but paying attention to feed costs is still prudent.

Productivity and Stewardship of the Environment

Our society cares about how we do agriculture. Most consumers may not be willing to pay more for dairy foods produced in certain ways, but politicians and food retailers are increasingly impacting what practices are acceptable. Whether we agree with their decisions or not, most of us in agriculture also have a sense that being good farmer means more than just productivity and profits. We are proud of the fact that we provide quality products to feed the world, and we admire a farmer who takes good care of his cows and his land. Wendell Berry, the Kentucky farmer poet, writes, "What is the measure of a good farmer? It is how he leaves the soil." A good word to describe this idea is “stewardship.” Hopefully, for most of us, a major objective in agriculture is to practice good stewardship. Dictionaries define stewardship as the discipline of taking care of something for someone else. The "something" is that which is under your control, which for a dairy farmer would include land and the environment, feed and other resources, cows, and milk. The "someone else" depends on your worldview, but at the least, we should take care of our world for other people and future generations. I think that there are four major areas to consider in agricultural stewardship. A good steward in dairy farming is one who 1) is environmentally-friendly, 2) makes efficient use of the earth's natural resources, 3) produces quality milk and meat, and 4) practices good animal husbandry. I will focus on environmental stewardship in the remainder of this paper. My goal is to encourage better stewardship in the dairy industry and to help defend our industry when it is unfairly criticized.

There are many practices in dairy farming that contribute to good stewardship of the environment. We should strive to limit run-off of phosphorus, nitrogen, and organic materials from our farms. Phosphorus causes eutrophication of surface waters, and nitrogen can contaminate ground water. Both of these nutrients are often overfed. Ammonia losses to the atmosphere are a growing concern without easy solution. Soil erosion should be minimized in crop farming and grazing, and stream banks should be protected from grazing cattle. A good environmental steward also protects some areas of native vegetation and retains some wildlife habitat. What role, if any, do productivity and efficiency play in environmental stewardship?

As the world population continues to increase, and land resources are not expanding, efficiency of using existing land becomes more important. Much of the land currently used for growing feed grains and forages for cattle could be used to grow grains and legume seeds for humans, or could be used to grow biofuels. Measures of efficiency that consider how we use human-consumable inputs and how we use land that could be used to directly grow food for humans must be considered. Although the efficiency of total feed use in the US dairy industry is 20 to 25% for energy and 20 to 30% for protein, the returns on human-digestible inputs ranges from 60 to 130% for energy and 100 to 280% for protein (Oltjen and Beckett, 1996). Increased use of by-product feeds with greater digestibility discounts may decrease the gross efficiency of total feed use, but most by-product feeds are not consumable by humans. Therefore, the use of by-product feeds in dairy diets increases efficiency of human-consumable inputs in the dairy industry. This advantage is especially important in light of the fact that one acre of land can produce only half as much human food when used for growing feeds for milk production at current milk production levels than when used to grow corn and soybeans for direct human consumption (VandeHaar and St-Pierre, 2006). Milk output per acre increases with greater milk production per cow. If byproduct feeds make up about one-third of a herd's diet and the cows produce 30,000 lb/year, then using land for milk production yields 90% as much food for human consumption as does corn and beans. Using land to produce corn and soybeans (or grains and legume seeds) for direct human consumption would be the most efficient way to feed people. Given that well-run dairy operations can achieve land efficiencies almost as high suggests that the dairy industry will be part of our food production long into the future. However, the use of fibrous by-product feeds with small particle size and high digestibility discounts may limit the ability of cows to produce the highest levels of milk. Because efficiency of use of human-digestible inputs may become the most important justification for the continued existence of a strong dairy industry in the US, the value of increasing productivity may decrease as more fibrous by-product feeds become available, especially if prices of grains and of land for feed production are high, but this will likely not occur in the foreseeable future. Extensive use of byproduct feeds for heifers, dry cows, and cows in late lactation, along with thoughtful use for cows in early lactation, should allow continued increases in productivity and efficiency for many more years.

As we consider feeding 9 billion people in a sustainable manner, and if they will consume dairy products, then we must find ways to produce milk that decreases negative environmental impacts. To do this properly, one must consider all inputs and outputs for the dairy industry, including even the fuel used to till the land to grow the crops. This is called a Life Cycle Analysis and, although it is fraught with imprecision, there is no other way to consider the big picture. Two recent studies highlight the value of increased productivity to enhance environmental stewardship. Thomassen et al. (2008) compared conventional and organic Dutch dairy farms. Milk yield per cow was 17,600 lb for the conventional farms and 13,500 lb for the organic farms. When considering all inputs (which included feeds being shipped in from outside the country) on a per unit of fat and protein-corrected milk basis, conventional farms used 60% more energy and caused 50% more eutrophication, but the organic farms required 40% more land. Acidification and climate change were not different for the two systems. In my view, the decreased need for land gives the advantage to the conventional system as the unneeded land could be used to produce biofuels or put into native habitats. Capper et al. (2008) modeled the environmental output of dairy management systems in the US to meet current USDA dietary guidelines for all Americans. If all milk was raised in organic systems, compared to our current conventional systems without bovine somatotropin (**bST**), we would need 25% more dairy cattle and 30% more land, the cows would excrete 39% more N and 34% more P, and the US dairy industry would cause 28% more eutrophication, 15% more acidification, and 13% more global warming. In contrast, if all cows were given bST, we would need 8% fewer cows and 5% less land, cows would excrete 5% less N and P, and the dairy industry would cause 5% less eutrophication, acidification and global warming. The major reason for these differences is that increased productivity increases efficiency, and increased efficiency generally is good for the environment. We can feed more people with fewer resources.

Management to Improve Feed Efficiency, Profitability, and Stewardship

The average US Holstein (21,000 lb milk/year) currently captures ~21% of her lifetime gross energy intake as milk and body tissues. Gross efficiency during lactation is greater than this, but ~24% of the feed a cow eats in her life is during nonlactating periods (heifer, dry cow). Maximum lifetime gross efficiency of GE use is 25 to 30% and likely occurs around 30,000 lb of milk/year. Thus, increases in productivity will continue to improve efficiency for most US dairy farms. However, even farms with average milk near 30,000 lb/cow can improve feed efficiency at the herd level through better grouping and feeding strategies, reproduction and culling management, and diet formulation to match cow requirements. Using the model described in VandeHaar (1998), the impact of various management changes on efficiency of using energy and protein were estimated (Table 1).

Maximizing Feed Intake

Maximizing feed and energy intake is a key component of enabling cows in early and mid-lactation to produce milk to their genetic potential. Maximum feed intake occurs when cows are comfortable and have plenty of water and fresh, well-balanced feed available most of the day. This topic has been discussed considerably in the past 20 years, with general agreement and no need for continued discussion here. Even if some extra feed must be discarded, strategies to improve intake will yield improved efficiency, profitability, and stewardship.

Nutritional Grouping

A major impediment to enhanced feed efficiency on many farms is the lack of nutritional grouping. Frequently, cows are grouped to improve management of health and reproduction, but a single totally mixed ration (**TMR**) is fed to all groups. Feeding a single TMR across lactation can never maximize production and efficiency. Precision feeding of the groups could help better allocate high energy feeds to maximize production, improve efficiency of N and P use, decrease N and P excretion, and improve sustainability (Kebreab et al., 2000; Wang et al., 2000).

If a single TMR is fed to all lactating cows, it is usually formulated for the higher-producing cows on the farm. Thus, it is more nutrient-dense than optimal for cows in later lactation, resulting in inefficient use of most nutrients in later lactation cows. For example, cows in late lactation could be fed diets with less protein than the rest of the milking herd (15 instead of 17%). In addition, although this single TMR is formulated for the high producers, it is nearly impossible to formulate a single TMR for "maximum milk". A diet that is optimal for health and productivity during one stage of lactation is not likely optimal at other stages. Diets low in fiber and high in digestible carbohydrate are needed to optimize production and reproduction in peak lactation. This type of diet would have inadequate fiber and increase the incidence of displaced abomasum and acidosis in fresh cows and the incidence of over-fattening in late lactation cows. Fat cows are more susceptible to health problems at next calving, resulting in less saleable milk and followed by increased body fat mobilization, impaired fertility, and extended lactation interval (Cameron et al., 1998). Consequently, the cows culled in single TMR situations are those that cannot adapt to less than optimal management, rather than those that are least efficient, productive, and profitable. Moreover, single TMR systems do not allow maximum advantage in use of supplements or expensive feeds that may profitably increase production in fresh or high producing cows but have a negative return in lower producers. This is relatively obvious for supplements designed to improve fresh cow health or for protein supplements high in rumen-undegradable protein (**RUP**) that benefit early lactation but not late lactation. This is less obvious but equally important in forage selection. Not all lactating cows benefit equally from highly digestible fiber; a single TMR prevents optimal allocation of forages.

Another impediment to feed efficiency is poor reproduction and culling management. Decisions regarding reproduction and culling determine the length of time a cow is in late lactation, a phase when she is less profitable and less efficient. Poor reproductive management exacerbates the problem of single TMR by further extending lactation interval, decreasing culling options, and impeding optimal grouping to make multiple TMR seem worth the effort.

One argument used by farmers against multiple ration groups is that milk production decreases when cows are switched to a different group with a different ration. However, many factors affect milk production during a grouping change; these factors include days in milk, pregnancy status, bST timing and use, stocking density, heat stress and fan placement, and cow social interactions. These factors confound observations on farms, and farmers are quick to notice temporary drops in production and may be overly influenced by them. Additionally, too often grouping decisions are made only on milk yield and reproductive status when many factors should be considered. In particular, the propensity to gain body condition in late lactation should be considered. Many nutritionists have long recommended that cows with body condition score (**BCS**) >3 should be moved to a diet with lower energy density. For maximal benefit of nutritional grouping in the long-term, grouping decisions should be weighted by cow requirements (which includes body condition management) rather than by milk yield alone.

Nutritional grouping and multiple TMR undoubtedly do increase capital, management, and labor costs; however, the economic returns can be significant in both the short and long term. Moreover, feeding cows according to requirements results in less waste. If you currently feed a single TMR, I encourage you to seriously consider how you can make this work.

Managing to Enhance Protein Efficiency

The inefficiency of using N in animal agriculture is becoming a major environmental concern. Urea in the urine of mammals is rapidly hydrolyzed to ammonia by urease in feces, and animal agriculture accounts for ~50% of total atmospheric ammonia. Ammonia and other volatile nitrogen emissions have been implicated in acid rain and global climate change.

Protein nutrition influences productivity, profitability, and the efficiency of N use. For mature cows in zero N balance, feed N that is not converted into milk N must be excreted. The efficiency of converting feed N to milk N seldom exceeds 30%; thus >70% of feed N is typically lost with ~30% lost in feces and ~40% lost in urine, mostly as urea. Feeding cows less protein can dramatically decrease urinary N excretion and increase the efficiency of N use. However, inadequate protein risks a drop in milk production, which would decrease energetic efficiency.

In the past, there has been little economic incentive to feed diets that increase the efficiency of N use. The economic cost in the form of lost milk due to underfeeding protein greatly exceeds the cost of feeding excess protein as a margin of safety. Maximum energy efficiency occurs with highest milk production, and, in general, N efficiency increases as milk production increases in a pattern much like that for energy. However, protein is used most efficiently when it is the first limiting nutrient, so that protein is consumed below that needed for maximum milk. Hanigan and coworkers (1998) showed that the efficiency of converting feed N to milk N was as high as 35% when N intake limited milk output but was only 25% for peak milk N output within various levels of energy intake, and even less when feed protein was above requirements. Most lactating cows are fed 17 to 19% of crude protein (**CP**) diets, which is generally above that optimal for maximizing N efficiency. If we could find ways to produce high quantities of milk per cow consistently with only 14 to 15% CP diets, we could decrease urinary N excretion by a third on commercial dairy farms.

With careful attention to all feed N fractions, especially RUP and rumen-degradable protein (**RDP**), diets theoretically can be balanced to maximize milk production and energetic efficiency while at the same time achieving acceptable protein efficiency and N excretion. Supplementation with the most limiting amino acids (lysine and methionine) in rumen-undegradable forms has allowed an even lower concentration of dietary CP. However, studies with diets varying in RUP, RDP, and rumen-protected amino acids are often disappointing (Santos et al., 1998). Thus, our ability to accurately predict the response to protein is poor and, at least, for the foreseeable future, most cows will likely be fed more protein than needed. However, grouping cows according to requirements and then feeding diets specifically formulated for each group would certainly help.

Managing Diet Formulation to Maximize Profitability

Current forecasts are that high feed grain prices may be here to stay. Cheaper alternatives to $5 corn could certainly enhance profitability, unless they cause a big drop in milk yield. Various ways of considering feed costs are shown in Table 2.

The first thing to consider in evaluating alternative feeds is their moisture content, so feeds must be compared on a 100% dry matter basis. For example, corn distillers grains with 90% dry matter at $160/ton calculates to $178/ton of DM or 8.9¢ per pound of DM (160/ 2,000/ 0.9 = 8.9). Corn distiller's grains with 30% DM at $50/ton is $167/ton DM or 8.3¢/pound DM. Corn grain at $5/bu ($179/ton) and 88% DM is 10.1¢/pound DM. At these prices, the distiller's grains cost 12 to 18% less than corn grain.

The second thing to consider is how much useable energy is in the feed. The energy value of a feed cannot be measured accurately, but there is no question that energy intake is a major determinant of how much milk a cow will produce. Thus, the feed cost per Mcal of NEL (even with its inaccuracies) is a better way to compare feeds than the cost per pound of dry matter. If a well-balanced diet can be formulated that costs less per Mcal NEL, and if the cows eat the same amount of NEL per day and produce the same amount of milk, then profitability will likely increase. Corn grain at $5/bu ($179/ton) and 0.88 Mcal NEL/lb costs 11.5¢ per Mcal of NEL. Dried corn distillers grains at $160/ton and 0.82 Mcal NEL/lb costs 10.8¢ per Mcal of NEL. With these prices, the distiller's grains are about 6% cheaper than corn grain.

The next thing to consider is protein. Although we could evaluate feeds based on cost per unit protein, we learn more by adding it to our evaluation of energy costs. One long-standing way nutritionists have compared feeds for energy and protein relative to cost is by asking "How much corn and soybean meal could be replaced by this feedstuff?" The resulting "corn-soy value" of a feed is calculated based on the economic value of energy and protein using the current prices for corn and soybean meal. If an alternative feed can be purchased for considerably less than its corn-soy value, it is worth considering. For example, using prices for corn at $5/bu and 48-soybean meal (**SBM**) at $340/ton, the corn-soy value for the dried distiller's grains in Table 2 is $242/ton. If it can be purchased for $160/ton, then it costs only 66% (160/242) of its corn-soy value and it is 34% cheaper than a mix of corn and soy.

Both cost per unit of energy and corn-soy values give a way to objectively compare feeds without actually putting them into a diet. However, they both are simple methodologies for comparing feeds and have serious limitations. We choose feeds for several reasons other than just the economic value of energy and crude protein. For example, how much feed must the cow eat to obtain the needed energy and protein? How much effective fiber is in the feed? What is the source of the energy (starch, sugar, fiber, fat, or protein)? How much of the protein will be degraded in the rumen? Does the feed contain valuable minerals or vitamins? Will the feedstuff alter appetite or partitioning of nutrients to milk vs. body tissues? How long can the feed be stored? Does it contain unwanted compounds? Is it consistently available and is the quality consistent?

To accurately compare feeds, you must incorporate them into a complete diet to appropriately consider all the nutrients cows might gain from different feedstuffs. This can be done using a computer ration evaluation program. However, even checking the value of feeds in a ration program is not good enough because even the best computer programs cannot accurately predict animal responses. Thus, it is very difficult to predict whether an alternative feed will be profitable. If a diet is fed with less corn grain and more corn distillers, the diet may be cheaper per pound, and if the cows produce the same amount of milk, the new diet will likely increase profit. However, if the cows eat less and produce less milk, this potential profit can quickly disappear. Thus, it is essential to monitor responses in feed intake and milk production before and after a diet change is made. Without monitoring actual intake and milk production, it is almost impossible to know if the new feed ingredient was profitable. Corn distiller's grain may look like a great buy on paper, but it has 10% oil, and the oil often decreases feed intake, and in the end may decrease profits even though it looks better on paper.

Table 3 shows two diets each formulated to meet the nutrient needs of cows producing 80 lb of milk/head per day, and Table 4 shows possible economic outcomes from switching to the cheaper diet. The "Current" diet contains home-grown forages, corn grain and supplements. The second "Cheaper" diet includes two alternative feeds, distiller's grains and malt sprouts, and costs about 10% less on an energy basis. When the cows are switched to the cheaper diet, and if they consume the same amount of energy (which requires 0.9 lb greater dry matter intake, **DMI**) and produce the same amount of milk, profitability goes up 38¢/cow/day. If, however, the cows consume the same amount of feed, then they will consume less energy and produce less milk over time, and the diet change will increase profits only about 9¢/cow per day if milk is $18/100 lb. However, if feed intake decreases, then the increased profit quickly disappears. When milk prices are low relative to feed, some lost milk production may be acceptable if a new diet costs substantially less. However, when milk prices are high, focusing on how to get more milk is almost always more profitable than finding ways to save money on feed!

Monitoring – The Key to Success!

What reasonably can be expected to occur when replacing expensive corn grain with an alternative feedstuff is difficult to predict. The only way to know for sure is to monitor what happens. Feeding a diet that is cheaper may lower feed costs, but no computer program can project accurately how the cows will respond. If the new cheaper diet lowers milk yield, it could be an expensive mistake! Likewise, if a supplement or more expensive diet is fed to enhance milk yield, monitoring cow responses is essential to determine if the desired response occurred. Key responses to monitor include milk yield and composition, dry matter intake, estimated energy intake based on updated feed dry matter and nutrient analyses, and cow body condition. Responses should be monitored for at least 2 weeks before and after a diet change to reasonably determine success, and it is especially helpful if cows are monitored by stage of lactation.

Conclusion

The dairy industry in the US has undergone many changes in the past 100 years. Milk production per cow has more than quadrupled, and along with it, feed efficiency has increased. Improvements in nutrition and management will continue to improve the productivity, efficiency, profitability, and environmental stewardship of the dairy industry. Because cows can make milk efficiently from feed, especially feeds that humans cannot or will not consume, the future of the dairy industry is bright.

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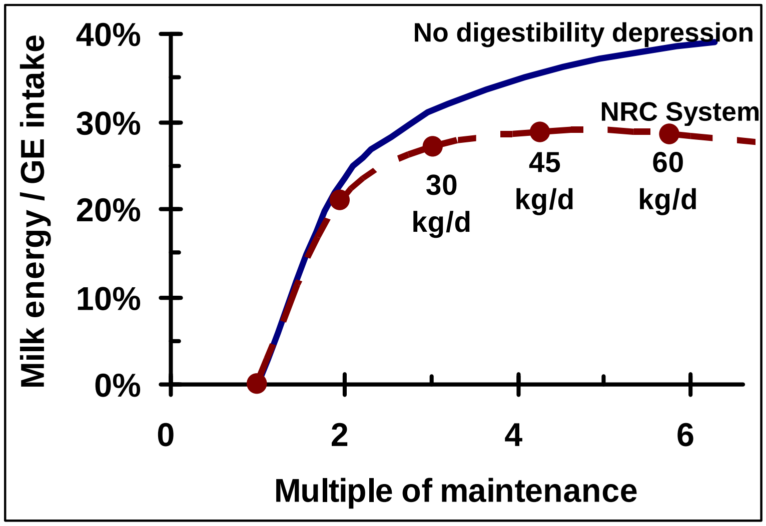
Figure 1. Gross efficiency (GE; assuming no change in body weight) vs. intake as multiple of maintenance for a lactating cow with no change in digestibility (solid line) or with digestibility decreased as per the NRC system (dotted line).



Daily milk production with the NRC system is shown for 30 kg (66 lb), 45 kg (100 lb), and 60 kg (132 lb). With NRC, the digestibility depression outweighs the dilution of maintenance as productivity increases, so gross efficiency is maximized at ~110 lb milk (3.5% fat) per day for a cow with 1,750 lb of body weight. For smaller cows, peak efficiency would occur at smaller milk yields. The NRC system may depress digestibility too much at higher intakes so that the line should be slightly higher that than shown.

Figure 2. Projected changes in efficiency (top panel) and profitability (bottom panel) with increasing milk production.

In bottom panel, the top line is milk income, and black area is income minus costs to represent total return to investment and management. Although expected gains in whole herd feed efficiency diminish as milk production surpasses 30,000 lb/cow/year, profitability is expected to continue rising due to dilution of capital costs. Based on VandeHaar (1998).

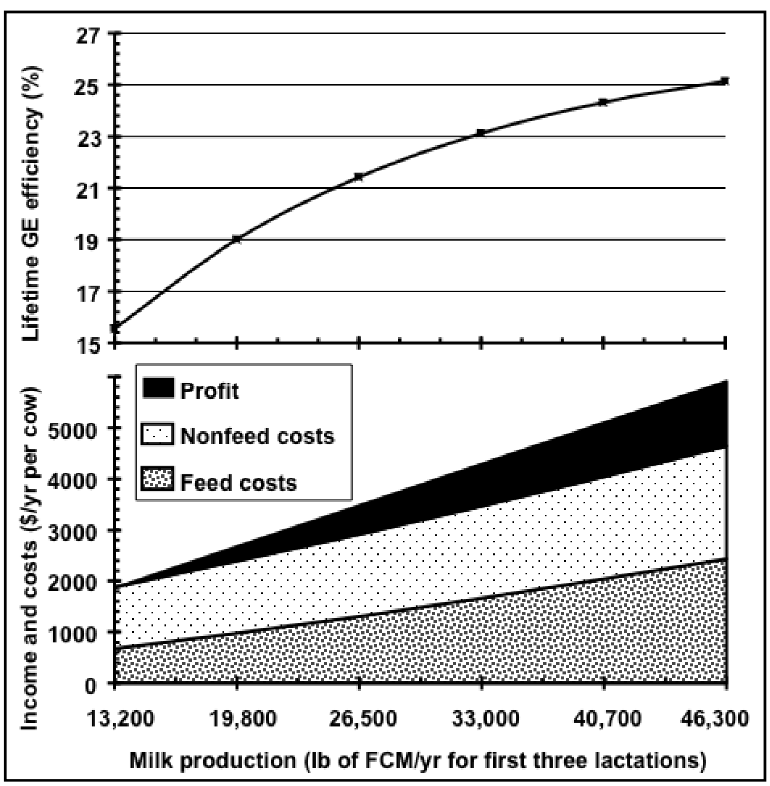


Figure 3. Nutrition and the law of diminishing returns.

Animals respond in a curvilinear fashion to increased concentration of a nutrient. Line P1-P2 represents the response in milk as the nutrient concentration of a diet is altered. The maximum physical efficiency is attained at point X1 whereas prevailing market prices determines the dietary concentration to maximize profits. With normal markets where the unit price of milk is greater than the unit cost of nutrients, profits are maximized at point X2, which corresponds to a diet with greater nutrient density than for maximum efficiency. Thus the efficiency of utilization of the nutrient at the point of highest profits is less than at the point of maximum efficiency.

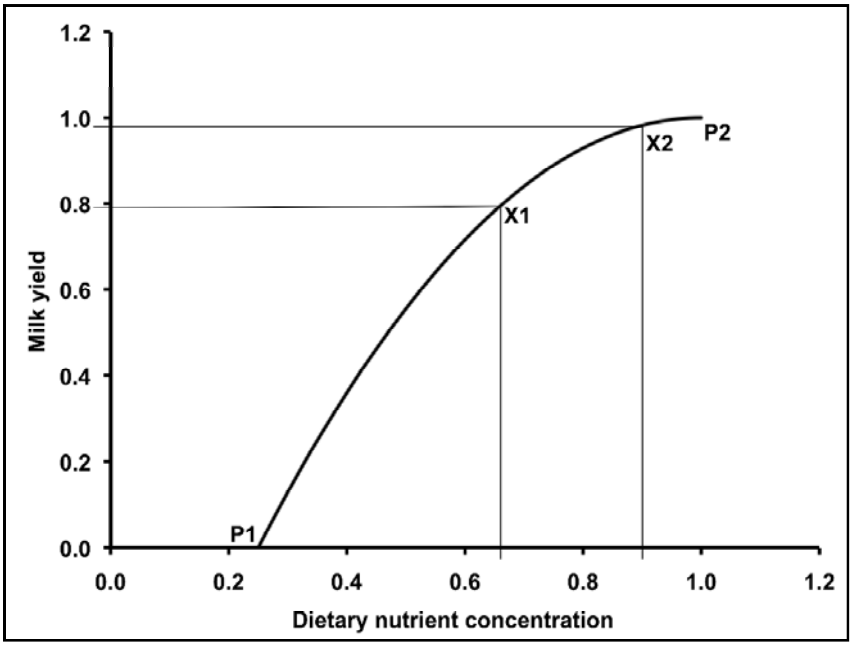


Table 1. Impact of selected management changes on energy and protein efficiency for a farm with 21,000 lb milk/cow/year[1]

	Energy	Protein
Base feed efficiency	21%	28%
Increase milk production 10% (2,100 lb/year)	+0.7%	+0.4%
Increase longevity from 3 to 4 lactations	+0.6%	+0.5%
Decrease maintenance requirement 10%	+1.1%	+1.2%
Improve efficiency of digestion by 10%	+1.2%	+1.0%
Reduce age at first calving 2 months	+0.3%	+0.3%
Reduce calving interval 1 month	+0.4%	+0.4%
Feed cows >150 DIM a diet with 2% less CP	+0.0%	+1.3%

[1] The added benefit of any of these generally decreases with each successive improvement. This is especially true for milk productivity. These figures are based on the model used in VandeHaar (1998).

Table 2. The relative costs and values of selected energy and protein feeds

Feed name	% DM	Mcal NEL / lb DM	% CP (DM basis)	$ per ton (as fed basis)	$ per lb DM	$ per Mcal NEL	Corn-soy value[1] $/ton as fed	Cost relative to corn and soy price
Concentrates								
Corn grain, ground	88	0.88	10	179	0.101	0.115	179	100%
SBM[2], 48% CP	90	0.92	54	340	0.189	0.206	340	100%
Expeller SBM	90	0.98	47	370	0.206	0.210	327	113%
Byproducts								
Barley malt sprouts	91	0.64	20	105	0.058	0.090	178	59%
Beet pulp, dried	88	0.64	10	280	0.159	0.247	139	201%
Whole cottonseed	90	0.84	23	280	0.156	0.190	217	129%
Distillers grains w/ solubles, dry	90	0.82	30	160	0.089	0.108	242	66%
Distillers grains w/ solubles, wet	30	0.82	30	50	0.083	0.102	81	62%
Soybean hulls	91	0.63	14	190	0.104	0.166	156	122%
Forages								
Wheat straw	93	0.38	5	70	0.038	0.098	84	83%
Grass silage, mid	35	0.51	17	35	0.050	0.098	56	63%
Corn silage	35	0.64	9	40	0.057	0.089	54	74%
Alfalfa silage, mid	35	0.54	20	60	0.086	0.157	62	96%

[1] Corn-soy value based on corn at $5.00/bushel and 48-soybean meal at $340/ton. Corn at $5.00/bushel is $179/ton. Corn price per bushel / 56 x 2000 = corn price per ton. Costs for most feeds are in line with recent prices in the US, but this table is only for use as an example!
An approximate calculation for the corn-soy value of a feed is:
[(1.5C – 0.25S) x NEL/lb + 2.5 x (S-C) x %CP] x %DM (gets within 2% of corn-soy value), where C is corn price per ton and S is 48-SBM price per ton (both on as fed basis).

[2] SBM = soybean meal.

Table 3. Comparison of a diet with cheaper alternative ingredients

Ingredients	Costs	Current diet	Cheaper diet
Legume Silage, 40% NDF, 35% DM	$70/ton	20.9%	15.9%
Corn silage, 35% DM	$40/ton	36.4%	33.6%
Corn grain, ground, dry	$5.00/ bu	27.3%	21.4%
Dried malt sprouts	$105/ton	0.0%	10.0%
Dried distillers grains w/ solubles	$160/ton	0.0%	10.0%
Soybean meal, 44% CP	$325/ton	10.5%	4.5%
Soybean meal, expellers, 45% CP	$370/ton	3.6%	3.2%
Supplements		1.4%	1.4%
Diet Nutrient Composition & Cost			
NDF, %		29.0	33.0
Energy, Mcal NEL/lb DM		0.744	0.730
CP, % of DM		17.5	17.4
Feed cost, $/lb DM		0.099	0.089
Feed cost, $/Mcal NEL		0.133	0.122

Table 4. Possible outcomes with the cheaper diet

	Current	Cheaper Diet			
Response scenario		1	2	3	4
DMI, lb/day	48.0	48.9	48.1	47.2	46.4
Change in feed intake, lb DM/day		+ 0.9	+ 0.1	- 0.8	- 1.1
Energy supply, Mcal NEL/day	35.7	35.7	35.1	34.5	33.8
Energy allowable milk, lb/day	80.0	80.0	78.0	76.0	74.0
Change in milk yield		0.0%	-2.5%	-5.0%	-7.5%
Change in milk yield, lb/day		0.0	-2.0	-4.0	-6.0
Value of milk @14/cwt[1], $/day	11.20	11.20	10.91	10.64	10.36
Value of milk @18/cwt, $/day	14.40	14.40	14.03	13.68	13.32
Value of milk @22/cwt, $/day	17.60	17.60	17.15	16.71	16.28
Feed cost, $/day	4.75	4.37	4.29	4.22	4.14
Return to diet change					
$14/cwt of milk		0.38	0.17	-0.03	-0.23
$18/cwt of milk		0.38	0.09	-0.19	-0.47
$22/cwt of milk		0.38	0.01	-0.35	-0.71

[1] cwt = 100 pounds.

SESSION NOTES