Managing Nutrition for Optimal Milk Components

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Introduction

Feeding dairy cows in excess of their nutrient requirements, especially nitrogen (**N**), is no longer an acceptable practice. Since the ruminant animal is not very efficient at N utilization, a substantial amount of these nutrients are excreted in manure. Feeding strategies that can reduce nutrient intake, without impeding animal performance, are needed to comply with environmental concerns.

Nitrogen is the primary nutrient of concern and the most complex for both the animal and the environment. From the animal perspective it is an important nutrient for maintenance and production. Protein tends to be overfed in rations either deliberately through ration formulation, or due to inadequate monitoring of feed management practices. Protein nutrition is challenging because there are various N fractions, especially with ensiled feeds, that add complexity when formulating rations and balancing them with carbohydrates. Excess protein fed results in increased N excretion. This is both an air and water quality concern.

Another concern is related to the large amount of N that can be brought onto the farm in the form of purchased feeds. The problem is that much of the N remains on the farm rather than being incorporated into milk, animal tissue, and crops. The end result is an animal operation that is out of nutrient balance. There are several strategies to improve a farm's nutrient balance. A key factor is improving forage quality. This will allow more farm raised feeds to be fed and minimize the amount of purchased N (and P).

Environmental Concerns

The first environmental issue with N is ammonia emissions. It can be released directly or indirectly from the degradation of proteins, which may occur within the soil or in the digestive system of the dairy cow and during manure storage. Ruminants excrete N in their urine and feces. The urea in urine, which in the presence of the enzyme urease found in the fecal material, rapidly decomposes to form ammonia. Ammonia is a very reactive compound and atmospheric ammonia can negatively impact the environment through several pathways.

Ammonia deposition contributes an estimated 35 to 60 % of the total N load to coastal waters (Paerl, 1995). Ammonia deposition can result in excessive build up of N in soil, leading to crop damage in sensitive plants and soil acidification as ammonia is converted to nitrate. Finally ammonia contributes to the formation of fine airborne particles or liquid droplets, called particulate matter. Ammonia contributes significantly to the formation of particles with a diameter of 2.5 μm or less (**$PM_{2.5}$**). Particulate matter of this size can penetrate deep into the lungs, contributing to respiratory disease and haze formation that reduces visibility. Ammonia and $PM_{2.5}$ are air quality concerns. They are regulated under the Clean Air Act; the Comprehensive Environmental Response, Compensation and Liability Act; and the Emergency Planning and Community Right-To-Know Act.

The regulations and environmental issues related to excess nutrients are real. Dairy producers are faced with implementing whole farm strategies that address these concerns. However, practical solutions are needed in order for the dairy industry to survive. It is possible to adjust silage based feeding systems to improve nitrogen efficiency of the dairy cow, as well as maintain milk volume and components.

Forage Quality

There are numerous feeding strategies that can be implemented to improve nutrient efficiency. Improving and maintaining high quality forage is the key to developing a sound ration program. Forage quality and how animals perform on those forages is more than just entering a few numbers in a ration formulation program. How the dairy cow utilizes ensiled forages is influenced by growing environment, cutting date, moisture content, and management practices at harvest, storage, and feed-out (mycotoxins and spoilage problems). In addition to these factors, the cow's size, amount of dry matter (**DM**) consumed, and the amount of forage in the diet affects rate of passage and digestibility of the forage.

Emphasis is always placed on how forage nutrients will be utilized in the rumen environment, however post ruminal digestion should not be overlooked as a critical component in dairy nutrition.

There are numerous nutritional interactions occurring in the rumen. It is unrealistic to assume one value or values can adequately predict how efficiently an animal will utilize nutrients. Many forage testing labs are offering fiber digestibility testing. One weakness of this one value is that it explains only extent of feed digested for a single nutrient over a given time period, i.e. 24 hr, 30 hr, or 48 hr. However, measuring the rate at which forages are digested can provide important information. Having rates for key nutrients can help nutritionists develop feeding strategies to make the cows more efficient. Consider the possible scenarios (rate of digestion) that can occur when feeding haycrop silage and corn silage.

Fast Fiber	*Fast Starch*	*Fast Protein*
Fast Fiber	*Slow Starch*	*Fast Protein*
Fast Fiber	*Fast Starch*	*Slow Protein*
Fast Fiber	*Slow Starch*	*Slow Protein*
Slow Fiber	*Fast Starch*	*Fast Protein*
Slow Fiber	*Slow Starch*	*Fast Protein*
Slow Fiber	*Fast Starch*	*Slow Protein*
Slow Fiber	*Slow Starch*	*Slow Protein*

Each scenario would require a different approach. For example, if fiber and starch are degrading at similar rates, then no special ration adjustments may be warranted. If starch degradability is slow along with fast fiber and protein, then altering starch particle size (fine grind vs. coarse grind) may be required. If fiber digestibility is slow, a more readily degradable fiber source may be needed. The same strategy, matching carbohydrate to protein rates, is just as important. It is easy to see why formulating rations is challenging. Many times nutritionists do not have access to detailed information on forages that would help explain animal response to various feeding strategies.

Several feeding strategies have been evaluated at the Penn State Dairy Complex over the past years. The question has been "Can lower protein diets be fed with various forage diets while improving N efficiency and maintaining or improving animal performance?" The various rates of carbohydrates and protein digestion were taken into consideration when diets were formulated. The Dairy National Research Council 2001 (**NRC**) and Cornell- Penn-Miner (**CPM**) were the models used to evaluate the diets.

Feeding Strategy 1 – Heavy Corn Silage Diet

Several studies have been conducted evaluating forage source and reduced protein feeding. The advancement of corn hybrids for silage has allowed the successful feeding of heavy corn silage-based diets, where corn silage makes up the majority of forage DM (Bal et al., 2000; Onetti et al., 2003). Wattiaux and Karg (2004) evaluated varying protein levels in alfalfa- and corn-based diets. They observed improved milk production in the corn silage-based compared to the alfalfa-based rations and observed no production difference on cows fed the lower protein diets (formulated for rumen degradable protein (**RDP)** and rumen unavailable protein (**RUP**)). Based on the diversity of the studies and the various incorporation of hybrid type, particle size, and ration components; milk components, especially fat percent, tend to be reduced (less than 3.5 %). The feeding strategy of a high corn silage-based ration and reduced protein level was initiated in the fall of 2002 at the Penn State Dairy Complex. The objective was to formulate rations with reduced protein and maintain or improve performance, including milk components.

Historically, rations for the Penn State Dairy Herd had been formulated to the industry standard of 17.5 to 18 % crude protein (**CP**) on a DM basis for a one-group total mixed ration. The average production of the herd when fed the higher protein diet was 76 to 79 lb on a 3.5 % fat corrected basis. When the ration was adjusted to a lower protein level, other changes also occurred. The corn silage was processed to reduce the large corn cobs and cottonseed hulls were added to provide fiber and replace 4 pounds of western hay. Table 1 shows the ration formulation for the 18 % and 16 % CP diets. The corn silage analysis was 37 % DM, 8.8 % CP, 41.7 % neutral detergent fiber, 42.4 % non-fiber carbohydrate and 0.74 net energy of lactation. Based on the forage quality and using CPM (ration formulation software), the scenario assumed to be most reflective of the forage ration was:
Slow Fiber Fast Starch Fast Protein.
To complement this feeding scenario coarsely ground corn grain was used to complement the fast starch. Protein sources with a balance of RDP and RUP were used.

The release of the 2001 NRC has given dairy cattle nutritionists an improved scientific template for designing rations. Balancing for CP is becoming an outdated concept. A more precise measure of protein nutrition is formulating for metabolizable protein (**MP**), RDP, and RUP. Metabolizable protein is the true protein that is digested post ruminally and the component amino acids absorbed by the small intestine. The RDP is the protein broken down in the rumen to microbial protein. The protein that escapes the rumen is the RUP.

In addition to protein, the source and types of carbohydrates are just as important. The balance between sugar, starch, and soluble fiber is essential for a healthy rumen. Table 2 presents the nutrient specifications for the 18 % and 16 % CP diets.

Table 1. Ration formulation for the Penn State dairy herd on an 18 % and 16 % CP diet.

Ingredient	2001-2002 18 % CP	2002-2003 16 % CP
	- - - -Ration, % DM- - - -	
Corn silage	25.6	26.5
Alfalfa silage	14.8	14.6
Hay	9.6	3.2
Cottonseed hulls	--	6.7
Shelled corn, coarse ground	14.2	20.3
Cookie meal	6.8	6.8
Liquid sugar (dextrose)	4.0	4.0
Distillers grain	5.0	1.7
Wheat midds	4.9	--
Heat treated soybean meal	4.9	1.6
Canola meal	4.0	6.7
Fish meal	0.4	--
Roasted soybeans	4.6	6.0
Min-vitamin mix	1.2	1.9

Formulating rations for protein and carbohydrate fractions to improve N efficiency is an important concept; however, what is an achievable goal and is it economical? Feeding strategies that improve nutrient efficiency are more likely to happen if there is a positive economic incentive. A tool that is available to producers to monitor the efficiency of feed N utilization by dairy cattle is milk urea nitrogen (**MUN**). Jonker et al. (2002) developed and evaluated a model to estimate N excretion, N intake, and N utilization efficiency for lactating dairy cows. The inputs required to run the model are body weight, milk production per cow, milk protein percentage, and MUN.

Table 2. Nutrient profile of the 18 % and 16 % CP diets.

	2001-2002 18 % CP	2002-2003 16 % CP
	- - - -DM basis- - - -	
Protein profile[1]		
MP required (lb/d)	5.71	5.72
MP supplied (lb/d)	6.18	5.65
RDP (lb/d)	6.02	5.64
RUP (lb/d)	3.74	3.11
Balance RDP (lb/d)	+0.66	+0.25
Balance RUP (lb/d)	+0.59	-0.09
CP-RDP % DM	11.1	10.3
CP-RUP % DM	6.9	5.7
Lysine, % of MP	6.17	6.42
Methionine, % of MP	1.81	1.89
Ratio	3.41	3.40
Carbohydrate profile[2]		
Sugar, %	7.4	6.8
Starch, %	26.5	29.7
Soluble fiber, %	6.6	4.7
Silage acids, %	3.2	3.1
NDF, %	31.0	31.4
NFC, %	43.8	44.3

[1]Protein profile based on the 2001 NRC. MP=metabolizable protein; RDP=rumen degradable protein; RUP=rumen undegradable protein; CP=crude protein.
[2]Carbohydrate profile based on CPM dairy ration analyzer.

Nitrogen efficiency was improved by 4.6 % when comparing the average values for the herd on the 18 % to the 16 % CP diets. It should be noted that when the 18 % ration was fed the calculated N efficiency was 34 %. In addition energy corrected milk increased from 78 to 84 lb of milk/d. The key to achieving improved N efficiencies is feeding cows closer to their requirement for protein, improving milk production and milk protein, and reducing MUNs.

Figure 1 illustrates the change in milk income comparing animal performance on the 18 % vs. 16 % CP diet. Because milk price can fluctuate considerably from year to year, the milk income was standardized. Milk price for the respective months of October, 2002 to July, 2003 were applied to the same months in the previous year (18 % CP diet). The lower protein diet resulted in improved components and similar milk production over the same time period. Eight out of the ten months showed improved milk income based on volume, fat, and protein response to the lower protein ration.

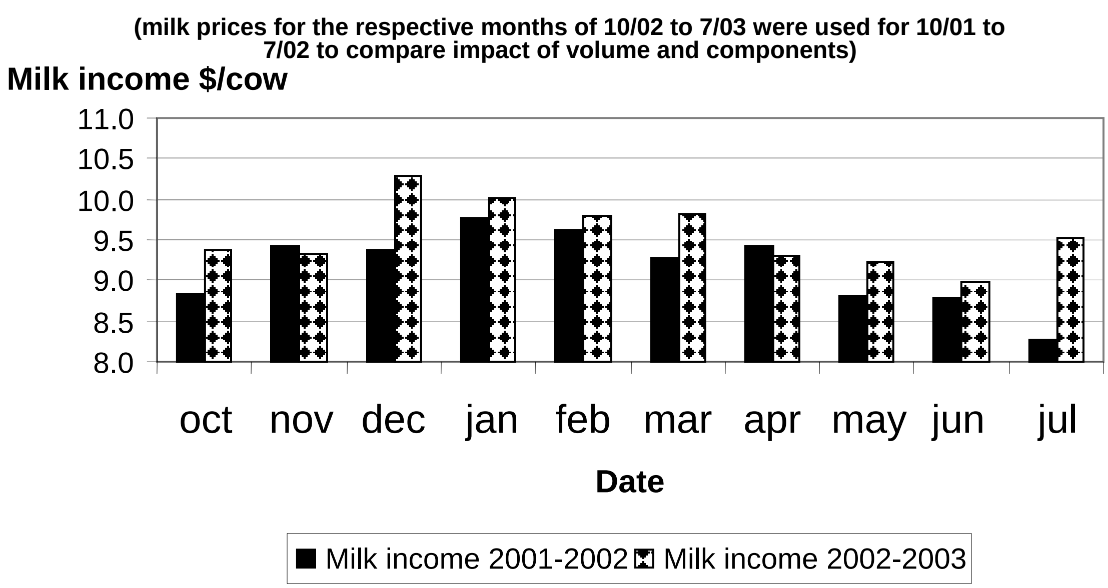
Feeding Strategy 2 – Heavy Haycrop Silage (Grass Versus Legume) Fed with Either Fine or Coarsely Ground Shelled Corn

The chemical composition of grass and legume are distinctively different. Crude protein content is generally lower for grasses than legumes; however the composition of the CP differs. Grasses contain more non-protein nitrogen as soluble protein and legumes contain more amino acids or peptides in soluble CP (Glenn et al., 1989). Feeding alfalfa silage as the sole forage for ruminants often results in diets with excessive CP that is poorly utilized. One of the strategies that has been applied to dilute alfalfa CP has been to partially replace dietary alfalfa with corn silage for lactating cows. As soluble nitrogen load is increased from legume sources this additional N load on the kidneys increases the energy needs of the cow. The added metabolic costs to the animal, inefficient capture of N as ammonia in the rumen, and the inefficient use of this nitrogen results in greater excretion of N.

The effect of cereal grain processing on starch fermentability in the rumen has been reviewed (Owens et al., 1997; Theurer, 1986; Yang et al., 2001). Matching ruminal energy fermentation with the various protein fractions can be effective in improving N efficiency. There are substantial differences among starch sources (Herrera-Saldana et al., 1990) and within grains due to processing, in the rates of energy release in the rumen. Owens et al. (1986) showed that the effects of processing on extent of ruminal digestion of corn starch are much greater than the effects on total tract digestibility. Ruminal digestibility of starch decreased from 70 % with ground corn to 54 % with coarsely rolled corn. Small intestinal digestibility of starch was not significantly affected by corn particle size and the amount of starch digested in the small intestine tended to be greater for rolled than ground corn (Remond et al., 2004). Starch digestion in the small intestine has been shown to be energetically more efficient than ruminally fermented starch (Harmon and McLeod, 2001).

Brito and Broderick (2003) assessed the effects of step-wise replacement of alfalfa silage with corn silage. The greatest improvement in N efficiency, without loss of production of milk, fat and protein, occurred at about 50 % of the forage from alfalfa silage and 50 % from corn silage. Additionally, replacing some of the dietary starch with rapidly fermenting sugars has been shown to enhance ruminal capture of degraded nitrogen. Another aspect to evaluate is how the balance of forage sources along with balancing carbohydrate and protein sources will affect daily ammonia emissions.

Figure 1. Comparison of standardized milk income when cows were fed an 18 % CP ration (2001-2002) or a 16 % CP ration (2002-2003).



In 2005 Penn State evaluated animal performance and monitored ammonia emissions on alfalfa and grass silage-based rations with either finely ground or coarsely ground corn. The objective was to formulate protein levels close to animal requirement and adjust the particle size of corn grain to evaluate effects on milk volume, milk components, N efficiency, and ammonia emissions. The rations are presented in Table 3.

Table 3. Ration formulas for the alfalfa- and grass-based silage rations.

Ingredient	Alfalfa silage-based	Grass silage-based
	- - - -DM lb- - - -	
Alfalfa silage	16.5	---
Grass silage	---	13.4
Corn silage	16.5	13.4
Cottonseed hulls	5.7	0.45
Shelled corn (fine or coarse)	11.1	11.8
Cookie meal	1.13	1.37
Liquid sugar (dextrose)	3.0	2.45
Canola meal	1.95	1.22
Roasted soybeans	6.1	4.95
Heat treated soybean meal	2.0	2.35
Mineral mix	2.14	2.19
Total DM intake	66.1	53.6

The spring of 2004 was extremely wet and it was a challenge to get good quality haycrop forage ensiled. The 1st cut grass silage was extremely high in moisture and low in quality. The alfalfa silage was 2nd cutting. The forage analyses for the alfalfa, grass, and corn silages are presented in Table 4.

One hundred twenty cows, 60 on the alfalfa and 60 on the grass-based diets, were fed in a freestall barn. The 60 cows consisted of 1st, 2nd, and greater lactation with an even distribution of early, mid, and late lactation cows. The average days in milk ranged from 185 to 195 d throughout the 4 mo trial (February to May). Each month the only ration adjustment was to substitute the corn grain based on particle size (i.e. 4 wk fine corn, 4 wk coarse corn). The fine corn averaged 70 % of the particles passing through a 1.18 mm screen. The coarse corn averaged 20 % of the particles passing through a 1.18 mm screen. The alfalfa and grass silage-based rations, using CPM are assumed to be the following:

Fast Fiber (alfalfa) – *Fast Starch* (fine corn) – *Fast Protein*
Fast Fiber (alfalfa) – *Slow Starch* (coarse corn) – *Fast Protein*
Slow Fiber (grass) – *Fast Starch* (fine corn) – *Fast Protein*
Slow Fiber (grass) – *Slow Starch* (coarse corn) – *Fast Protein*

Diets for the alfalfa and grass silage based rations were formulated for similar nutrient densities (Table 5). In order to achieve similar fiber levels in the diet, cottonseed hulls were used at a higher inclusion level for the alfalfa silage-based ration compared to the grass ration. Dry matter intakes were greater on the alfalfa diet vs. the grass diet. Some possible explanations for the higher intakes include the level of cottonseed hulls. Both alfalfa and cottonseed hulls have a high lignin content (rumen unavailable fiber). This tends to allow less rumen fill and increased DM intakes. Morales et al. (1989) showed that feeding cottonseed hulls increased voluntary NDF intake as a percentage of bodyweight to 1.4 to 1.5 %.

Table 4. Forage analyses on alfalfa, grass and corn silages fed 2004-2005.

Nutrient	Unit	Alfalfa, 2nd cut haylage[1]	Grass, 1st cut haylage[1]	Corn silage[1]
Dry matter	%	35.3	23.2	31.9
Crude protein	% DM	19.6	13.2	8.4
Soluble protein	% CP	58.7	61.0	62.1
TDN	% DM	63.9	55.3	71.9
Net energy lactation	Mcal/lb	0.66	0.56	0.76
Acid detergent fiber	% DM	32.5	41.8	22.7
Neutral detergent fiber (NDF)	% DM	40.8	64.3	37.9
NDF 48 hr digestibility	% NDF	50.1	61.1	61.0
Ash	% DM	9.2	11.1	2.9
Nonfiber carbohydrate	% DM	29.2	10.2	48.4

Source: Wet chemistry analysis from Cumberland Valley Analytical Services, Inc.
[1]All values are on a DM basis.

Table 5. Ration evaluation for the alfalfa and grass silage-based diets.

Item	Alfalfa silage-based TMR	Grass silage-based TMR
DMI – actual	66.0	53.6
DMI - predicted	61.7	56.9
Protein profile[1]		
MP required (lb/d)	6.53	5.69
MP supplied (lb/d)	7.16	5.98
Balance RDP (lb/d)	+0.27	+0.01
Balance RUP (lb/d)	+0.79	+0.36
CP-RDP % DM	10.0	10.1
CP-RUP % DM	6.6	6.5
CP - % DM	16.6	16.5

[1]2001 NRC. MP=metabolizable protein; RDP=rumen degradable protein; RUP=rumen undegradable protein; CP=crude protein.

Both high levels of milk production and components were achieved while maintaining DM intake efficiencies around 1.5 (Table 6). Using the Penn State Particle Size Separator, the average particle size distribution of the alfalfa and grass TMRs respectively were, upper: 9 %, 24 %; middle: 46 %, 30 %; bottom: 36 %, 37 %; and pan: 9 %, 10 %. The reduced DM intake on the grass-based diet can also be explained. The grass silage, because it was ensiled very wet, had higher levels of butyric acid. It had a less than ideal smell and palatability probably was an issue. The particle size distribution was much coarser compared to the alfalfa diet. Most of the particles in the top box of the Penn State Particle Separator were comprised of the long particles of grass silage. Because of its high moisture content, cows were not able to sort. Particle size and, with grass containing higher levels of digestible NDF, rumen fill was probably an issue.

Table 6. Animal performance results from the alfalfa and grass silage-based TMRs.

Parameter	Alfalfa silage-based TMR	Grass silage-based TMR
Milk, lb	96.2	84.3
Fat, %	3.94	3.91
Protein, %	3.02	3.07
ECM, lb	100.4	87.9
DMI-Eff	1.51	1.66
IOFC	$10.74	$10.09

[1]ECM= energy corrected milk;
[2]DMI-Eff= DM intake efficiency; and
[3]IOFC = income over feed cost

The fine grind of the corn appeared to have no added benefit to the alfalfa ration compared to the grass, where it appeared there was some benefit in improved components. Income over feed costs was better for the alfalfa-based ration compared to the grass-based ration. Nitrogen utilization efficiency was calculated using the equation of Jonker et al. (2002). The MUN averaged 10.3 mg/dl and 11 mg/dl over the 4 mo period on the alfalfa and grass silage-based diet, respectively. The resulting N utilization efficiency calculated was 38.0 % and 34.6 % for the alfalfa and grass-based diets, respectively. The alfalfa N utilization efficiency is comparable to the high corn silage ration discussed under feeding strategy 1.

One of the main objectives of balancing N for the ruminant is to minimize N excreted and the resulting emission of ammonia, which is an environmental concern. During the course of the alfalfa and grass feeding trial, ammonia emissions were measured in the free stall barn. A photoacoustic infrared analyzer capable of very accurate measurement of ammonia level was used. This data is currently being analyzed.

Conclusions

Silage-based rations can be adjusted to improve nutrient efficiency. It has been demonstrated that through proper feeding management practices and careful nutritional formulation, N inputs can be reduced without compromising animal performance or income over feed costs. Nitrogen utilization efficiency can be improved and MUN is a practical tool for monitoring herd performance. Nutritional strategies, with a focus on N, appear to reduce ammonia emissions.

There is more work needed in this area as feeding systems, feeding sequence, and times fed per day can vary dramatically among herds and may require different approaches. The common denominator is that forage quality is a key component in improving nutrient efficiency. Strategies involving corn silage, alfalfa silage, and grass silage can be successfully manipulated such that milk yield and components can be maintained or improved; thereby enhancing the economic profitability of the dairy business.

Literature Cited

Bal, M. A., R. D. Shaver , H. Al-Jobeile , J. G. Coors, and J. G. Lauer. 2000. Corn silage hybrid effects on intake, digestion, and milk production by dairy cows. J. Dairy Sci. 83:2849-2858.

Brito, A.F., and G. A. Broderick. 2003. Effects of different dietary ratios of alfalfa and corn silage on milk production and rumen metabolism in lactating dairy cows. J. Dairy Sci. 86 (Suppl. 1):62.

Glenn, B. P., G. A. Varga, G. B. Huntington, and D. R. Waldo. 1989. Duodenal nutrient flow and digestibility in Holstein steers fed formaldehyde and formic acid treated alfalfa or orchardgrass silage at two intakes. J. Anim. Sci. 67:513-528.

Harmon, D. L., and K. R. McLeod. 2001. Glucose uptake and regulation by intestinal tissues: Implications and whole body energetics. J. Anim. Sci. 79(E suppl.):E59-E72.

Herrera-Saldana, R., R. Gomez-Alarcon, M. Torabi, and J. T. Huber. 1990. Influence of synchronizing protein and starch degradation in the rumen on nutrient utilization and microbial protein synthesis. J. Dairy Sci. 73:142-148.

Jonker, J. S., R. A. Kohn, and J. High. 2002. Dairy herd management practices that impact nitrogen utilization efficiency. J. Dairy Sci. 85:1218-1226.

Morales, J. L, H. H. Van Horn, and J. E. Moore. 1989. Dietary interaction of cane molasses with source of roughage: intake and lactation effects. J. Dairy Sci. 72:2331-2338.

National Research Council. 2001. Nutrient Requirements of Dairy Cattle. Nat'l. Acad. Press, Washington, D. C.

Onetti , S. G., R. D. Shaver, S. J. Bertics, and R. R. Grummer. 2003. Influence of corn silage particle length on the performance of lactating dairy cows fed supplemental tallow. J. Dairy Sci. 86:2949-2957.

Owens, F. N., R. A. Zinn, and Y. K. Kim. 1986. Limits to starch digestion in the ruminant small intestine. J. Anim. Sci. 63:1634-1648.

Owens, F. N., D. S. Secrist, W. J. Hill, and D. R. Gill. 1997. The effect of grain source and grain processing on performance of feedlot cattle: A review. J. Anim. Sci. 75:868-879.

Paerl, H. W. 1995. Coastal eutrophication in relation to atmospheric nitrogen deposition: current perspectives. Ophelia. 41:237-259.

Rémond D., J. I. Cabrera-Estrada, M. Champion, B. Chauveau, R. Coudure, and C. Poncet. 2004. Effect of corn particle size on site and extent of starch digestion in lactating dairy cows. J. Dairy Sci. 87:1389-1399.

Theurer, C. B. 1986. Grain processing effects on starch utilization by ruminants. J. Anim. Sci. 63:1649-1662.

Wattiaux , M. A., and K. L. Karg. 2004. Protein level for alfalfa and corn silage-based diets: I. Lactational response and milk urea nitrogen. J. Dairy Sci. 87: 3480-3491.

Yang, W. Z., K. A. Beauchemin, and L. M. Rode. 2001. Effects of grain processing, forage to concentrate ratio, and forage particle size on rumen pH and digestion by dairy cows. J. Dairy Sci. 84:2203-2216.