Effects of Grain Variability and Processing on Starch Utilization by Lactating Cows

Jeffrey Firkins
Department of Animal Sciences
The Ohio State University

Introduction

One of the fundamental principles of dairy nutrition is the need to formulate rations to maximize energy intake for high producing cows. We have improved our ability to predict dry matter intake **(DMI)** and can formulate rations for increasingly precise fractions of carbohydrate, but a major limitation to the science of carbohydrate allocation continues to be the unaccounted variability in starch digestibility in the rumen and total tract among grains and the resulting effects on milk production. My objectives are to help identify sources of this variability and some concepts to help nutritional advisors make ration decisions with less trial feeding to groups of cows. Benefits of reduced variability are hard to measure in the short run, but probably decrease feed costs and increase cow longevity through a more sustainable feeding regimen.

Laboratory Analysis of Starch

Many nutritional advisors balance nonfiber carbohydrates (**NFC** = 100% - protein – NDF – ash – fat) for various dairy rations (**NDF** = neutral detergent fiber). Because NFC percentage doesn't account for differences in rate of degradation, it should be considered a baseline value. That is, the NFC concentration still can be a valuable standard from which to make feeding changes so long as its limitations are known. In particular, NFC overestimates starch plus sugar, especially in diets with legumes or citrus pulp (Hall, 2002). As alfalfa or citrus pulp increase in the diet, either allow 3 to 5 percentage units more NFC compared with corn silage-based diets or else correct for soluble fiber winding up in the NFC fraction. Soluble fibers can actually be more rumen available than some starches, but apparently not as fast as corn from well-preserved silage. Although soluble fibers probably yield little lactate, there typically is little lactate in rumen fluid when measured; therefore, the effect of soluble fiber on rumen pH and microbial ecology presumably varies with different dietary conditions. Although problems with NFC are important, variability in starch digestibility among grains or processing methods probably has a greater impact on milk production and components.

With regard to variability in ration formulation, the chemical measurement of starch should be a more reliable analysis for rations. Unfortunately, laboratory errors are too common and might not be given enough consideration by some field labs (Firkins et al., 2001). We think these errors contribute to considerable experiment-to-experiment variation that masks real differences among grain processing methods and contributes to the need for more trial feeding on farms. This experiment-to-experiment variation will be a key recurring theme in this paper because it is analogous to herd-to-herd variation, which can be a big source of frustration for nutritional advisors.

Site of Starch Digestion

Practical Significance

Researchers have debated the efficiency of energy usage, whether starch is digested in the small intestine or fermented in the rumen. Although biochemically a more efficient capture of energy occurs from intestinally absorbed glucose rather than from volatile fatty acids, the best way to provide glucose for lactose synthesis still appears to be through ruminal propionate (Huntington, 1997). For one thing, considerable *disappearance* of starch from the small intestine could be through bacterial degradation. Second, the digestive tissues extract much of the glucose before it can reach peripheral tissues such as the mammary gland (Reynolds, 2002). Third, practical methods to decrease ruminal digestibility of starch are generally associated with decreased total tract digestibility (see later discussion).

Table 1. Kernel and starch digestibility in the total tract for dry cows fed whole shelled corn.

	High forage control	Limited-fed corn
Dry matter intake, lb/d	21.1	15.0
Kernel intake per day	5,834	16,198
Kernels excreted per day	714	2,087
Kernel digestibility, %	88.5	87.0
Apparent starch digestibility, %	88.9	88.3

Driedger and Loerch (1999).

In contrast with the negative aspects of shifting starch digestion postruminally, too much degradation of starch in the rumen increases laminitis and other problems associated with sub-acute ruminal acidosis. Also, assuming acidosis is under control, feed intake could be depressed, perhaps by the higher production of propionate (Allen, 2000).

The optimal processing of grain depends on several factors. In order to evaluate these factors as they fit into a feeding program, particularly deciding how much of which processed grain to feed, I would like to go through some basics on which to build on my theme that there are not necessarily *right* or *wrong* ways to process corn (within reason).

Corn in the feces

New corn silage typically promotes visible passage of corn kernels. Kernel processing helps to reduce this problem, as well as their visibility. However, I think this real problem with new silage has been adapted to *corroborate* a similar assumed problem with grain. Are visible kernels from grain in the feces necessarily indicative of a grain processing problem? The natural reaction of nutritional advisors is to grind more finely until they see no grain in feces, but then should the amount of grain in the diet also be reduced to prevent acidosis? With the popularity of manure screening, how many kernels are *too many*?

Driedger and Loerch (1999) limit-fed nonlactating Holstein cows diets with whole shelled corn as a strategy to reduce forage intake. One group was fed 11.4 lb/d of corn (DMI = 15.0 lb/d), which was mostly whole shelled. As seen in Table 1, kernel digestibility was still 87.0%, and starch digestibility in the total tract approached normal values for lactating cows fed cracked corn (see later discussion). The excretion rate of 2,087 kernels/day translates to about 87 kernels per hour per cow. The point is that the presence of some large kernel pieces in manure screens doesn't necessarily mean there is a large problem with the ration; I hope to show you that it also indicates that more starch is being shifted to post-ruminal digestion so more grain could be fed before occurrence of acidosis symptoms.

Statistical Evaluation of Grain Source

Differences Among Studies

A few years ago, I was asked to review the published literature concerning starch digestibility (Firkins et al., 2001). One of the first things I noticed was that the data were not distributed evenly. For example, from Huntington's (1997) review, you can see that the much lower apparent ruminal digestibility of ground corn than rolled or steam-flaked corn could be a result of the dramatically higher intake and passage rate by lactating cows fed ground corn compared with the data from cattle with lower feed intakes (Table 2). Even when only lactating cows were used in other reviews (see citations in Firkins et al., 2001), differences like this among experiments could partially confound the relationships under consideration. Therefore, when we evaluated the published literature, we tried to evaluate differences among grain processing treatments without this confounding factor of experiment-to-experiment variation.

Compared with other reviews, we adjusted the means as if all data were taken from the same (the *average*) experiment. In so doing, we also tried to account for other dietary variables such that the means were determined at the average of those effects for the entire sampling of data. An analogy might be that cows all of similar genetic merit are on different farms with different managers, environmental effects, forages, etc. A response to processing of grain on one farm might be the opposite of that on another farm. Yet, if statistically adjusted to the average response (like what is done for bull testing), the results should be comparable to evaluation of

Table 2. Average apparent starch digestibilities in the rumen and total tract from corn processed in different ways. [1]

	Steam-flaked	Dry-rolled	Ground
Starch intake, lb/d	4.8	4.5	23.4
Rumen digestibility, %	84.8	76.2	49.5
Total tract digestibility, %	98.9	92.2	93.5

[1]From Huntington (1997).

grain processing all on the same farm and under the same conditions. You still don't know what would happen for various individual farms, but at least your expected response is standardized to the average. Of course, there are assumptions and potential errors, but we think these are much less problematic than ignoring these variables. This statistical analysis also allowed us to look at other relationships in addition to grain processing some of which will be discussed in this paper.

Nutrient Digestibilities by Lactating Cows Fed Different Grain Sources

Corn. What can be seen from the results in table 3 is a pattern for increasing apparent digestibility of corn starch in the rumen with more aggressive processing methods. However, NDF digestibility declined, resulting in a much lower net effect on true ruminal organic matter **(OM)** digestibility and minor response in microbial protein flow. It is important to note that the apparent rumen starch digestibility for steam-flaked corn is probably too low. A more appropriate value should be about 65%, because the analysis included grains flaked at higher than optimal densities (Firkins et al., 2001). In sharp contrast with other processing methods, although low numbers decrease our confidence, starch from high moisture corn was nearly completely degraded (86.8% apparent digestibility corresponds to nearly 100% true digestibility if bacterial starch was subtracted from duodenal starch) with no negative effects on NDF digestibility or pH (data not shown). Cows fed high moisture corn spent more time chewing (data not shown), apparently compensating for the greater acid production. More OM was available to cows fed high-moisture corn to support microbial growth, yet they had the lowest microbial N. We think the microbes dissipated (*spilled*) the energy available to them because either rumen-degraded protein was limiting or passage rate and efficiency of growth was decreased.

In general, the accompanying regressions (see data in Firkins et al., 2001) supported the rumen data (Table 3). Increasing the intake from the minimum 31.0 lb/d to the maximum 59.0 lb/d was predicted to decrease apparent starch digestibility in the rumen by >15 percentage units. Therefore, high producing cows would be expected to have lower apparent starch digestibilities (Figure 1) than previously thought based on older literature from cows with low feed intakes. In contrast, DMI was not shown to directly affect NDF digestibility or true OM digestibility in the rumen (data not shown). As expected (Oldick et al., 1999), DMI had a profound positive influence on microbial N flow to the duodenum, and DMI partially compensates for decreasing rumen-degraded starch (Figure 1). Collectively, these results seem to indicate that DMI has a far greater effect on the flow of microbial protein to the duodenum than does ruminal starch digestibility.

Total tract starch digestibility increased with more aggressive processing (Table 3), but because starch was only about 1/3 of the dry matter, the response in OM digestibility was moderate (2 to 3 percentage units). As with the rumen data, high-moisture corn had the highest total tract OM digestibility. It is important to note that means for high-moisture corn were from fewer replications, and the data were from properly processed and fermented sources. Not all high-moisture corn sources on farms would result in the same benefits.

Grain Sorghum. Steam-flaking sorghum increased rumen starch digestibility and shifted some fiber degradation post-ruminally. However, total tract starch and OM digestibility appears to support a benefit for steam-flaking (Table 3), which has been well described (Theurer et al., 1999).

Table 3. Ruminal and total tract digestibilities of nutrients and duodenal flow of microbial N by lactating dairy cows fed different grain sources. [1]

	Rumen, %				Total tract, %		
Grain Source	Starch, Apparent	NDF	OM, true	Microbial N, g/d	Starch, apparent	NDF	OM, Apparent
Corn,							
Dry, cracked or rolled	44.6	48.1	52.3	276	85.0	52.0	66.6
Dry, ground	52.3	44.9	48.6	257	90.7	49.0	67.8
Dry, ground finely					91.4	51.2	69.8
Steam-rolled					88.8	49.8	67.2
Steam-flaked	56.9	41.9	52.8	296	94.2	48.2	68.6
High-moisture, rolled	86.8	47.1	60.1	236	94.2	50.0	71.9
High-moisture, ground					98.8	50.4	73.9
Sorghum							
Dry, rolled or ground	48.1	49.6	49.2	278	83.5	45.2	64.6
Steam-flaked	74.0	43.9	56.3	357	94.9	52.3	67.7

[1] Adjusted for effects of experiment and other significant variables (Firkins et al., 2001). All data are on an apparent basis (not accounting for endogenous or microbial contributions) except OM digestibility in the rumen. Note that 56.9% apparent rument starch digestibility for steam-flaked corn is probably too low (see text). The total tract digestibility data were from lactating cows without cannulas and correspond with table 4.

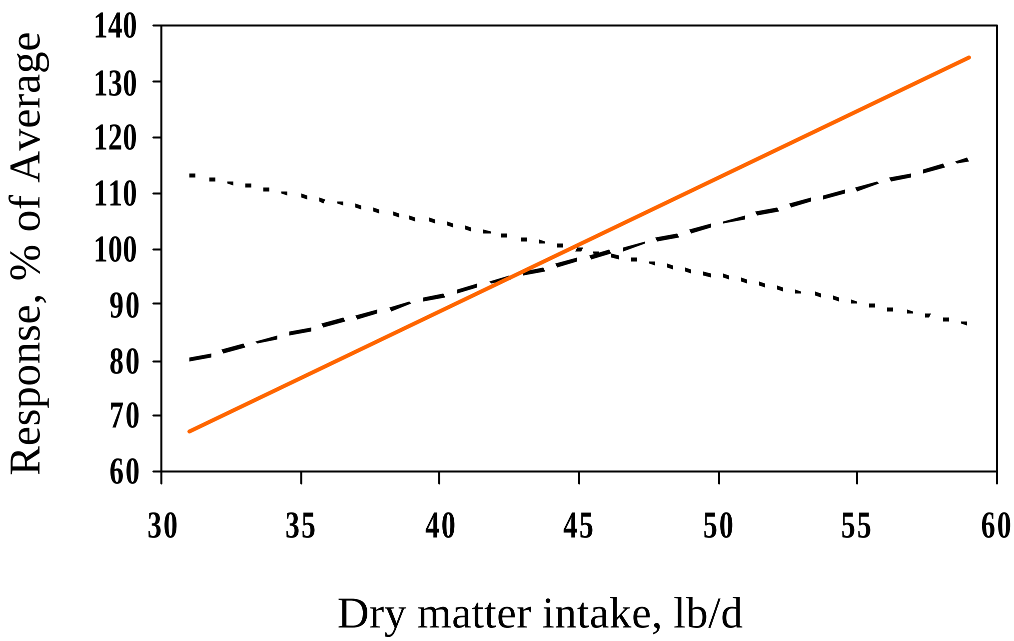

Figure 1. Response in apparent ruminal starch digestibility (%, …), intake of ruminally digested starch (lb/day, apparent basis, ---), and microbial N flow to the duodenum (grams/day, —). All data were calculated from regressions in Firkins et al. (2001) and are standardized to their value at the median DMI. The lines don't intersect because the data are not completely normally distributed.

Lactation Performance for Cows Fed Different Grain Sources

Corn. Our results (Table 4) showed no major deleterious responses in DMI resulting from processing. Small milk responses were detected as corn was processed more aggressively. Milk protein and fat concentrations were only minorly impacted by grain source, except that steam-flaking and finely grinding high-moisture corn decreased fat percentage. These results are more moderate than results of other comparisons, probably because our data were adjusted to the average effect of all other variables remaining in the model. For instance, milk production was estimated as if all cows consumed the average 49.1 lb/d of dry matter and percentages of forage and concentrate that were at the average of the entire data set. Milk responses on farms would be greater if DMI increased or decreased as a result of grain processing.

Based on the accompanying regressions (data not shown), milk protein percentage was predicted to increase considerably if forage was reduced down to the median value (39%), but minor effects would be predicted as forage decreased below that. Because many trials had moderate to low levels of forage to maximize treatment response to corn processing, milk protein percentage was not dramatically influenced. Milk fat percentage was not statistically influenced by dietary variables other than DMI. Figure 2 shows the striking response that adjustment to the average experiment effect had on variability of data. I consider this strong evidence that milk fat percentage among herds is a poor diagnostic compared with its use for different feeding changes within herds.

Grain Sorghum. As expected, steam-flaking of grain sorghum resulted in an average response of 2.6 lb/day of milk, when calculated at the average effects of other variables (Table 4). Milk protein was considerably higher, but fat percentage was only marginally lower, compared with dry-rolled sorghum controls. Because of the large increase in starch digestibility (Table 3), steam-flaking appears to be highly warranted for grain sorghum.

Site of Digestion Dampens Responses to Processing

Our results relate well with discussion in the NRC (2001). The correlations between either NFC or nonstructural carbohydrates (chemical assay including starch and sugars) with milk production were poor (r = 0.20). However, the correlation between the intakes of those chemical measurements (concentration x DMI) and milk production were much stronger (r = 0.63). This could indicate that DMI is again the driving variable, but also that concentration provides little description of effects on site of digestion.

I have selected two publications to illustrate important points for grain processing. Plascencia and Zinn (1996) reported significant responses in site of digestion of starch from corn that was steam-flaked to different densities Table 5). Because acid detergent fiber

Table 4. Lactation performance for Holstein cows fed different grain sources. [1]

Grain	DMI, lb/d	Milk, lb/d	Protein, %	Fat, %
Corn				
Dry, cracked or rolled	49.5	68.0	3.09	3.59
Dry, ground	50.8	69.3	3.18	3.53
Dry, ground finely	48.2	71.3	3.02	3.49
Steam-rolled	48.6	70.2	3.10	3.49
Steam-flaked	50.2	71.5	3.10	3.36
High-moisture, rolled	49.9	71.5	3.17	3.54
High-moisture, ground	50.8	74.6	3.17	3.37
Sorghum				
Dry, rolled or ground	51.5	69.3	2.99	3.50
Steam-flaked	50.6	71.9	3.11	3.41

[1]Data are adjusted for effects of experiment and other significant variables (Firkins et al., 2001). DMI = dry matter intake.

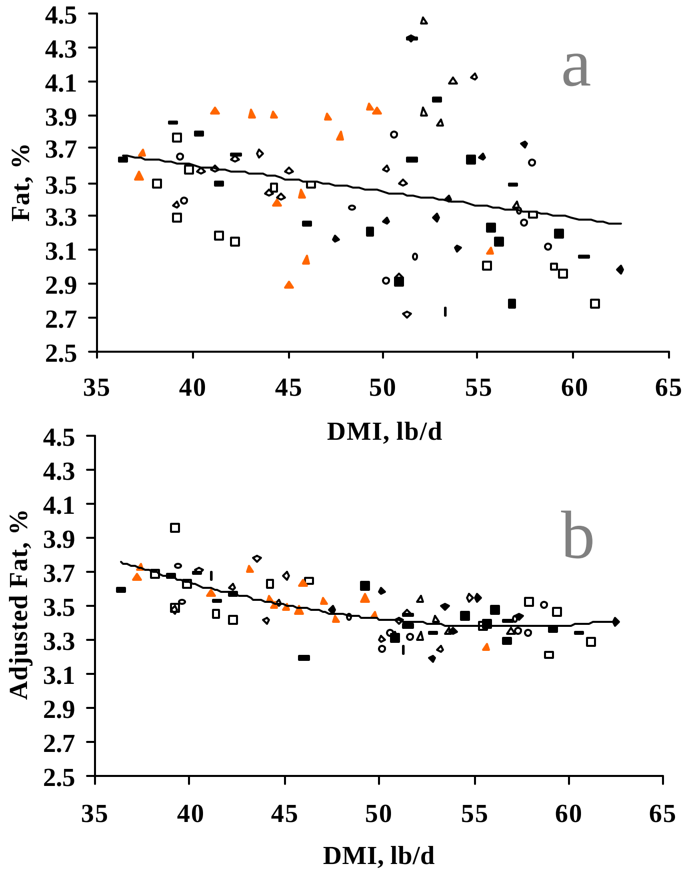

Figure 2. The response in milk fat percentage relative to DMI for raw data (Panel a) and for data adjusted for the effect of experiment (Panel b). From Firkins et al. (2001).

digestibility followed opposite trends, the overall effect of flaking density was dissipated. Theurer et al. (1999) reported that a flaking density of 28 lb/bu should be optimal for processing of both corn and grain sorghum. Data from Table 5 seem to support this recommendation for optimal starch digestion, and data from Table 3 show that steam-rolling to higher densities resulted in lower starch digestibility than steam-flaking. Yet, within a more narrow range like 20 to 30 lb/bu, there seems to be no major response in total tract OM digestibility (Table 5). All three densities had much greater OM digestibility than the dry-rolled corn control, yet this total tract digestibility is considerably lower than expected (Table 3). The low digestibility of the control can be explained by results of Callison et al. (2001), who showed that particle size of rolled corn had a large impact on site and extent of starch digestion (Figure 3). However, similar to Table 5, we noted reciprocal effects on site of starch versus NDF digestibility, resulting in minor impact on total tract OM digestibility.

Recommendations for Forage NDF and Rumen Degraded Starch

Based on these results, there appears to be a range in which various processed forms of corn can be used effectively to meet energy needs for lactating dairy cows. As grain increases in price relative to forage or when steam-flaking costs are low, lower amounts of more highly processed grain seem justified. As grain prices decrease relative to forage or when flaking costs are high, higher amounts of less aggressively processed grain can be used. More starch digestion will likely be shifted to the hindgut, but this appears to have only a modest biological impact. So long as DMI is high, microbial protein supply

Table 5. Site of digestion in dairy cows fed corn that was dry-rolled or steam-flaked to different densities.

		Density, lb/bu		
Digestibility, %	Dry rolled	30	25	20
Starch				
Rumen[L]	47.0	45.3	64.6	69.1
Total Tract[S,l]	76.6	92.8	96.8	98.5
ADF				
Rumen[S,L]	49.7	41.8	36.9	25.4
Total Tract[Q]	45.0	50.0	42.4	40.5
OM				
Rumen	46.0	41.6	49.8	47.2
Total Tract[S]	62.7	71.2	72.6	72.8

[L]($P < 0.05$) or [l]($P < 0.10$) linear effects of steam-flaking densities.
[S]Dry-rolled corn versus average of all steam-flaked corn densities.
[Q]($P < 0.05$) quadratic effects of steam-flaking density.
ADF = acid detergent fiber, and OM = organic matter. From Plascencia and Zinn (1996).

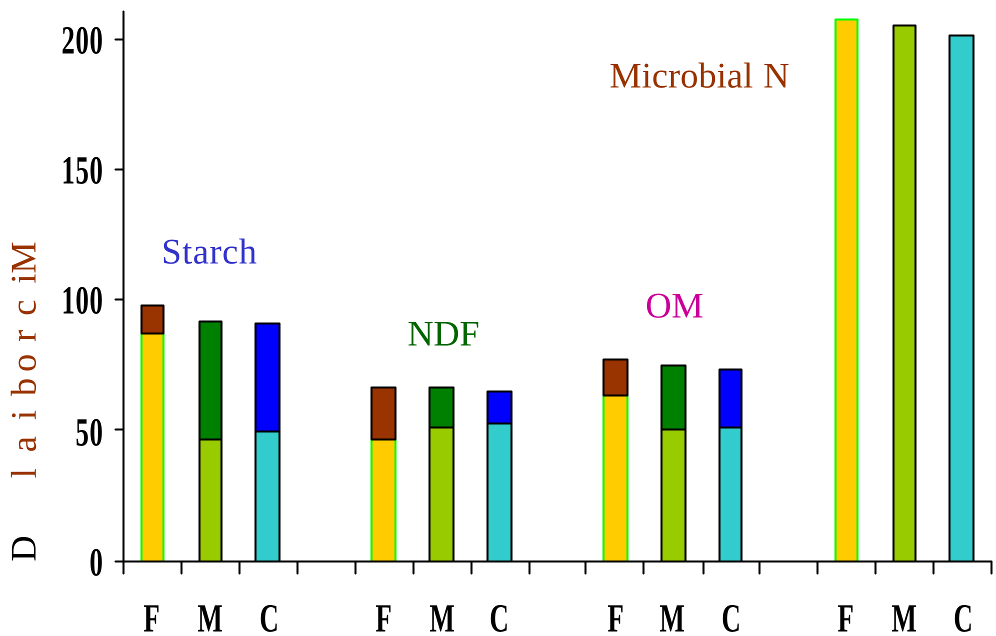

Figure 3. Digestibility of starch, NDF, and organic matter (OM) for fine (F), medium (M), and coarse (C) ground corn. The bottom portion of each bar represents rumen digestibility (all true bias), and the total bar represents total tract digestibility. Also shown is microbial N flow to the duodenum. Data taken from Callison et al. (2001).

probably won't be appreciably decreased, and milk yield seems more responsive to DMI than NFC or starch concentration. Probably a 10% reduction in total tract starch digestibility will be incurred, but total OM digestibility will likely be decreased by only 2 to 3 percentage units.

The summary of short-term trials (Table 4) seems to indicate even more modest responses (2 to 4 lb/d). It should be noted that most studies fed the same amount of corn processed in different ways. If studies would be designed to compare processed corn sources at the same predicted intakes of rumen-degraded starch, potentially I think there would be slight improvement in total tract OM digestibility and less risk for reduced DMI and acidosis-related problems on farms. Based on theoretical energy calculations and assuming constant DMI, a 2 to 3 percentage unit change in OM digestibility translates to about 4 to 6 lb of milk. This might justify more stringent processing methods (fine-grinding or steam-flaking). Based on limited data (Poore et al., 1993; Beachemin et al., 1997), the ratio of forage NDF to rumen degraded starch could be balanced to be about 1.25. Because most studies evaluating grain processing had low amounts or no corn silage, means from Table 3 represent primarily the corn grain and could be used for formulation or evaluation of rumen-degraded starch in rations. As with the use of more sophisticated models, actual DMI should be monitored and coupled with adequate cow monitoring.

Conclusions

Our sophisticated statistical analysis documented what you already knew: DMI is probably the key component in prediction of milk response to grain processing. If grain is aggressively processed (e.g., steam-flaking), you can improve milk production by about 5 lb/day if DMI is not decreased. In studies comparing barley (high availability of starch in the rumen), the decline in DMI removed the benefit from improved starch digestibility (Firkins et al., 2001). Therefore, until more data are available, balancing forage NDF: rumen-degraded starch should help you to efficiently use steam-flaked grain. If you choose to dry-roll it, you will likely lose some of its potential energy, but you could feed more grain and less forage to compensate. With low forage availability, high forage costs, or lower feeding management skills, this option could be very viable. Steam-rolling seems a less viable option to me because you inflate processing costs with less benefit. Of course, these are *average* expectations that could be improved with better synchronization of rumen-degraded protein, improved forage quality, and other factors. I hope this approach reduces the amount of trial feeding and cow monitoring that you do. If not, we can always talk about college football.

Literature Cited

Allen, M. S. 2000. Effects of diet on short-term regulation of feed intake by lactating dairy cattle. J. Dairy Sci. 83:1598-1624.

Beauchemin, K. A., L. M. Rode, and W. Z. Yang. 1997. Effects of nonstructural carbohydrates and source of cereal grain in high concentrate diets of dairy cows. J. Dairy Sci. 80:1640-1650.

Callison, S. L., J. L. Firkins, M. L. Eastridge, and B. L. Hull. 2001. Site of nutrient digestion by dairy cows fed corn of different particle sizes or steam-rolled. J. Dairy Sci. 84:1459-1467.

Driedger, L. J., and S. C. Loerch. 1999. Limit-feeding corn as an alternative to hay reduces manure and nutrient output by Holstein cows. J. Anim. Sci. 77:967-972.

Firkins, J. L., M. L. Eastridge, N. R. St-Pierre, and S. M. Noftsger. 2001. Effects of grain variability and processing on starch utilization by lactating dairy cattle. J. Anim. Sci. 79(E. Suppl.):E218-E238. Available: http://www.asas.org/jas.

Hall, M.B. 2002. Working with non-NDF carbohydrates with manure evaluation and environmental considerations. *In:* E.R. Jordan, ed. Proc. Mid-South Ruminant Nutrition Conf. Texas A & M Univ. p 37-48.

Huntington, G. B. 1997. Starch utilization by ruminants: From basics to the bunk. J. Anim. Sci. 75:852-867.

National Research Council. 2001. Nutrient Requirements of Dairy Cattle. 7th rev. ed. Natl. Acad. Sci., Washington, DC.

Oldick, B. S., J. L. Firkins, and N. R. St.Pierre. 1999. Estimation of microbial nitrogen flow to the duodenum of cattle based on dry matter intake and diet composition. J. Dairy Sci. 82:1497-1511.

Plascencia, A., and R. A. Zinn. 1996. Influence of flake density on the feeding value of steam-processed corn in diets for lactating cows. J. Anim. Sci. 74:310-316.

Poore, M. H., J. A. Moore, R. S. Swingle, T. P. Eck, and W. H. Brown. 1993. Response of lactating Holstein cows to diets varying in fiber source and ruminal starch degradability. J. Dairy Sci. 76:2235-2243.

Reynolds, C. K. 2002. Economics of visceral energy metabolism in ruminants: Toll keeping or internal revenue service? J. Anim. Sci. 80(E. Suppl. 2):E74-E84. Available: http://www.asas.org/jas.

Theurer, C. B., J. T. Huber, A. Delgado-Elorduy, and R. Wanderley. 1999. Invited review: Summary of steam-flaking corn or sorghum grain for lactating dairy cows. J. Dairy Sci. 82:1950-1959.