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Fiber and Starch Digestibility: Past, Present and Future

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Introduction

Fiber and starch digestibility are important factors in optimizing milk and beef production. Numerous research trials have documented the fact that lactating dairy cows will have increased DMI and produce more milk when fed forages that have higher NDF digestibility. In addition you will see higher peak milk yield and persistency along with improved milk production efficiency (Milk/DMI).

Michigan State researchers (Oba and Allen, 1999) reviewed the published literature and found that for every one percentage-unit of increase in NDF digestibility, there is a

- ➢ 0.44 lb/d increase in dry matter intake
- ➢ 0.51 lb/d increase in milk yield
- ➢ 0.55 lb/d increase in 4% fat-corrected milk yield
- ➢ 0.09 lb/d increase in body weight.

Work from Shaver, UW 2005, quote…"a 14% unit difference in Starch Digestibility would translate into a 10 % unit difference in TDN. At a 10lb dry matter/cow/day feeding rate of corn, failure to account for this difference could cost about 3lb of milk/cow/day.

Fiber and starch digestibility measurements can help improve the accuracy of ration balancing as related to milk production.

Analytical Variation

For a meaningful discussion of digestibility measurements, a good understanding of analytical terms is necessary.

1) *Accuracy* – a measure of the ability of a procedure to measure or predict the "true" or agreed upon values. For feeds and forages, accuracy implies how closely the analytical value of the samples submitted, compares to the true value of the feed.
2) *Precision* or repeatability – is a measure of the ability of a procedure to repeatedly provide the same result for a particular sample.
3) *Bias* – is a systematic distortion from the known or consensus value.

Both precision and accuracy are important for nutritional analyses. Accuracy insures the analytical measurements are useful for establishing the value of a feed and in formulating diets. Precision is needed to gain confidence in the sampling and the analytical method used as well as the laboratory performing the analysis.

Forage and feedstuff can vary significantly in NDF and starch digestibility. In addition, the analytical techniques also vary from run to run and from laboratory to laboratory. Variation is a natural and unavoidable phenomenon. It exists for two reasons

1) Feeds and forages inherently vary in chemical and biological makeup due to genetic and environmental effects and 2) laboratories use different analytical procedures. If no variation existed among feeds, analytical labs would not be necessary and book values would suffice to predict animal performance. However, analytical variation adds noise to the data and must be minimized.

Because variation can never be eliminated, unnecessary variation must be controlled. Statisticians employ the term "error" to explain variation, however that word has the connotation that a mistake was made or someone did not perform their tasks correctly. Numerous studies have documented that the analytical variation of feeds and forages is generally quiet small when compared to variation involved with sampling, feed preparation and mixing.

Mathematical Reality

Certain procedures (DM, ash, protein) can be measured quite accurately whereas fiber fractions and fiber digestibility are considerably more variable. In addition the larger numeric number increases the perceived variation. Horwitz standard deviation is a statistical approach used in National Forage Testing Assn. and provides an estimate of the variation among single analyses that we should expect for acceptable methods. Using the Horwitz equation you can calculate the expected variation of analytical reproducibility of an analysis.

Table 1. Expected Analytical Reproducibility using Horwitz's (1982) equation to calculate analytical coeffients of variation and Standard Deviation. (Mertens 2006)

% Con.	HCV (%)	HSD	Analyte/ Source	OBS.SD	NFTA
5	3.14	0.16	Ash, Lignin	ADL = .62	0.46
10	2.83	0.28	Ash, Lignin	Klas.Lig. = .80	0.54
15	2.66	0.40	CP forages		0.62
20	2.55	0.51	CP forages		0.70
30	2.40	0.72	ADF forages		0.86
40	2.30	0.92	ADF for. NDF leg.		1.02
50	2.21	1.11	NDF legumes		1.18
60	2.16	1.30	NDF grasses		1.34
70	2.11	1.48	NDF grasses		1.49
80	2.07	1.65	NDF straws		1.65

The larger the number you are measuring the larger the standard deviation.

Table 2. Expected Analytical Variation. (Mertens 2006)

Constituent	SD(R)	Avg. Conc.	95% CI	Min[a]	Max[a]
Ash, DM (Moisture)	0.5	10	1.40	9.3	10.7
Crude Protein	0.5	20	1.40	19.3	20.7
Lignin	0.7	7	1.96	6.0	8.0
ADF, NDF	1	40	2.80	38.6	41.4
NDF	1.3	60	3.64	58.2	61.8
NDF	1.8	80	4.48	77.8	82.2
IVdNDF (%DM)	1.3b	20	3.64	18.2	21.8
IVNDFD (%NDF)	2.6b	40	7.28	36.4	43.6
IVdNDF (%DM)	2.6	20	7.28	16.4	23.6
IVNDFD (%NDF)	**5.2**	**40**	**14.56**	**32.7**	**47.3**

[a] 19 out of 20 analytical results should be between the minimum and maximum confidence interval. b Standard deviation of reproducibility in one laboratory over 7 months - SD of reproducibility would be expected to be 2 to 3 time this value.

NDF Digestibility is the combination of two analytical measurements. Original NDF concentration of the sample and the Invitro Dry Matter Disappearance of the samples. The following equation calculates the NDFD.

IVTDMD = 100*((DMwt – NDFres)/DMwt))
iNDF = 100 – IVTDMD
dNDF = NDF – INNDF (% of dry matter)
NDFD = 100 * dNDF/NDF (% of NDF)

Where: NDF = neutral detergent fiber, % of DM
IVTDMD = in vitro true dry matter digestibility, % of DM
NDFD = neutral detergent fiber digestibility, % of NDF

Table 3. Relationship of dNDF (% DM) and NDFD (% of NDF)

Large NDFD Variation is a mathematical reality

Run	NDF	IVdNDF	IVNDFD ind.a	IVNDFD ave.b
1	40.5	22.3	55.1	55.1
2	40.2	18. 2	45.2	44.9
3	40.3	18.9	47.0	47.0
4	40.3	21.8	54.1	53.8
5	40.9	19.2	47.0	47.5
6	40.2	20.1	50.0	49.6
7	41.0	20.4	49.7	50.3
8	40.2	20.3	50.6	50.2
9	40.5	22.4	55.2	55.3
10	40.7	19.7	48.4	48. 7
Avg.	40.5	20.3	50.2	50.2
StDev.	0.30	1.4	3.6	3.5

aNDF calculated using individual NDF concentration for each run.
bNDF calculated using average NDF concentration for each run.
Dividing any series of numbers by a fraction (.40) increases the SD by the reciprocal of the fraction (1/. 40)

Challenges in measuring NDFD.

Biological measurements are analytically challenging for several reasons. Rumen fluid is greatly influenced by animal, animal diet, collection time, transportation to lab, type of incubation vessel, lag time and time of incubation. In addition, the grind size of the sample greatly influences the final results. The finer the grind size the higher the NDFD values and the more compressed the data.

Given the variation that exists with NDFD analysis, comparing results across laboratories will result in much frustration. Most laboratories that are proficient with NDFD analysis are able to rank feeds similarly, although the lab values may be different. A more practical approach to using NDFD values is to compare your results with the lab average for that particular forage type. For example, a BMR CS from Lab A has an NDFD30 of 69%, and for the same sample the NDFD30 from Lab B is 58%. You may conclude that the NDFD analysis is not very accurate. However, the average for all CS NDFD30 in Lab A is 62% and for Lab B the average is 53%. While the lab values from each lab are different, the interpretation of analysis is the same for each laboratory

BMR sample	Lab A	Lab B
NDFD 30hr.	69%	59%
Average of all CS Samples	62%	54%
Interpretation	Highly Digestible	Highly Digestible

Incubation time - point debate.

The question always is; what is the best time point? The longer time points are less influenced by lag time and also have a lower CV. 48 hrs. is the reference in the Dairy NRC summative equation that reflect maintenance intake. 24 and 30 hrs. are more closely related to ruminal retention time and are preferred by some model users. It is also a fact that shorter time points have more variation. This variation can be managed by running more replicates for each sample and also by following a very strict protocol for handling rumen fluid. For practical use of time points it is advisable to be consistent and use the same time point when analyzing forages.

Application of NDFD

NDFD measurements are used by nutritionist for a variety of reasons. Most common is to benchmark forages. Estimates of energy content are available through models and Milk 2006. It is important to remember that lower NDF content is still the primary driver of forage quality and should be evaluated before looking at NDFD. NDFD relates to rumen fill. When NDFD is poor, low producing cows will increase feed intake to compensate. High producing cows are already limited by ruminal fill and feed intake will likely decrease. Research from University of Nebraska showed that cows with greater energy corrected milk yield at the start of the experiment had a much greater response to improved NDFD than lower producing cows.

New Approaches at Standardizing NDF Digestibility.

The primary source of variation in NDFD is the run to run differences and the across laboratories difference. Researchers from the University of WI and the U.S. Dairy Forage Research Center are taking steps to help minimize the variation.

Dr. Combs and associates at University of Wisconsin are evaluating a "Priming" technique that may reduce the run-to-run variation for NDFD analysis. The theory being that as rumen micro flora undergo stress during collection and processing, could rumen inoculums be made more consistent by allowing it to recover, rather than speeding up the collection and processing. Preliminary results show they have reduced the run to run variation by a factor of 10 and also significantly improved NIR calibrations based on this "Priming" technique.

Hall and Mertens at the US Dairy Forage Research center are working with laboratories and industry groups to standardize not only the technique but also the interpretation of NDFD analysis. If may be possible to standardize digestibility results if labs included feedstuffs standards representing a range of digestibilities for a feed fraction in each fermentation run. Results of the standard feeds could be used to rank feeds as high, medium or low. These qualitative grades could then be assigned a numeric digestibility value that is consistent with the range of values utilized in equations/models.

Use of a ranking system based on common digestibility standards could increase the coherence and the applicability of digestibility values by reducing the effects of the variability inherent in biologically-based assays.

Starch Digestibility

Characteristics unique to starch make it much more problematic for determining digestibility compared to NDF digestibility measurements. In addition the amount of post ruminal digestion is significant and therefore important to measure. Three important relationships should be considered when evaluating starch availability; 1) Particle Size, 2) Moisture content… plant maturity, 3) Germplasm.

Most all research and commercial laboratories grind samples to a 1mm grind for conducting analysis. The value of starch availability on a fine ground samples is yet to be determined. Table 4. Illustrates the effect of particle size on starch digestibility.

Table 4. Ruminal Starch Digestibility at 12 hrs. (STRD12) and Total Tract Starch Digestibility (ttSTRD) of a ground corn grain.

Micron Particle Size	Ruminal STRD 12 hrs.	Total Tract STRD
2380m	55.5%	61.6%
1680m	67.9%	70.5%
1190m	62.7%	68.7%
840m	62.8%	81.4%
590m	81.7%	87.8%
420m	82.5%	95.6%
300m	83.3%	99.3%
212m	95.9%	99.7%
150m	98.8%	99.4%
106m	99.3%	99.7%
75m	97.4%	100%

A collaborative study was conducted by the University of Idaho and Washington State University looking at relationship between 48hr. *in situ* analysis of samples ground through a 2, 3, 4, or 8mm and *in vivo* DMD, dry matter intake and lactation results. There was a poor relationship to *in vivo* results with samples that were ground to less than 8mm.

The Sapienza/Dairyland method of determining Ruminal and Post Ruminal Starch Digestibility utilize a coarse grind size so that 70% of the particles are between 6 & 8 mm.

Mertens (2002) published an equation for estimating corn silage total tract starch digestibility derived from published experiments in which STRD was measured. The equation is based on silage DM

and percentage of starch retained on screen >4, 75. Corn Silage StarchD _1x = 12200.65 * (CS_DM %) = .39*(% Starch.4.75) – 0.0129*(CS_DM)*(%Starch.4.75) with a maximum of 100%.

Sapienza/Dairyland further refined the Merten's equation by adding results from 106 corn silage samples analyzed for dry matter, STRD12 hr., ttSTRD and Corn Silage Processing Score. Adjustment factors for both ruminal STRD12 and ttSTRD were calculated using principle regression analysis based on relationships among (1) measured ruminal STRD12, (2) measured ttSTRD, (3) calculated ttSTRD (Mertens logic with expanded database) and (4) the relationship of calculated ttSTRD to measured ttSTRD.

Table 5. The adjusted ruminal STRD 12hr. based on Corn Silage Processing Score and Dry Matter.
Corn Silage; Starch 29%, Ruminal STRD12hr. 80%

	Corn Silage Processing Score			
DM	**20%**	**40%**	**60%**	**80%**
25%	81	82	82	83
30%	80	80	80	80
35%	77	78	78	78
40%	73	75	77	79
45%	68	72	75	78
50%	63	68	73	78
55%	58	64	70	77

Table 5 shows that when applying these adjustment factors, well processed silage (CSPS = 80%) with proper moisture content has essentially no adjustment, while silage that is very dry and poorly processed (CSPS = 20%) receives a significant discount on starch coefficient.

Conclusions

While there are challenges in measuring NDFD and the variation is a mathematical reality, the use of this analytical tool continues to increase. Lower NDF is still the primary tool in evaluating forage quality. Over the last 6 years the number of samples requesting NDFD in Dairyland Labs has increased from 2,138 samples to 42,561 samples.

When used in the proper context of comparing the test result to the lab average then the interpretation will be consistent across laboratories that are proficient in performing this analysis.

Allocate higher NDFD forages to the highest producing cows. The greater the milk production levels of the cow, the greater the milk response to NDF digestibility. When feed intake is limited by rumen fill, then greater NDFD will decrease rumen fill and more feed will be consumed. More Feed Intake = More Milk Yield.

Sample particle size is an important consideration when determining starch availability and will greatly influence interpretation of results.

New equations have been developed to adjust corn silage STRD values based Corn Silage Processing Score and dry matter content.

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Dietary Factors Affecting Manure Output in Dairy Cows

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Manure is an inevitable byproduct of the production of meat and milk destined for human consumption. Excessive excretion of manure and manure nutrients represents inefficiencies that increase feed costs, increase the environmental impact of dairy farming, and increase costs associated with moving and storing manure. Current environmental regulations are usually based on when, where, and how much manure can be land applied. The 'where' and the 'how much' are usually based on nitrogen (N) and phosphorus (P) concentrations in the manure and the soil, and on crop removal rates of P and N. The primary purpose of this paper is to discuss factors affecting manure output rather than excretion of N and P, but diets that promote high milk production and just meet requirements for P and N result in the lowest quantities of N and P excreted per unit of milk produced.

Manure production by lactating cows

Based on research conducted at Ohio State, an average lactating Holstein cow producing about 70 lbs of milk/day and fed typical Midwestern diets produces about 150 lbs/day of manure (in our measurements, no bedding is used so manure is the sum of feces and urine) with 12.5% dry matter (DM), 0.59% N, and 0.077% P (Table 1). On average about one-third of the manure weight was urine and two-thirds feces but that ratio is highly variable. In 2006, the US had about 9 million dairy cows producing 177 billion lbs of milk/year (USDA statistics). Using equations we developed, last year the U.S. dairy herd (excluding replacements) excreted an estimated 493 billion lbs of manure, 2.9 billion lbs of N and 380 million lbs of P. Significant variation in the amount of manure excretion is caused by feed intake, dietary concentrations of certain nutrients, digestibility, and environmental conditions (e.g., hot weather). We should be able to take advantage of this variation and formulate diets that result in less manure production without adversely affecting milk yields.

Effects of intake and milk production on manure production

Manure output and dry matter intake (DMI) are strongly correlated but significant variation still occurs (Figure 1). In our data set, manure output varied by about 75 lb/d within a specific DMI. On average, manure output increased about 3 lbs/lb of DMI but this relationship was not constant. Increasing DMI from 35 to 40 lb/day resulted in an increase of 2.7 lb of manure/lb of increased DMI, but increasing DMI from 55 to 60 lb/day resulted in an average increase of 3.5 lb/day of manure/lb of increased DMI. As intake increases, digestive efficiency tends to decrease because feed passes through the digestive system quicker. Because water is needed to move digesta, a small decrease in digestibility results in a much larger increase in excretion of manure. If everything else is equal, we would expect slightly lower digestibility at high intakes resulting in more manure per pound of intake at high intakes than at lower intakes. Intake and milk production are correlated and on average high producing cows eat more than low producing cows. However, you should not restrict intake so that cows produce less manure because it will also likely reduce milk production and actually increase manure production on a global basis. Feeding diets that are highly digestible results in high milk production at reasonable intakes with reasonable rates of manure excretion. Monitoring feed efficiency (lbs of fat-corrected milk per lb of DMI) is a means of evaluating diet digestibility. For most situations, herd average feed efficiency should be around 1.5 to 1.6.

Table 1. Statistics describing Holstein cows and manure output from 15 experiments conducted at Ohio State involving 315 observations and 67 dietary treatments.

Measure	Average	Standard Deviation
Dry matter intake, lbs/day	48.2	8.1
Milk yield, lbs/day	68.6	16.0
Wet feces, lbs/day	98.5	21.8
Urine, lbs/day (gallons)	52.4	20.2
Manure, lbs/day	150.9	35.1
Manure dry matter, %	12.5	1.0
Manure nitrogen, %	0.59	0.07
Manure phosphorus, %	0.077	0.017

Milk production and manure output are also correlated but the relationship is not strong (Figure 2). This means we can increase milk production without necessarily increasing manure output. Indeed, because cows produce manure even when they are not lactating (80 to 100 lb/day), high producing cows usually produce less manure per pound of milk than do low producing cows. A Holstein cow producing 50 lbs of milk averages about 129 lbs of manure (2.6 lbs of manure/lb of milk) but a Holstein producing 100 lbs of milk produces 175 lbs of manure or only 1.75 lbs of manure/lb of milk. Increasing milk production is usually the most effective means of decreasing manure output per unit of milk produced.

Dietary factors affecting manure production

Corn Silage. The dietary factor that had the greatest effect on manure production in our data set was the ratio of corn silage to haycrop forage (in our experiments, alfalfa silage was the predominant haycrop fed). As the percentage of forage that was corn silage increased (resulting in a decrease in the percentage of haycrop forage) urine output decreased substantially, resulting in a significant decrease in manure output (Figure 3). A 10 percentage unit increase in corn silage (as percentage of forage) resulted in a decrease in manure output of about 4 lbs/day. The response in total manure we found was essentially the same as reported in a study from Wisconsin (Wattiaux and Karg, 2004). In our data set, increasing corn silage decreased urine output but had essentially no effect on fecal output but in the Wisconsin study increasing corn silage decreased both urine and fecal output. In our studies, cows fed diets with 100% of the forage as haycrop forage produced about twice as much urine per day as cows fed diets with 100% corn silage. The most likely reason for this effect is differences in potassium concentrations in diets. Corn silage almost always has lower concentrations of potassium than haycrop forages so as corn silage increases and haycrop decreases, dietary concentrations of potassium usually decrease. Any diet modification that results in lower concentrations of potassium should reduce manure output. Increasing corn silage in the diet should reduce manure output but several studies have shown that the ratio of corn silage to haycrop silage does not affect milk production. Therefore, feeding more corn silage should reduce manure output but have little effect on milk production as long as diets are balanced correctly.

Protein. Increasing the concentration of protein in the diet increases manure output. Manure output by dairy cows increases, on average, about 2 lbs/day when dietary crude protein concentration increases by 1 percentage unit (Frank and Swensson, 2002; Wattiaux and Karg, 2004; Weiss and Wyatt, 2006). When diets contain grasses and clover that have very high concentrations of crude protein (and usually high potassium concentrations), manure output may increase even more as diet protein increases (Van Dorland et al., 2007). On a relative basis, a change in dietary protein has a very large effect on manure output. A 1 percentage unit change in corn silage would only increase manure output by about 0.4 lbs/day, but a 1 percentage unit change in crude protein would increase manure output by about 2 lbs/day. However, the concentration of crude protein in the vast majority of diets fed to dairy cows probably only varies by 3 or 4 percentage units (i.e., most diets contain between 14 and 18% crude protein). That means the overall impact of changing diet crude protein on manure output is quite modest. Increasing protein from 14% to 18% would only increase manure output by about 8 lbs/day. On the other hand, corn silage, as a percent of total forage can range from 0 to 100% so that changes in corn silage can have a marked effect on manure output (approximately 40 lbs/day).

Fiber and digestibility. Manure output usually increases as the concentration of dietary fiber (measured as neutral detergent fiber, NDF) increases. This occurs because, in general, NDF is less digestible than other nutrients. On average, a 1 percentage unit increase in NDF concentration increases manure output by 0.5 to 1 lbs/day. Because most diets for lactating cows contain 25 to 35% NDF, the overall effect of varying NDF concentration on manure production is usually less than 10 lbs/day. Other dietary changes that improve digestibility, such as feeding corn silage made from brown midrib hybrids, can also reduce manure output slightly (about 7 lbs/day) (Weiss and Wyatt, 2006).

Manure from Non-lactating Animals

Daily manure output by a dry cow or a growing heifer is much less than that by a lactating cow (Table 2), but nonlactating animals still contribute to the manure stream of a dairy farm. Assuming a 2 month dry period, approximately 16% of the adult cows on a typical dairy farm will be in the dry cow group. Based on average calving intervals, age at first calving, and mortality rates, a typical farm will also have 80 to 90 replacements/100 adult cows. Assuming a typical herd makeup and average manure outputs, nonlactating animals produce about 25% of the total manure produced on a farm (Table 3). Therefore, one method to substantially reduce manure volume on a farm is to move dry cows and heifers to another location. Dietary factors (corn silage, protein, and NDF) probably affect manure output by dry cows in a similar fashion as with lactating cows. However because of the risk of metabolic disorders nutritionists do not have much

leeway to change concentrations of corn silage, protein or NDF in diets for dry cows.

Table 2. Average manure output for various types of Holstein dairy cattle.

Type of cattle	Body Weight lbs.	Milk, lbs./day	DM intake, lbs./day	Manure lbs./day
Average lactating cow[1,2]	1390	69	47.7	146
High producing cow[2]	1300	90	53.8	177
Dry cow[1]	1660	0	22.9	85
Heifer, < 1yr old[1]	340	0	7.4	27
Heifer, >1 yr old[1]	960	0	18.3	54

[1]Data from Nennich et al. (2005).

[2]Data from studies conducted at Ohio State.

On average, about 17% of the manure produced on a dairy farm comes from replacement heifers and diets for those can be manipulated substantially without reducing rates of gain or increasing health problems. Manure production by 12 month old heifers (approximately 740 lbs.) was reduced from 51 lbs/day to 44 lbs/day by changing their diet from 77% corn silage and no corn grain to one with 33% corn silage, 28% corn grain, and 25% soyhulls (protein ingredients also changed) (Moody et al., 2007). The low corn silage diet was higher in protein and K but lower in NDF but most importantly dry matter intake of heifers fed that diet was restricted so that intake was about the same for both diets (about 14 lbs./day). If intake was not restricted, heifers would likely have gotten too fat and would have produced more manure because they consumed more dry matter. This new method of raising heifers is being investigated at several universities (especially at University of Wisconsin and Penn State University) and has the potential of substantially reducing manure output. In this system, heifers

Table 3. Daily manure production on a typical Holstein dairy farm with 100 lactating cows.

Type of animal	Number of Animals	% of Herd	Manure, lbs./day	% of Total Manure
Lactating cows	100	50	15,000	76
Dry cows	16	8	1360	7
Heifers, <1 year old	44	22	1190	6
Heifers, > 1 year old	40	20	2160	11
Total	200	100	19,710	100

are fed a high energy diet but intake is restricted so that animals consume enough energy to meet requirements for the desired rate of gain. Because DMI is restricted this system should substantially reduce manure production.

Conclusions

On average, manure output increases with increased milk production, however, certain diet modifications should reduce manure output and not affect milk yield.

- Increasing the concentration of corn silage and reducing the concentration of haycrop forage should reduce manure output.
- Increasing the concentration of crude protein in a diet increases manure output. Make sure diets contain adequate but not excessive amounts of protein.
- Feeding a highly digestible diet reduces manure output. Harvest haycrop forages at an immature stage and grow highly digestible corn hybrids for silage.

On a typical dairy farm, nonlactating animals (dry cows and replacements) produce about 25% of the total manure. Moving those animals to another location will substantially reduce manure volume and should be considered if manure storage volume is limiting. Modifying the diets of replacement heifers has the potential to reduce their manure output substantially but on a whole farm basis the effect will probably be less than 5% of total manure output.

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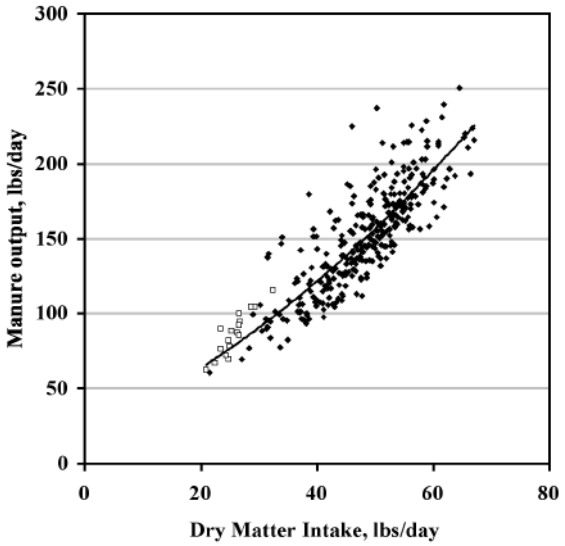

Figure 1. Relationship between dry matter intake and manure excretion in lactating and dry Holstein cows. Open squares are data from dry cows, filled diamonds represent lactating cows. The equation is: $Y = 21.7 + 1.7X - 0.02X^2$.

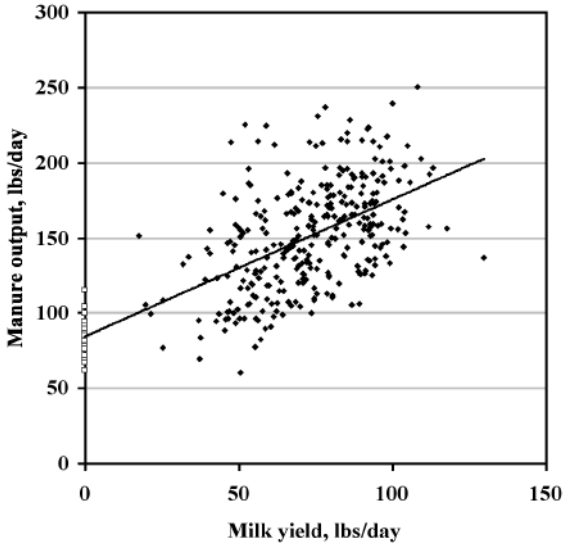

Figure 2. Relationship between milk productin and manure output in lactating and dry Holstein cows. Open squares represent data from dry cows, solid diamonds represent data from lactating cows. The equation is: Y = 87 + 0.9X.

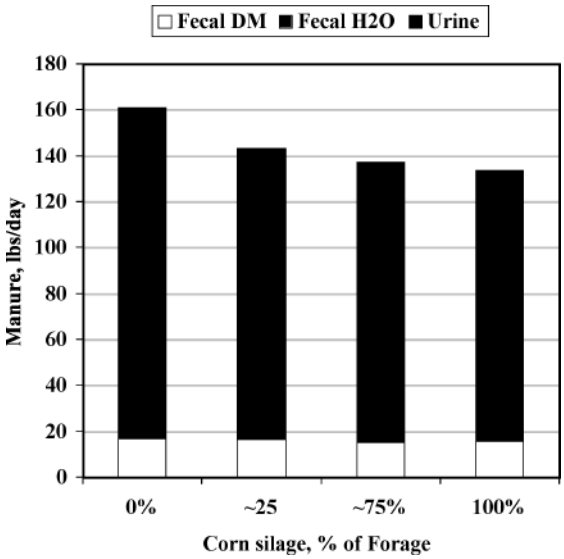

Figure 3. Effect of increasing corn silage in the diet (with a concomitant decrease in hay crop forage) on output of feces, urine, and total manure.

Corn Silage Considerations When Feeding Corn Milking Co-Products

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Introduction

Inclusion of distillers grains in dairy diets has been intensely studied for many years. For example, in the classic text entitled *Feeds and Feeding* (1898), W.A. Henry describes a Finish study published in 1893 which reported that compared to cows consuming oats, those consuming corn-whiskey distillers grains produced 12% more milk and 9% more milk fat. A later version of this textW.A. Henry (1911) estimated an annual production of merely 60,000 metric tons of distillers grains. This is in stark contrast to today where it is estimated, the U.S alone produces 13 million metric tons of distillers grains from corn-ethanol production. Type and chemical composition of products available continue to change, and the supply continues to grow presenting new challenges to the dairy producer and feed industry. With the recent expansion of the ethanol production industry the feed industry has seen an increase availability and use of distillers grains. The primary product of the dry milling production process is ethanol; however, approximately one-third of the total dry matter is recovered in the form of co-products, primarily wet or dry distillers grains plus solubles (WDGS and DDGS). Over the last 10 years a considerable amount of research has evaluated the use of WDGS and DDGS in dairy diets. A portion of this research has improved our understanding of the chemical composition and availability of nutrients in co-products. In turn, this information can be used to help us understand how these feeds can be included in diets and aids in understanding the impact these rations will have on performance.

Corn silage continues to be a major component of rations fed to dairy cattle in the Midwest and Plain States. Because of this, nutritionists often utilize feed analysis data of corn silage as the starting point for ration balancing. More specifically, the quality of corn silage usually dictates how a ration is balanced and what ingredients are included. The aim of this paper will be to summarize recent research that outlines the chemical composition and availability of nutrients in corn milling co-products. The nutritional impact of corn milling co-products in diets containing corn silage will then be discussed.

Nutrient Availability and Chemical Composition of Distillers Grains

The chemical composition of distillers grains is different from that of the original feedstock used in the ethanol production process. For example, Table 1 lists the chemical composition of corn, and corn WDGS and DDGS (Note samples of WDGS and DDGS originate from different sources thus cannot be compared statistically.) In Table 1, perhaps the most noticeable difference between corn and WDGS/DDGS is the increased proportion of crude protein (CP) in WDGS/DDGS (29.5/30.5 versus 9.4% CP for WDGS/DDGS and corn respectively). Logically, the proportion of starch is also much lower in WDGS/DDGS (6.68/5.97%) compared to corn (70.5%). Together, these simple observations support the historical use of WDGS/DDGS as replacements for high protein containing feedstuffs such as canola or soybean meal.

Protein

Protein contained in the feed can be utilized by rumen microbes. However, the rumen undegradable protein (**RUP**) portion may by-pass the rumen and flow to the small intestine where it is digested and absorbed. Recent research at the University of Nebraska-Lincoln has evaluated both the rumen undegradable protein (RUP) values and the intestinal digestibility of this protein (dRUP) (Kononff et al. 2007). Using 16 h in situ incubations, we observed the RUP of DDGS averaged 43.0 % CP, which was higher than soybean meal (28.4 %CP) but not as high as non-enzymatically browned soybean meal (SBM) (75.7% CP). A large proportion of this protein was also digested in the small intestine (86.2 % CP), although it was slightly lower than soybean meal and non-enzymatically browned SBM (98 and 96% respectively).

In the Midwest, diets that are formulated to contain a high proportion of corn silage usually rely on ingredients such as SBM to supply rumen degradable protein (**RDP**). In an experiment which SBM comprises 17% of the total ration, WDGS could act as an effective replacement of protein (Birkelo et al., 2002). Along with several other ingredients Janicek et al. (2008) replaced both SBM and bypass soy (9% of the total ration) with WDGS in a high corn silage diet and noted an increase in milk production. Alfalfa is low in RUP and because of this, it is a

challenge to meet the cows needs for RUP in rations that are high in alfalfa. In fact, it is likely that this is a major reason why inclusion of distillers grains in diets high in alfalfa usually result in an increase in milk yield (Grings et al., 1992).

In addition to ruminal protein degradability, our growing understanding of protein nutrition and utilization has lead us to consider the use and supply of individual amino acids (AA) during ration balancing procedures. Limiting AA are defined as those amino acids that are in shortest supply (Socha et al., 2005). The NRC (2001) suggests methionine (MET) is most limiting in rations that depend upon soy or animal protein for major RUP supply. In rations formulated to contain high levels of corn products, such as, corn distillers grains and corn silage, the supply of lysine (LYS) is believed to be more limiting (Liu, et al., 2000). Using 16 h rumen incubation, research at the University of Nebraska-Lincoln has demonstrated that the concentration of lysine in the RUP fraction of corn DDGS (1.86% CP) is low. A similar level has been observed in wheat distillers grains (1.16%) (Boila et al., 1994). As a consequence, it is often suggested that diets containing high proportions of corn silage and corn distillers grains may be deficient in LYS. Interestingly enough, a reduction in milk protein yield has rarely been observed. However, it should also be noted that in most published studies, the CP content of the diet was high (i.e. > 17%) and as a consequence, the supply of LYS to the small intestine may have been adequate even if, in relation to MET, the concentration was low.

Energy

It has only been recently that WDGS/DDGS have been extensively thought of as source of energy to replace forage fiber and non-fiber carbohydrate in dairy diets. Feeding distillers grains to replace corn grain is useful in providing energy in the form of fermentable fiber. Because fiber is digested at a slower rate and less lactic acid may be produced compared to other energy sources such as starch, feeding WDGS/DDGS to ruminants may be useful in reducing the incidence of rumen acidosis (Klopfenstein et al., 2001). Compared to corn, WDGS/DDGS contains a higher proportion of NDF (28.9/33.1 versus 9.76%), and this NDF is not highly lignified thus it is also highly digestible. Commercial and publicly available data sets have reported 24 and 48 h hour in vitro rumen NDF digestibilities of DDGS to be high (i.e. > 50 %). Because fiber is digested at a slower rate than other forms of energy such as starch, feeding corn distillers grains to ruminants may be useful in reducing the incidence of rumen acidosis (Klopfenstein et al. 2001).

The fermentability of both fiber of diets high in corn silage is usually quite high and this is liked to an increase in rumen microbial protein yield and ultimately metabolizable protein (Hristov and Broderick et al., 1996). Practically when used together, nutritionists should be sure to avoid rumen acidosis and track associated risk factors. In doing so some of the most important factors are concentration of non-fiber carbohydrates, level starch and sugars. The NRC (2001) committee recommends that ration NFC concentrations should be between 32-42% of the diet DM. Users of the CPM-Dairy model may also track the levels of soluble fiber and available NDF which, when fermented, contribute to the rumen acid load (Lanzas et al., 2006).

Effective Fiber

Effective fiber is the portion of the diet that is believed to stimulate rumination, chewing activity and saliva secretion, all which are designed to help to maintain healthy rumen function and normal pH levels. When rumen pH levels fall below 6.0, fiber digestion may be impeded and milk fat levels may become depressed. It is believed that rumen pH is a function of lactic acid and other acid production and is buffered by saliva (Maekawa et al., 2002). Because of this finding, it is a common practice to feed diets of longer particle size causing a greater amount of effective fiber so salvia production is stimulated. In support of this hypothesis, Krause et al. (2002) noted that the intake of particles > 19.0-mm was negatively correlated with the amount of time rumen pH was below 5.8. However, it is also known that diets should not be excessively long or coarse as they are more difficult to mix and may induce cattle to sort out ration ingredients (Kononoff et al., 2003). When WDGS or DDGS are used to substitute forage in the TMR, chewing activity is believed to be reduced due to the finer particle size. Nutritionists should not necessarily use this logic to infer that feeding co-products will result in lower rumen pH. In fact, it is likely that diets may be balanced so that the inclusion of co-products will not influence rumen pH. When evaluating a diet to determine a possible risk of subclinical acidosis, it is important to consider both levels of fiber and non-structural carbohydrates, along with their associated fermentability (Yang et al., 2001).

Using the Penn State Particle Separator, at least 5-10% of the particles should be at least 19.0-mm long and the diet should contain 26-30% NDF. General recommendation suggests that rations should contain 30-50 % of the particles between 8-19.0-mm. Diets which are high in both corn silage and co-products generally have less material within this range. If this is the case, poor quality roughages such as chopped straw or grass can be added to increase effective fiber levels.

Feeding Considerations
Wet and Dry Distillers Grains Plus Solubles

As mentioned earlier, distillers grains may be available in either a wet or dry form and the nutrient content, when expressed on a dry matter basis, is similar for both (Table 1). One possible major difference between these forms may be due to the RUP portion being higher in the dry form (Firkins et al., 1984). Although it is generally believed that there is little difference in milk production when animals are fed either form, beef feedlot studies have demonstrated that rations containing wet distillers grains are consumed in lower quantities and result in greater feed efficiencies than those containing dried distillers grains (Ham et al., 1994). Unfortunately, less research has investigated possible differences in milk performance. In one study, in which lactating dairy cattle were fed diets containing 15% (DM basis) of either wet or dry forms were fed and no differences were observed in milk production, composition, fiber digestibility, or efficiency of milk production (Al-Suwaiegh et al., 2002).

When deciding which form may fit best, producers should evaluate several factors including distance from plant of origin, the anticipated feeding rate, the on-farm storage facilities and handling equipment. Because a wet product may not be stored as long and is usually associated with high shipping charges, dried forms may be most feasible for feeding if a plant is not located near the farm. However, this also increases the price of the feedstuff. If the farm is located near a plant, wet forms may be cost effective, but producers should be mindful of the fact that the rate of spoiling is also dependent upon the feeding rate and environmental temperature. Generally speaking, wet loads should arrive at least weekly to ensure the pile is "fresh." There continues to be interest in ensiling feeds such as wet distiller's grains as a method to eliminate oxygen exposure and ultimately reduce feed spoiling and loss. Additionally, a number of commercial direct application preservative products may be useful in extending shelf life of these feeds, but producers should be mindful of these added costs.

Feeding Levels and Production Responses

Recently, a number of investigators have evaluated the effects of increasing levels of corn-ethanol distillers grains in replacing both forages and concentrates (Powers et al., 1995; Owen and Larson, 1991; Leonardi et al., 2005). Research suggests that the addition of distillers grains to dairy diets high in corn silage usually results in a modest increase in DMI (Nichols et al., 1998; Powers et al., 1995; Owens and Larson, 1991; Janicek et al., 2008); however, this is not observed in all cases (Leonardi et al., 2005 and Schingoethe et al., 1999). Nevertheless, the increase in DMI is somewhat predictable, given that intake is influenced by feed particle size and digesta passage rate (Beauchemin et al., 2005), both of which have been demonstrated to increase in diets containing milling co-products (Boddugari et al., 2001).

In published studies evaluating corn DDGS as a protein supplement, milk production was observed to be either unaffected (Clark and Armentano, 1993; Owen and Larson, 1991) or increased (Powers et al., 1995; Nichols et al., 1998). The high level of fat is one factor believed to affect milk fat synthesis and as a result, the inclusion of DDGS should be limited in dairy diets. This effect was not observed by Leonardi et al. (2005), who evaluated the effects of increasing levels (up to 15%) of DDGS and the addition of corn oil to the control diet. Nonetheless when co-products are included at increasing amounts they will make major contributions to the overall rumen fat load. Consequently, a nutritionist considering increasing the proportion of co-products should reduce the inclusion level of high fat ingredients such as cottonseed

It is impossible to recommend an optimal inclusion level for distillers grains or other co-products, as it depends upon many factors including price and nutrient content of all available feedstuffs. A number of investigators have evaluated the effects of increasing levels of distillers grains in replacing both forages and concentrates (Powers et al., 1995; Owen and Larson, 1991; Garcia et al., 2004; Kalscheur et al., 2004; Leonardi et al., 2005). Conservative estimates from these studies suggest that 15-20% of the ration DM may easily be included in a properly formulated ration for a lactating cow. Further evidence also suggests that even greater amounts of DDGS may be fed (Janicek et al., 2006) without sacrificing production. However, at these levels and often in those high in alfalfa, the diet may contain excessive levels of N that is poorly utilized, resulting in increased N excretion.

CPM-Dairy Model: Corn Silage and DDGS

Table 2 lists two high corn silage dairy rations that were formulated using least cost solutions and the CPM-Dairy model. These rations differ in the amount of DDGS included, 0 or 15% of the diet DM. A 15% inclusion level of DDGS replaces a portion of the forage, ground corn, and protein ingredients. The aim of formulating this diet was to maintain metabolizable protein (MP) and metabolizable energy (ME) allowable milk at 75 lbs. but to do so with less energy from corn grain and less protein from soy. In practice one of the most challenging things for a nutritionist may be to pay less attention to thumbnail rules of starch or nonfiber carbohydrate (NFC). Recent research has demonstrated similar diets may be formulated to be successful (Janicek et al., 2008). For this low NFC ration to be successful the

availability of fermentable fiber is critical as a greater proportion of energy will originate from fermentable fiber. Thus, good harvesting techniques and the use of highly digestible and/or low lignin hybrids should prove useful in this circumstance. Currently the University of Nebraska-Lincoln employs the technique of Tilly and Terry (1963) to evaluate the fiber digestibility of corn silages fed in research projects. We categorize highly digestible good quality corn silage when in vitro 30-h incubations result in NDF digestibility to be greater than 50% (Gehman et al., 2008). Feeding high proportions of such corn silage may result in large contribution of fermentable carbohydrate and ultimately energy supply to the animal.

The CPM-Dairy model is also usefully because it allows the user to strive to optimize rumen fermentation and contribution of rumen bacterial crude protein to MP supply. Table 2 also lists the predicted rumen microbial crude protein which is similar between diets (511 and 493 g for 0 and 15% DDGS). Rumen N balance may also be evaluated using the CPM-Dairy model. Rumen bacteria that ferment (NFC) use both ammonia and peptides as N sources. In contrast, those that ferment fiber are believed to utilize ammonia (Russell et al., 1992). Generally speaking, the predicted rumen N pools of these components should be at least 100%; however up to 150% may be needed in the least cost solution to optimize and solve. Given that DDGS are a rich source of P, S and protein these nutrients are expectedly higher in the diet containing DDGS. Lastly peNDF in these rations was maintained at 22.2 % by adding a low protein, long roughage in the form of grass hay.

Summary and Conclusions

Feed byproducts from the dry milling industry will continue to be common and cost effective ingredients in dairy diets. Assuming the price of distillers grains will continue to remain lower than corn grain and soybean meal, it is easy to predict that rations including these feeds will be cheaper. This economic benefit underscores the growing importance of understanding how co-products may be included into dairy diets high in corn silage. Current research suggests dairy rations may be easily formulated to contain 15% DDGS. When including distillers grains into dairy diets, nutritionists should ensure that the diet contains adequate levels of digestible NDF, and effective fiber and should be mindful of the high concentration of fat in this feedstuff.

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Table 1. Chemical composition of wet distillers grains (WDGS) and dry distillers grain (DDGS) (Dairy One Forage Analysis Lab results, January 21, 2008)

	Shelled Corn			WDGS			DDGS		
	n[1]	Mean	SD[2]	n[1]	Mean	SD[2]	n[1]	Mean	SD[2]
DM, %	4745	90.1	3.53	1177	28.6	13.0	2914	87.6	8.9
CP, %	4064	9.40	1.63	1171	29.5	12.3	2805	30.4	4.1
ADICP, % DM	1452	0.53	0.99	1119	3.5	2.20	2397	4.8	2.1
NDICP, % DM	1454	0.96	0.33	720	8.11	4.3	790	9.6	3.4
Lignin, %	1655	1.17	0.34	307	5.0	2.0	830	5.3	1.9
ADF, %	2680	3.49	1.5	1088	14.4	5.9	2389	16.7	3.7
NDF, %	2710	9.76	3.0	1091	28.9	10.3	2376	33.3	4.8
Starch, %	1946	70.49	5.13	552	6.68	12.5	1433	5.97	5.39
NFC3, %	2050	76.8	4.33	1046	32.4	19.4	2079	26.0	6.98
Crude Fat, %	2238	4.30	1.26	678	12.1	4.90	2086	13.0	3.0
Ash, %	1869	1.52	0.48	267	5.33	2.37	968	5.93	1.10
Ca, %	2344	0.04	0.12	489	0.08	0.12	1928	0.09	0.13
P, %	2338	0.32	0.10	489	0.85	0.16	1945	0.91	0.14
Mg, %	2322	0.12	0.09	489	0.31	0.07	1920	0.32	0.05
K, %	2325	0.41	0.10	489	0.97	0.30	1920	1.08	0.21
Na, %	1050	0.03	0.17	434	0.14	0.13	1554	0.19	0.19
S, %	1830	0.10	0.09	378	0.54	0.16	1421	0.64	0.18

[1]Number of samples
[2]Standard Deviation
[3]NFC = Nonfiber carbohydrates calculated by difference 100 – (%NDF + %CP + %Fat + %Ash)

Table 2: Dairy ration with and without dried distillers grains plus soluble (DDGS)

	Ration Inclusion	
	0 % DDGS	15% DDGS
Ingredient, %DM	**Lbs As Fed (DM)**	**Lbs As Fed (DM)**
Ingredient		
DDGS1	0.0 (0.0)	7.9 (7.0)
Corn silage	30.1 (12.0)	27.6 (11.0)
Alfalfa haylage	13.7 (4.1)	8.4 (2.5)
Alfalfa hay	2.8 (2.5)	4.4 (4.0)
Brome hay	3.3 (3.0)	4.4 (4.0)
Ground corn	10.68 (9.4)	8.4 (7.4)
Soybean meal	4.5 (4.1)	3.4 (3.1)
By-Pass Soy	1.9 (1.8)	0.84 (0.75)
Cottonseed	1.2 (1.0)	0.0 (0.0)
Soybean hulls	6.5 (6.0)	4.1 (6.4)
Vit/Min Mix	1.4 (1.4)	1.6 (1.6)
Nutrient Concentration		
DMI, lb/d DM	45.4	45.5
CP, % DM	17.5	18.2
P, % DM	0.36	0.40
S, % DM	0.21	0.26
Starch, % DM	26.0	23.4
Lignin, % DM	3.1	3.3
EE, % DM	3.33	4.91
NDF, % DM	34.8	35.1
CPM-Dairy Predictions		
Allowable Milk, kg		
Metabolizable Energy	75.0	75.0
Metabolizable Protein	75.1	75.0
Bacterial CP Yield		
NFC Bacteria, g	1624	1499
Fiber Bacteria, g	511	493
Total, g	2,136	1,992
Fermentability		
NDF, % DMI	13.1	12.7
Starch, % DMI	21.8	19.5
ME, mcal/lb	1.17	1.17
Bacterial MP, % MP	53.4	49.4
Lys:Meth	3.5:1	3.21
Duodenal 18:1 T Flow, g	45.1	84.4

[1]Chemical Composition as described by Greenfield Ethanol, Varennes, QC (CP=30.3%, Fat = 15.8%, NDF = 33.8%, Ash, 6.13%, P = 0.98%, S=0.67%)

Update on Forage Management

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Introduction

Harvest and storage management can have marked effects on silage quality. The objective of this paper will be to briefly discuss some recommended management practices to make high quality silages.

Evaluating Corn Forage Hybrids

Much emphasis has been placed on selection of corn hybrids for dairy cattle. There has been a significant resurgence in using brown mid rib (BMR) corn as newer hybrids now come with many stacked traits and yield drags have been significantly reduced. A good tool that can help in a farm evaluation is the MILK2006 spreadsheet from the University of Wisconsin at http://www.uwex.edu/ces/crops/uwforage/dec_soft.htm. The MILK2006 program calculates milk/ton and milk/acre for silage hybrids. This latest version allows for input data related to kernel processing score, degree of starch access and in vitro/in situ starch digestibility. This version also allows one to enter data using either 24, 30 or 48 h in vitro NDF digestibility estimates. Depending on your specific situation, most would try to choose hybrids that give high milk/ton and milk/acre. CornPicker is another program for evaluating corn silage hybrids and is available from Michigan State University (http://www.msu.edu/~mdr/cornpicker.html). This program calculates partial budgets and compares net farm income between two corn silage hybrids. The program is more complicated than MILK2006 but unlike that program, CornPicker provides a monetary bottom line between hybrids. Some of the inputs that users can manipulate include the cost of SBM and corn, cost of the seed; planting densities, amount of the hybrid fed to various groups of cows and of course NDF-digestibility.

Forage Maturity and DM

Harvesting forages at optimum maturity is important because it sets the stage for the rest of the year. High forage quality drives intake and in turn, this drives milk production. Not even the best nutritionists in the world can make cows maximize their milk production if they are working with poor quality forages. Corn silage should be harvested when the whole plant is at 32 to 35% DM and the kernels are at ½ milk line. However, milk line and whole plant DM do not always match up. In all cases, whole plant DM should be the overriding factor for corn silage harvest. To monitor whole plant DM, cut representative samples of corn plants from the field and have them chop them. Collect the chopped material and dry it down with a microwave or Koster moisture tester. Depending on the conditions, corn silage will dry down at a rate of about 0.5 percentage units per day (faster in dry and hot weather). Based on your acres and equipment you may have to start at a lower DM and you may end at a higher DM but the key is to avoid the extremes. Harvesting corn silage that is too wet (typically < 28-30% DM) results in excessive fermentations that produce high concentrations of acids and results in nutrient run off. Specifically, these wet silages are often characterized by high concentrations of acetic acid produced from "wild-type" fermentations. A common problem when feeding large quantities of wet corn silages is a reduction in DM intake because of the high acid content. In contrast, extremely dry corn silage (> 38-40% DM) should be avoided because the low moisture restricts fermentation and this material is more difficult to pack which often leads to poor aerobic stability. In addition, dry corn silage is usually very mature and thus fiber and starch digestibility are low.

One of the biggest challenges for making good alfalfa or grass silage is managing the period of wilting to result in maximum conservation of fermentable sugars and obtaining an adequate dry matter level to prevent the growth of clostridia. During prolonged wilts, sugars are metabolized by the plant in the windrow thus a quick dry down is beneficial. Wet grass and alfalfa silages are highly prone to undergo clostridial fermentations when the dry matter is less than 30-35%. Wilting these crops above this level makes it harder for clostridia to dominate the ensiling process.

Cutting Height

Corn silage is normally harvested to leave 4 to 6 inches of stalk in the field. Typically, the only time that cutting height should be higher is during drought years when the potential for nitrate

accumulation in the lower third of the stalk may occur. However, some dairymen have been high-cutting their corn silage as a normal practice for years. Leaving more of the stalk in the field that contains high concentrations of fiber and lignin may also help to improve soil conditioning. Research has shown that high cut corn silage (typically leaving 18 to 20 inches of stalk) results in silage with slightly lower concentrations of fiber and lignin, but higher concentrations of starch and net energy (Wu and Roth, 2003). A small yield drag of about 5 to 10% can be expected. Disappointingly, improvements in NDF digestion have been very small. The ultimate success of high cutting corn silage will depend on milk produced per ton of forage and milk produced per acre of forage but it is clear that high cutting normal corn silage does not make BMR corn silage.

Particle Size

Chopping corn silage too fine and too coarse should be avoided. Finely chopped silage reduces the effective fiber and coarsely chopped silage does not pack well and often leads to sorting of the TMR. Recommendations for theoretical chop size usually run between ⅜ to ½ inch for unprocessed corn silage and about ¾ inch for processed silage). In diets where corn silage makes up the majority of the forage, 15 to 20% of the particles should be greater than 1.5 inches long. If using a Pennsylvania State Forage Separator with the fourth box (now with a top, middle, low screens and bottom pan), about 8 % of the corn silage should be retained on the top screen to ensure optimum levels of effective fiber in the diet. If corn silage is not the major forage in the diet, about 3% of the top screen may be sufficient. For corn silage, the middle screen should have 45 to 65% of the particles after shaking and there should be no more than 5% of particles on the bottom pan. If corn silage is processed, a higher proportion of particles can be targeted for the top screen. In measurements that we have taken, some baggers decrease the proportion of corn silage particles on the top screen by about 10 to 15 units so this must be taken into consideration when setting chop length. Instructions for using the new particle size separator can be found at: http://www.das.psu.edu/TeamDairy/. In general, if faced with drier forages, one can cut shorter to achieve a tighter pack. If feeding long hay, silages may also be cut a bit shorter.

Mechanical Processing

Mechanical processing of whole plant corn has been an accepted method to improve the quality of corn silage (Johnson et al., 1999). Whole plant processing crushes the entire plant through rollers and can be accomplished in the field during harvesting, at the silo but prior to storage, or after ensiling and just prior to feeding. Processing corn silage improves starch and allows for good packing in silos even with a longer length of particle chop. Rollers should be set obtain adequate kernel damage. In drier and more mature corn silage, clearances between rollers will usually need to be tighter. However, care should be taken to monitor the effectiveness of the processing. When large amounts of acreage require harvesting, there may be a tendency to open the rollers more than what is recommended in order to speed up the harvest, reduce energy use and to reduce wears on equipment. As a rule of thumb, adequate processing is occurring if more than 90-95% of the kernels are crushed or cracked and cobs are more than quartered. Many labs currently provide a Corn Silage Processing Score, which is coupled to NIR analyses of corn silage. A dried corn silage sample is sifted through several screens and particles of corn that are greater than ¼ to ½ of a kernel are retained on a screen and considered difficult to digest. The score provides feedback on processing as “optimum”, “average”, or “inadequately processed”. (One draw back is that the test takes several days for completion). An improvement in starch digestion is greater when more mature corn silage (e.g., black layer) is processed. However, always target harvest for 32-35% DM (whole plant DM). Corn should probably not be processed if harvesting forage that is less than 30% DM and especially if the corn has not dented. Improvements in fiber digestion due to mechanical processing are inconsistent. When there are reasons out of your control (inclement weather, equipment problems, and scheduling problems with a contractor) those results in corn being harvested at later stages of maturity, processing should be considered. A common observation by producers switching to processed corn silage is the reduction in cobs in the feed bunk and a reduction in kernels in the manure.

Keys to Making Good Silage

The keys to making quality silage are to 1) rapidly exclude air from the forage mass, which will result in 2) a rapid production of lactic acid and reduction in silage pH, and 3) to prevent the penetration of air into the silage mass during storage. Excessive air, due to slow silo filling or poor packing (overly dry forage or forage chopped too coarsely) allows the plant to respire for prolonged periods of time. This results in utilization of sugars and excessive degradation of plant protein. Air also encourages the growth of undesirable microbes such as yeasts and molds.

Air can be eliminated by fast filling (but not too fast), even distribution of forage in the storage structure, chopping to a correct length and ensiling at recommended dry matters (DM) for specific storage structures. Bunk and pile silos should be filled as a

progressive wedge to minimize exposure to air and packed in 6 to 8 inch layers. The recommended optimal packing density for bunk silos is 14 –16 lbs. of dry matter per cubic foot (Ruppel et al., 1995). Silage corers can be obtained from several commercial sources. An Excel spreadsheet can be downloaded from the University of Wisconsin Extension web site that helps with bunker silo filling (www.uwex.edu/ces/crops/uwforage/storage.htm). Users can input silo dimensions, tractor weight, forage delivery rate, forage dry matter, and packing time to estimate packing density. In several recent surveys of bag silos, packing densities are more commonly between 9 top 12 lb of DM/cu ft. Silage in bags should be packed tightly by monitoring the stretch marks on the bags. Tunnel extensions on older units can be added to increase pack density. Silo bags should be vented for about 3 days to rid the bags of excess gas.

Under anaerobic conditions (lack of air) silage fermentation is dominated by microbial activity. Fermentation is controlled primarily by a) type of microorganisms that dominate the fermentation, b) available substrate (water soluble carbohydrates) for microbial growth, and c) moisture content of the crop. Lactic acid-producing bacteria utilize water-soluble carbohydrates to produce lactic acid; the primary acid responsible for decreasing the pH in silage. Unlike alfalfa and other grass silages, corn silage rarely undergoes clostridial fermentation. However, because of its high starch content, preventing the proliferation of yeasts that produce alcohol and cause lower DM recovery is a challenge in corn silage. Yeasts are also responsible for aerobic spoilage of silages during storage and feed out.

Microbial Inoculation

Because forage often naturally contains many detrimental types of bacteria, the concept of adding a microbial inoculant to silage was to add fast growing homofermentative lactic acid bacteria in order to dominate the fermentation resulting in higher quality silage. Some of the more common homolactic acid bacteria used in silage inoculants include *Lactobacillus plantarum, L. acidophilus, Pediococcus acidilactici, P. pentocaceus, and Enterococcus faecium.* Microbial inoculants contain one or more of these bacteria which have been selected for their ability to dominate the fermentation. The rationale for multiple organisms comes from potential synergistic actions. For example, growth rate is faster in *Enterococcus* > *Pediococcus* > *Lactobacillus.* Some *Pediococcus* strains are more tolerant of high DM conditions than are Lactobacilli and have a wider range of optimal temperature and pH for growth (they grow better in cool conditions found in late Fall and early Spring). When compared to untreated silages, silages treated homolactic acid bacteria are often lower in pH, acetic acid, butyric acid and ammonia-N but higher in lactic acid content and have better DM recovery (Muck and Kung, 1997).

Lactobacillus buchneri has been proven to improve the aerobic stability of silages. In the silo, *L. buchneri* results in a "controlled" fermentation that produces moderate amounts of acetic acid which limits the growth of spoilage yeasts. Production of moderate amounts of acetic acid by this organism is not detrimental to intake nor does it lead to excessive amounts of DM loss during ensiling (Kleinschmit and Kung, 2006). Recently, L. buchneri has been combined with traditional homolactic acid bacteria to form "combination" inoculants that are specifically designed to speed up the fermentation process and to improve the aerobic stability (shelf life) of silages.

The location of applying a microbial inoculant is important. If silage is to be stored in a bunk, pile or pit silo I would recommend that the inoculant be applied at the chopper for a more even distribution. Remember that these bugs don't have legs, nor do they swim! If all the inoculant gets put on in one spot, it will probably stay there. (Some distribution will occur during tractor movement and packing, but this is not efficient.) For silage that will be stored in a bag silo, application at the chopper or bagger will probably not make a difference. (In a few instances, forage is chopped and harvested far away from where it is ensiled. Under these circumstances, I would prefer to have the inoculant applied at the chopper so that the microorganisms can begin their work right away.) Don't forget to properly calibrate your applicators to match forage delivery and don't increase the dilution or reduce the application rate! Also, remember that inoculants in water are stable for about 2 to 3 days but maybe less under very hot temperatures. If for some reason, unused liquid inoculants must be stored, do so in shade and place a few ice packs into the liquid to lower the temperature of the liquid. Do not allow the temperature of water in the applicator tanks to rise above about 100°F as this may decrease the viability of the bacteria (Mulrooney and Kung, 2008). Seal any unused portion of powders tightly to protect from moisture and stored in a cool area.

Sealing Silos and Fermentation

After filling a silage should be covered with plastic as soon as possible and weighted down with tires (tires should be touching) or gravel bags to exclude air. Split tires are a good alternative because they are easier to handle, do not accumulate water (thus less breeding grounds for mosquitoes that could carry the West Nile Virus), and are undesirable for animals to nest in. The return on investment (labor and plastic) is extremely high for covering bunk and pile silos (Bolsen et al., 1993). Oxygen barrier plastics are also now available for use (Borreani et al., 2007).

When conditions allow for it, silage should ferment for a minimum of 6 to 8 weeks before feeding. A gradual transition over a 10 to 14 day period from old silage to new silage is also recommended. Unfermented feed is the equivalent of feeding green-chop that is high in fermentable sugars and can cause cows to go off feed and have loose manure.

Silage Feedout

Proper management for removal of silage from silos and management at the feed bunk can help producers to maximize profits and production. Enough silage should be removed between facing to minimize aerobic spoilage. Lesser amounts may be removed in areas of the country where ambient temperatures remain cool during the winter months. Removal of silage should be such to minimize loose silage on the ground between feedings. Hot, moldy feeds should not be fed because they are low in nutritive value and digestibility and depress intakes. Feed bunks should be kept full but clean of decaying feed. Face shavers are becoming popular but research is needed on their benefit. Extreme care should be taken to prevent air from penetrating between the plastic and reaching the silage mass. Examples of putting more weight on the plastic at the leading face are shown (Figure 1).

Conclusions

Great care should be taken to preserve and maintain the nutritive value of forage crops. Management starts in the field with harvesting crops at the optimum maturity and then following this with a quick wilt (for grasses and alfalfa), by chopping to an adequate particle size, treating with a good microbial inoculant, processing the plant (for corn silage), filling silos quickly and packing them tightly and finally managing the silage in the silo with plastic and weights to minimize exposure to air.

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Figure 1. Placing more weight on the leading face of silos minimizes air from penetrating into the silage mass.

Managing Alfalfa-Grass and Grass Silage for High Producing Dairy Cows

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A 2007 survey in N.Y. determined that over 80% of alfalfa seedings in the state were made with a cool-season companion grass such as timothy, orchardgrass, reed canarygrass or tall fescue. While herd averages continue to climb and forage management becomes ever more intensive, there's no sign that this percentage is decreasing. New York and much of New England are the exceptions in this regard, since in most of the rest of the U.S., alfalfa is usually seeded without a forage grass—hereafter termed "clear" alfalfa.

Something old, something new

Cornell University agronomists have been recommending seeding alfalfa with companion grass for over thirty years, with the recommendation based on trial results across the state. This research has included several harvest schedules, only one of which is intensive enough to approach current harvest management recommendations. Using the most intensive harvest management, over a four-year period there were modest differences in forage yield, with alfalfa-timothy yielding about 10% more than clear alfalfa. The differences in weed encroachment were somewhat greater, with broadleaf weeds—mostly dandelions—constituting 20% of dry matter yield for clear alfalfa compared to only 10% for alfalfa-timothy. Cornell University agronomists' recommendation, based on this research: "Clear alfalfa should be grown only on well-drained, fertile soils. On marginally-drained soils or soils where heaving occurs, alfalfa should be grown with a companion crop to ensure long-term production."

Since this long-ago research was published, neither Cornell agronomists nor most farmers in the region have changed their opinions on the subject alfalfa vs. alfalfa-grass. Cornell's forage management website, www.forages.org, recommends seeding alfalfa with a forage grass for a great majority of the soil types in N.Y. State. Even for many of the potentially more productive soil type-drainage combinations (including tile-drained fields), clear alfalfa is listed as an alternative but with the statement that alfalfa is "acceptable but not recommended for this particular application". Among the several reasons cited for the advantages of alfalfa-grass: Reduced heaving damage, slightly higher yields, less insect damage, and "something to harvest if winter takes out all the alfalfa".

Let them eat grass

Farmers in the Northeastern U.S. are increasingly turning to grass species that respond better to today's more intensive harvest management than do old favorites timothy and bromegrass. This is the case for alfalfa-grass mixtures as well as for pure grass stands. Today's aggressive forage managers, especially those storing most of their crop as silage, are harvesting at least one more cutting of alfalfa, alfalfa-grass, and grass than they did 10-20 years ago. (We had a farmer in Northeastern N.Y. harvest alfalfa-grass five times last year, for the first time ever.) While alfalfa has generally persisted quite well under more intensive management, some grass species don't tolerate frequent cuttings nearly as well, either by reduced persistence (bromegrass), or simply by "going to sleep" for the summer (timothy). Timothy often behaves much like a college professor with a 9-month appointment, working hard through May, then taking the summer off. This has increased the interest in more aggressive grass species including reed canarygrass and, more recently, tall fescue.

Reed canarygrass is slow to get going during the seeding year, both when seeded alone and when seeded with alfalfa. It's less frost-tolerant than most other grasses, and doesn't tolerate close mowing in the seeding year. In a 2006 greenhouse trial at Miner Institute, reed canarygrass cut at a 2" stubble height was completely killed, while cut at a 4" stubble height recovered quickly with no adverse effects. Once established, however, reed canarygrass is a high-yielding, very persistent species with an almost insatiable appetite for manure. Forage quality isn't as good as that of several other cool-season grasses including tall fescue. Tall fescue has a distinct quality advantage over reed canarygrass. Canarygrass loses quality very quickly with advancing maturity (much like orchardgrass), but even at the late boot stage (just prior to head emergence), both NDF and NDF digestibility are distinctly inferior to tall fescue. This, plus the difficulty in establishing canarygrass in alfalfa-grass seedings, has increased farmer interest in tall fescue. Tall fescue is easier to establish than reed canarygrass, and does well in somewhat poorly

drained soils. While not well suited to droughty fields, it has much better summer production than does timothy. The newer varieties of tall fescue are endophyte-free and while more research is needed, appear to fit well in modern dairy rations.

Forage quality comparisons

Following is the most recent 7-year summary from the Dairy One Forage Laboratory in Ithaca, NY., comparing legume, mixed mostly legume, and grass silages (Table 1). Protein and fiber analyses are based on a very large number of samples—approximately 20,000, 65,000 and 22,000 for legume, mixed mostly legume and grass silages respectively, while Relative Forage Quality, Milk/ton (based on *Milk2006*) and 30-hour NDF digestibility are all based on much smaller numbers—approximately 2000, 3000 and 700 samples respectively.

Table 1. Selected forage quality parameters of legume, mixed mostly legume, and grass silages.

	Legume	Mixed mostly legume	Grass
Crude protein, %	21.1	19.0	14.6
ADF, %	35.2	36.8	38.3
NDF, %	44.8	49.2	58.6
NE (lactation), MCal/lb	0.60	0.58	0.54
RFQ	154	145	138
Milk lbs/ton	2644	2601	2611
30-hr NDF-d, %	49.0	51.4	59.9

Dairy One Forage Laboratory, 2008.

One obvious conclusion from the above data is that (on the average) farmers aren't harvesting hay crop forages early enough, since we'd like to see NDF about five percentage points lower for each forage type. Imagine this, after all the years of encouragement, cajoling and pleading from those of us in the "agri-professional" field! Because hay crop ADF should be about 30% when harvested at the right stage of maturity, the DairyOne data suggest that farmers are doing a better job of getting legumes into the silo on time than they are with mixed stands or straight grasses. An average of 14.6% crude protein indicates that farmers aren't applying quite enough nitrogen to grasses harvested for silage, thus sacrificing both yield and quality. However, milk per ton—while based on a much smaller number of samples—is very similar for each of the three forage types. While grasses have a much higher NDF concentration, the NDF in grasses is considerably more digestible.

A case study

A few years ago we seeded a 40-acre field at Miner Institute to a mixture of 14 lbs/acre alfalfa and 5 lbs/acre of reed canarygrass, rates that are close to current Cornell University recommendations. (It's worth noting that with few exceptions Cornell's recommended seeding rates for alfalfa-grass haven't changed in 30 years, perhaps giving a different meaning to the word "current".) This field, while tile drained (in 1912), has at least 8 different soil types including an excessively well-drained stony loam, a moderately well-drained sandy loam, and a poorly drained clay loam. Three years after seeding the forage mixture on the stony loam was almost 100% alfalfa, the sandy loam had a nice mixture of alfalfa and canarygrass, while the clay loam was almost 100% grass. Had we seeded this field to clear alfalfa, by the third year after establishment we'd either have rotated the field to corn or would have been harvesting a low-yielding combination of alfalfa, dandelions and native grasses.

Another reason we decided that reed canarygrass wasn't the perfect companion to alfalfa was an analysis based on hand separations of first cut forage when the alfalfa was in the late bud stage. By this time the reed canarygrass was at the early heading stage, which is past ideal quality (Table 2). Canarygrass variety selection wouldn't have helped much, since a number of university trials have found that the several commercial varieties on the market all head at about the same calendar date.

Table 2. Forage quality of first cut alfalfa and reed canarygrass in a mixed stand.

	Alfalfa	Reed canarygrass
Dry matter, %	21.9	20.8
ADF, %	31.5	36.0
NDF, %	41.0	61.0
30-hr NDF digestibility, %	47.0	66.0

Miner Institute, 2004

The ADF concentration shows that the canarygrass was almost a week past its prime while the alfalfa was just about at the ideal stage of harvest. We've stopped seeding reed canarygrass at Miner Institute and are now using tall fescue with our alfalfa. We're seeding 4 lbs of tall fescue per acre with 12-14 lbs of alfalfa but don't know if this is the ideal ration of fescue to alfalfa. Research is underway that should zero in on the correct seeding rates. Three years ago we seeded both alfalfa-canarygrass and alfalfa-tall fescue in the same field, and were impressed at how much better the tall fescue performed, especially later in the growing season.

Alfalfa vs. alfalfa-grass in the feedbunk

Several years ago Cornell University compared several ratios of alfalfa and tall fescue: 1: 0 (100% alfalfa), 2: 1, 1: 2, and 0: 1 (100% tall fescue). Five cows were included in a Latin Square design, with two periods and five replications (Table 3).

	1: 0	**2: 1**	**1: 2**	**0: 1**
Milk, lbs/day	71.2[a]	76.1[b]	85.8[c]	89.3[c]
DMI, lbs/day	45.2[a]	45.9[a]	51.6[b]	54.2[b]
Milk/DMI	1.58	1.66	1.66	1.65
Forage: Grain ratio	84:16	70: 30	59: 41	51: 49
Milk true protein%	2.70[a]	2.74[ab]	2.81[ab]	2.90[b]
MUN, %	16.4[a]	13.7[b]	13.0[b]	13.1[b]

P = <0.05 Cornell University, 2002

The inclusion of tall fescue in these rations increased milk production, and the more grass in the ratio, the higher the DMI and milk production. As the proportion of grass in the ration increased, cows had higher grain consumption and a lower forage-to-grain ratio. However, the alfalfa was 28% ADF while the tall fescue was 32% ADF; ideally both species should have been at the same ADF. An economic analysis of two of the rations found that income over feed cost was similar for alfalfa and 2: 1 alfalfa: tall fescue. This data suggests that dairy farmers can make the decision to grow clear alfalfa or alfalfa-grass based on crop management factors rather than on significant differences in forage quality or milk production potential.

Feed Energy Applications

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Introduction

A feed energy system has two main purposes: ration formulation and economic valuation of feedstuffs. For ration formulation, energy requirements for maintenance, pregnancy, milk production, and growth are estimated, feedstuffs are given energy values, and then linear programming is used to find the combination of feedstuffs that meet the energy requirement within a set of constraints. The logic behind balancing diets for energy is to provide a diet that has adequate energy for milk production while maintaining desirable body condition. Within a local market, nutritionists have dozens of different feedstuffs available to be included in diets. Usually one feed is chosen over another because it provides a nutrient or nutrients at a lower cost. Because energy is a primary nutrient for cows, the energy concentration of a feed has a major impact on its economic value. If a feed can be assigned an accurate energy concentration and if we know the value of a unit of energy, then economically wise decisions regarding feed choices can be made.

The most widespread energy system used for both these purposes is the net energy for lactation (**NEL**) system. On a theoretical basis the NEL system is far superior to other energy systems such as TDN. However, the current NEL system (and any other energy system) has serious flaws that should limit it value, especially in ration formulation. We need to continue develop and eventually adopt better methods for ration formulation but until such methods are available we need to make the current NEL system as accurate as possible. The purposes of this paper are to: 1) review the basics of the NEL system including its limitations, and 2) discuss adjustments in the current system that should make it more accurate.

Review of the NEL System

The underlying basis of the NEL system is the first law of thermodynamics and all things, including cows, must obey that law. In terms relevant to animal nutrition, the first law of thermodynamics can be stated as: Energy input must equal energy output plus or minus any change in body energy. If we can accurately estimate the NEL of a diet and NEL requirements, then energy balance can be calculated and we can project changes in body energy reserves (i.e., body condition). The health and long term productivity of a cow depends on proper management of body condition. The average energy flow calculated from many different diets is shown in Figure 1. On average about one-third of the energy consumed is lost via feces, about one-fourth is lost via heat and only about one-third of the energy consumed is converted to NEL. In comparison, a gasoline-powered car converts about 15% of the chemical energy in gasoline to mechanical energy.

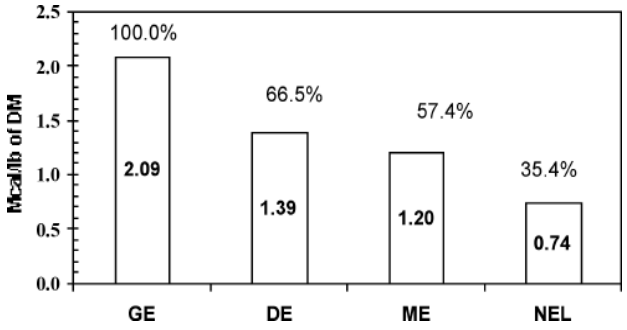

Figure 1. Average energy concentrations of mixed diets fed to dairy cows. Data derived from USDA Beltsville energy lab.

Gross energy (GE) is the total amount of chemical energy in the diet (Mcal/lb of diet dry matter) and is measured by completely burning a sample in a bomb calorimeter. This measurement is easy, precise, and accurate. The concentration of GE depends solely on the chemical composition. Ash, carbohydrate, fat, organic acids, and protein have different energy values per unit of mass and as the concentrations of these fractions change, GE changes. High protein and high fat feeds will have more GE than high carbohydrate feeds and feeds with high ash will have less energy than lower ash feeds.

Digestible energy (DE) is the energy remaining in the diet after fecal energy is subtracted. Because measurement of DE requires measurement of fecal output it is less accurate and less precise than measuring GE and can only be measured by feeding animals. The DE is a function of GE and all factors (animal and feed) that affect digestibility. The digestibility of the carbohydrate fraction of diets is extremely variable and has a substantial impact on GE. Dry matter intake is the major cow factor that

influences energy digestibility; the marginal efficiency of digestion decreases as dry matter intake increases.

Metabolizable energy (ME) is the energy remaining after urinary and gaseous energy arising from fermentation (essentially methane) is subtracted from DE. Collection of urine, bomb calorimetry of urine, and measuring methane is difficult and prone to errors plus measurement of ME includes all the errors associated with measuring DE; therefore ME is less accurate and less precise than DE. Dietary fiber increases methane production in the rumen and high protein increases synthesis of urea both of which reduce the efficiency of converting DE to ME. High starch diets and ionophores such as monensin reduce methane production and increase the efficiency of converting DE to ME.

Net energy for lactation is the energy consumed by a cow that actually does something; it is the energy secreted in milk, retained in the body (fat, growth, fetus), and used to perform maintenance functions such as pumping blood. It is calculated as ME minus the heat generated by the inefficiency of transforming energy from one form to another (i.e., the heat increment). Heat increment cannot be measured directly; it is calculated from total heat production measured using a whole animal calorimeter. Because these instruments are extremely expensive and only a few are available in the entire world, measured NEL data are extremely limited. Type of carbohydrate and concentrations of dietary fat and protein affect the efficiency of converting ME to NEL. As fiber and protein increase, the efficiency of converting ME to NE usually decreases and as fat and starch increase, efficiency increases. Measurement of NEL is the least accurate and precise measure of energy because it includes all errors associated with measuring GE, DE, and ME plus the errors associated with measuring heat increment.

Why we Should Stop Using the NEL System

The NEL system (as all current energy systems) has two serious problems. First, cows do not really have an energy requirement, they have requirements for ATP and the substrates that produce ATP. Energy was something we could measure and therefore energy systems were developed as proxies to the requirements for ATP-generating compounds. The second problem with the NEL system is that feeds do not have NEL, diets have NEL. We assign feeds NEL concentrations so that we can use linear programming to formulate diets. This approach assumes nutrients from different feedstuffs are additive (i.e., the ingredient and nutrient composition of the final diet has no effect on the nutrient value of the individual ingredients). The metabolizable protein (MP) concept is the best example of non-additivity Urea is an excellent source of MP when added to a diet deficient in rumen degradable protein (RDP), but if urea was added to a diet with excess RDP it would contribute no MP. With the MP system, feeds are not given MP values, only the diet has an MP concentration. Similar to MP, NEL should be considered non-additive and only diets, not ingredients, should have an NEL value. Although difficult and expensive, we can measure NEL concentrations of diets. We cannot measure the NEL of individual feedstuffs within a diet, therefore, it is not possible to determine whether the value used for a feed is correct. However, because with most ration balancing software, the only way a nutritionist can change the energy value of the diet is to adjust the NEL values of individual feeds. This paper will present approaches to fine-tune NEL values of selected feeds. However the reader must remember that individual feed ingredients do not have NEL values. As our knowledge base, computing capacity, and analytical abilities increase, practical nutritional models will be developed that do not include energy.

Living with What We Have: The Application of NEL System

Although the NEL system has flaws, it still have useful applications for feeding cows as the following example illustrates. A dairy farmer has a group of 100 Holstein cows. Actual body weights (BW) are not known but you estimate the average BW is about 1400 lbs (636 kg). The farm has the ability to measure milk weights and the average milk yield for that group is 75 lbs and milk from that pen averages 3.7% fat and 3.0% protein. The group averages about 150 days in milk (most cows are pregnant but at least 100 days from calving). Feed delivered to the pen and feed refusal is measured and average dry matter intake is 50 lbs. Knowing that you should not balance for the average cow, you formulate a diet that will support 90 lbs of milk (20% more milk than the current average).

The daily NEL requirements (NRC, 2001) for the average cow are:

Maintenance: $636^{0.75}$ x 0.08 = 10.1 Mcal/day

Lactation: 75 lbs x 0.32 Mcal/lb = 24.0 Mcal/day

Total NEL use = 34.1 Mcal/day

The diet was formulated to contain 0.77 Mcal NEL/lb because that will support 90 lbs of milk without any change in body condition at an intake of 50 lbs.

NEL intake = 50 lbs x 0.77 = 38.5 Mcal/d

NEL balance = NEL intake - Maintenance - Milk energy = 38.5 - 10.1 - 24.0 = 4.4 Mcal/d

Cows in this example have an average daily surplus of 4.4 Mcal of NEL which should result in a daily increase in body energy reserves equal to 1.9 lbs of BW. Therefore, if the NEL system is accurate, cows in that group will on average produce 75 lbs of milk per day and gain approximately 1.9 lbs of BW and if

cows continue to consume this diet for 110 days, body condition score will increase by an average of 1unit. To project body condition changes, you must compare NEL intake to actual NEL expenditures (i.e., use actual mean milk production, not the target milk production).

Now comes the part that requires a good nutritionist rather than just a computer. You must evaluate estimated energy balance by asking: Is the value reasonable? Is it reasonable to expect a group of cows to produce an average of 75 lbs of milk **AND** gain an average of almost 2 lbs of BW per day with a feed intake of 50 lbs? The probable consensus among nutritionists is that it is unlikely and therefore not reasonable. The focus of this paper is to discuss adjustments that a nutritionist may have to make to obtain reasonable projected energy balances. Measuring dietary concentrations of NEL is extremely difficult and measuring some NEL requirements is problematic. A good nutritionist should not hesitate to make appropriate adjustments to either feed NEL values or requirements based on apparent energy balance and experience.

Errors in Calculated Energy Balance Because of Incorrect Maintenance Requirement

The past several versions of NRC has calculated maintenance requirement (Mcal NEL/day) as: 0.08 $BW^{0.75}$ where BW is in kilograms. That equation was derived from calorimetry data mainly from USDA, but because maintenance requirements cannot be directly measured, the accuracy of that equation is subject to debate. An analysis of calculated energy balances (Ellis et al., 2006) suggested that the average maintenance requirement should be calculated as $0.096*BW^{0.75}$ (equivalent to a 20% increase of the NRC equation) and that maintenance changed from about $0.08*BW^{0.75}$ at calving to $0.098*BW^{0.75}$ at 15 weeks of lactation. The problem with that paper is that all the difference between estimated energy balance and BW change was assumed to be caused by an error in the maintenance requirement. Feed NEL concentrations were not measured and changes in BW in early lactation may not reflect change in body energy. Although an error of the magnitude (i.e., 20%) suggested Ellis et al. is unlikely, the NRC equation may underestimate maintenance expenditure in many situations. With large pens and 3X milking, the distance some cows walk can be substantial and the NEL used for activity (included in the maintenance requirement) is probably underestimated. A typical Holstein cow needs about 0.1 Mcal of NEL to walk 1000 ft on flat surfaces so even with large pens, long distances between the pen and milking parlor, and 3X milking, a 3 to 5% increase in maintenance requirement will probably cover the NEL used for increased walking.

Errors in Estimating Gross Energy of Feeds

The nutrient fractions that have the greatest impact on GE concentrations are ash, crude protein (CP), carbohydrate, and fat. The 'carbohydrate' fraction as defined by NRC contains NDF, starch, simple sugars, organic acids, and several minor compounds. The GE concentration of starch and NDF are similar but simple sugars such as sucrose have about 10% less GE per pound than starch. This means that the NRC system will overestimate GE of feeds that contain substantial amounts of simple sugars (e.g., molasses). The predominant organic acids found in well-fermented silage have about 15% less GE than does starch which means that silage will have less GE than the value estimated by NRC. The NRC value for GE of CP is a reasonable estimate for plant-based feeds that contain predominantly true protein. A large proportion of the CP in silage can be nonprotein N which generally has a lower GE concentration than protein, therefore GE of silage CP is overestimated by the NRC system. The GE value for long chain fatty acids used by NRC is a reasonable average, but GE/lb increases as fatty acid chain length increases and saturated fatty acids have slightly more GE per pound than unsaturated fatty acids. Although several factors affect GE that are not considered in the NRC model, in practice most of these factors will not greatly affect the end results. The GE concentration of silage is probably overestimated by 1 or 2%. For feeds with a high concentration of simple sugars, GE may overestimated by about 6%, but those feeds generally make up a small proportion of the diet and the overall effect on diet NEL would be small.

Error is Estimating Digestibility

Energy digestibility (86 treatment means) of mixed diets fed to lactating cows varied from 60 to 78% (mean = 68%) and DE concentrations varied from 1.28 to 1.54 Mcal/lb. (mean = 1.38 Mcal/lb) (Wilkerson et al., 1997). Although the variation in energy digestibility and DE concentrations are much less among diets than among feedstuffs, the variation is still substantial and important sources of variation must be identified and modeled. For the purpose of estimating energy values, feeds can be broken down into five major nutrient fractions (CP, fatty acids, NDF, starch, and the non-starch portion of NFC). Of the common nutrient fractions, digestibility of NDF is most variable, but digestibility of starch can also vary substantially. For a wide range of diets, total tract NDF digestibility measured in lactating dairy cows ranged from 29 to 64% with an average of 46% (Wilkerson et al., 1997). Firkins et al. (2001) reported a range in total tract starch digestibility in lactating dairy cows of 70 to 99% (average = 91%). Because starch and NDF comprises 50 to 60% of diet DM for typical diets, variation in digestibility of those fractions has a large impact on the DE concentration in the diet.

The other fractions make up a relatively small portion of the diet or digestibility is less variable. The non-starch portion of NFC is a heterogeneous mixture of mostly simple sugars, organic acids, and neutral detergent soluble fiber all with expected high digestibility (approximately 100%). The digestibility of CP is variable but the equations used by NRC (based on acid detergent insoluble CP) appear to account for most of the variation. The NRC assumes that digestibility of fatty acids is constant except for fat supplements. This probably is not true and better models of fat metabolism are being developed. The most important fine-tuning that should be done regarding the energy contribution of fat is to use accurate fatty acid concentration data. Feeds that contain appreciable concentrations of fatty acids should be assayed for fatty acids. The NRC has averages of measured digestibilities for several common fat supplements and the use of these values gave good estimates of measured diet DE (Weiss and Wyatt, 2004). If the NRC does not contain a digestibility value for a specific fat supplement, users should request the information from the manufacturer of the supplement. Because fat supplements are only fed to provide NEL, I would not use a product if fatty acid digestibility (measured in lactating dairy cows) data were not available.

Corn Grain

Diets for lactating cows typically contain between about 20 and 35% starch (dry basis) and total tract starch digestibility ranges from about 70% to 100% with a mean of 91% (Firkins et al., 2001) Assuming an average dietary starch concentration of 28%, a range in starch digestibility equal to the mean (91%) plus or minus two standard deviations (7%) would cause DE concentrations of diets to vary by ± 0.07 Mcal/lb from the DE value calculated using average starch digestibility. Varying NFC digestibility using the Processing Adjustment Factor (PAF) in the NRC model will only change discounted DE concentrations by about ± 2%. Clearly the NRC model does not account for all the variation in high starch feeds.

Dry Grinding of Corn. Total tract digestibility of starch is higher when cows are fed 'ground' corn compared with 'cracked' corn (Firkins et al., 2001). Because particle size of the corn was not reported in most studies, a quantitative relationship between particle size of corn and digestibility cannot be derived at this time. Based on differences in digestibility, measured dietary NEL, and milk yields, diets with ground dry corn have 1 to 3% more NEL than do diets with cracked corn but the NRC model only estimates a difference of about 1%. *Proposed adjustment:* Reduce NEL-3X (i.e., NEL concentration calculated using NRC (2001) equations assuming an 8% discount factor) value for cracked corn by 2.5% and increase NEL-3X value for ground corn by 2.5%. These values were derived by assuming diets with cracked corn have 2% less NEL than diets with ground corn and corn comprised 30% of the diet.

High Moisture Corn. Based on digestibility, measured NEL and production data, diets with high moisture corn have 4 to 6% more NEL than diets with dry corn, but the NRC model estimates about a 1% difference. The effect of moisture concentration of high moisture corn on digestibility in lactating cows is lacking but in vitro digestibility of starch is usually higher for wetter corn; however this does not mean that extremely wet corn is more digestible than normal high moisture corn. *Proposed adjustment:* Increase NEL-3X value of high moisture corn by 10%. This value was derived by assuming that diets with high moisture corn have 4% more NEL than diets with dry ground corn and that corn comprised 30% of the diet. As the DM concentration of high moisture corn increases above 75%, a smaller adjustment would presumably be appropriate.

Steam-flaked corn. Most data with dairy cows suggests that diets with steam-flaked corn have 1 to 2% more NEL than diets with dry corn but NRC estimates the difference at about 0.5%. As flake density increases above 28 to 30 lbs/bushel, steam-flaked corn becomes more similar to ground corn and steam-rolled corn (38 lbs/bus) was essentially equal to dry ground corn (Firkins et al., 2001). Extremely low density flakes may have detrimental effects on ruminal digestion and may result in lower, not higher, dietary NEL values. *Proposed adjustment:* For steam-flaked corn with a density of approximately 29 lbs/bu, NEL-3X values should be increased by 3 or 4%. This value was derived by assuming that diets with steam-flaked corn have 1.5% more NEL than diets with dry ground corn and that corn comprised 30% of the diet. As density increases, the adjustment will be less.

Starch Chemistry. Corn starch can be branched (amylopectin) or linear chains (amylose) of glucose. Corn grain with mostly amylopectin is less dense (more floury or lower vitreousness) than corn with a high proportion of amylose (more flinty or higher vitreousness). Across corn hybrids, the structure of starch is a continuum ranging from very floury to very flinty with average dent corn being intermediate. In situ and in vitro studies have shown that vitreousness has a strong inverse relationship with ruminal starch digestibility (Correa et al., 2002) but data from experiments with lactating dairy cows is limited. Density of whole kernels is positively correlated with vitreousness (Correa et al., 2002) suggesting that density might have value in fine-tuning NEL values of different types of corn hybrids. More data with lactating cows are necessary before the effect of starch chemistry on starch digestibility can be quantified but flinty corn probably has less NEL than floury corn.

Corn Silage

Corn silage contains appreciable concentrations of both starch and NDF and variation in digestibility of either fraction can have a substantial affect on its energy value. Although highly variable, the average starch concentration for corn silage is about 30% and NDF averages about 45%. The digestibility of starch and NDF provided by corn silage cannot be directly measured in lactating dairy cows fed mixed diets because diets contain other sources of starch and NDF. However digestibility of total dietary starch by lactating dairy cows ranged from about 88 to 98% when corn silage provided 20 to 65% of the dietary starch (Bal et al., 1997; Johnson et al., 2003; Weiss and Wyatt, 2000) which is within the range of starch digestibilities when most of the starch comes from corn grain. Digestibility of dietary NDF by lactating dairy cows fed mixed diets when corn silage was the sole forage range from 46 to 55%.

Maturity Effects. The DM concentration of corn silage is positively correlated with maturity (drier plants tend to be more mature). Data from three different experiments (Bal et al., 1997; Johnson et al., 2003) were compiled to derive an equation to adjust energy values of corn silage based on DM. If the change in dietary DE concentration is assumed to be caused entirely by the corn silage, DE concentration of the corn silage decreases 0.01 Mcal/lb of DM per every 1 percentage unit increase in DM concentration. Assuming an average efficiency of converting DE to NEL of 0.54, the NEL of corn silage decreases 0.005 Mcal/lb for every 1 percentage unit increase in DM concentration above 28%. Although the only variable included in the regression was DM, the nutrient composition of silage change as plant mature (e.g., lignin as a percent of NDF tends to increase). The difference in NEL between a corn silage with 35% DM and 45% DM (i.e., 10 x 0.005 = 0.05 Mcal NEL/lb.) was the same as that estimated by NRC between average normal (35% DM) and average mature (44% DM) corn silage suggesting that, the NRC model accounts for the affect of corn silage maturity. The affect of plant maturity on NEL of corn silage is dependent on hybrid. For a hybrid in which the vitreousness of the grain did not change appreciably with maturity, DE concentrations did not change appreciably but a hybrid in which vitreousness increased with maturity, DE concentrations decreased with maturity (Johnson et al., 2003). This suggests that more accurate estimates of energy from corn silage will require information regarding vitreousness. *Proposed adjustment:* Analyze the silage for standard nutrients and calculate NEL-3X. For silages with DM concentrations equal or less than 28%, set PAF at 1.00 and for every 2 unit increase in DM concentration decrease PAF by 0.015 units.

Hybrid Effects. Corn silage hybrids have been developed to have high NDF digestibility, different concentrations of nutrients (e.g., starch, NDF and fatty acids), and different physical characteristics of starch. These differences should lead to differences in NEL; however, reported differences in DE, digestible organic matter, TDN, or NEL concentrations between diets with different corn silage hybrids have been remarkably modest (from several experiments published in the Journal of Dairy Science). For example, the measured NEL concentration of a diet based on brown midrib (bmr) corn silage was the same as that for a diet based on its isogenic control when fed at ad libitum intake (Tine et al., 2001). Interactions have been found between hybrid and kernel processing, hybrid and maturity, and hybrid and diet formulation for dietary energy values. At the current time we do not have adequate data to quantify the effects of these interactions based on measurable inputs.

Kernel Processing. On average kernel processing of corn silage has little effect on energy values (e.g., DE, TDN, DM digestibility) of diets when fed to lactating cows (Bal et al., 2000; Johnson et al., 2003; Johnson et al., 2002; Schwab et al., 2002; Weiss and Wyatt, 2000). An interaction between processing and corn silage maturity has been reported (Johnson et al., 2002). In that study, diets with processed immature corn silage tended to have less DE than diets with unprocessed corn silage but processing tended to increase dietary DE with mature corn silage. *Proposed adjustment:* Inadequate data are available to determine whether kernel processing consistently reduces the energy value of immature corn but no data are available showing a benefit. More data are available showing that kernel processing usually increases the energy value of more mature corn silage (>two-thirds milk line). To obtain accurate estimates of NEL, use actual composition data, and then increase the NEL-3X of mature corn silage by 7.5% when processed. This was derived by assuming processing increased DE concentrations by 3% and that corn silage comprised 40% of the diet. Corn silage from different hybrids probably responds differently to processing but those changes cannot be quantified at this time.

Use of In Vitro NDF Digestibility to Estimate NEL

The NRC system estimates NDF digestibility using lignin but allows users to enter in vitro NDF digestibility (IVNDFD). Brown midrib corn silage generally has higher IVNDFD than its isogenic control, however when fed to lactating dairy cows as a component of a mixed diet in vivo NDF digestibility has not been consistently higher, and a diet with bmr corn silage had the same measured NEL as a diet with the isogenic hybrid when fed to

lactating cows at ad libitum intakes (Tine et al., 2001). Intake of NEL was significantly increased when bmr was fed, but energy concentration was not affected by hybrid. Beckman and Weiss (2005) found that using in situ or in vitro NDF digestibility (both 30 h) to estimate dietary DE was less accurate than using the lignin-based NRC equation in corn silage based diets that included different concentrations of soyhulls and cottonseed hulls. Although the data base is extremely limited, available in vivo data with lactating cows fed mixed diets do not support the use of IVNDFD to estimate in vivo NDF digestibility or NEL concentrations of feeds but it can be used to estimate NEL intake (higher IVNDFD = higher DMI).

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Copper Sulfate for Footbaths: Problems, Opportunities and Alternatives

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The use of copper sulfate ($CuSO_4$) in footbaths as a preventative measure for foot health has been a common practice on dairy farms for over ten years. The reasons for copper sulfate's popularity are obvious: It was (until recently, at least) low-priced, and is very effective on hairy heel warts, AKA interdigital fibropapillomas. One of the challenges of using copper sulfate is that on almost all farms the waste material from the footbaths ends up in the manure storage and soon after that, on cropland.

Local experiences – I

We didn't use copper sulfate for footbaths in the Miner Institute dairy operation until the summer of 1998. Prior to that, the copper concentration in our slurry manure was always less than 0.10 lb/1000 gallons and typically less than 0.05 lb/1000 gallons. But as soon as we started using copper sulfate in footbaths, the Cu concentration began to increase, topping out at over 0.70 lb/1000 gallons in 2000. The reason for the dramatic increase in manure copper concentrations: Our footbath protocol for 160 cows plus replacements between mid-1998 and 2000 resulted in the use of over 2 tons of copper sulfate per year, or about 3300 lbs of Cu. Forage crop removal of copper is trivial at about 0.01 lbs/acre—in our case a total of about 4 lbs of Cu per year, and milk is also very low in Cu (thankfully!), on our dairy accounting for about 4 lbs of Cu in the 4.5 million lbs. of milk we sold. Therefore, over 99% of copper imports stay on the farm, and since copper doesn't volatilize or leach, it stays where it's put—which on most farms is cropland.

Based on the rate of copper we were applying and the concentration in our slurry dairy manure, we were on the average applying about 7 lbs of Cu per crop acre per year. However, some fields received as much as 28 lbs/acre of Cu in a single year. A survey of manure analyses from the University of Vermont Agricultural Testing Laboratory confirmed that Miner Institute wasn't the only farm with high copper concentrations in its manure. While little was known about the effects on crop yield or quality of the copper in slurry dairy manure, the immediate concern was a legal one: Both the N.Y. State Department of Environmental Conservation and New England environmental regulations place a "cumulative loading limit" for copper at 74 lbs/acre. At the rate Miner Institute was using (and disposing of) copper sulfate, we would reach the loading limit in 10 years on the average field, and a lot faster than that on fields receiving higher rates of manure.

Current DairyOne Forage Laboratory (Ithaca, NY) forage analysis summaries show a gradual increase in copper concentrations for both corn silage and grass silage, beginning in the mid-1990s—coinciding with the increased use of copper sulfate on dairy farms. Forage copper concentrations at Miner Institute increased when we started to use high rates of copper sulfate, and decreased to only modestly more than original (pre-copper sulfate) concentrations when we reduced our usage rates by two-thirds.

The problems caused by copper sulfate in manure storages aren't limited to field applications; there have been reports from both Colorado and Vermont of decreased biological activity in manure storages, due almost certainly to copper sulfate additions. We also encountered this situation at Miner Institute during "the copper sulfate years" while preparing to use an experimental product intended to increase slurry pH, thereby killing E. coli and other bacteria. After sending a sample of manure from our slurry pit to Cornell University for microbial analysis we were told that it was already so low in bacteria that the product wouldn't have had the desired effect. (Analysis of fresh manure prior to additions of copper sulfate revealed normal populations of E. coli species.)

Local experiences – II

Reaching the lifetime loading limit in ten years wasn't particularly appealing, so in 2001 we reduced our frequency of copper sulfate use from 5 to 3 days per week, alternating its use with tetracycline: One week of copper sulfate and the next with tetracycline. These changes reduced our Cu use from 3300 lbs per year to about 1000 lbs. But it also increased the incidence of hairy heel warts from almost nothing to about 25%.

Therefore, in 2002 we again modified our foot bath protocol, continuing the three times per week use of copper sulfate every second week, this time alternating it with oxytetracycline. This didn't change our Cu use much at all, still about 1000 lbs/year, but hoof health definitely improved.

Our current program, begun in spring 2007, consists

of copper sulfate two days per week, changed once during each of the three daily milkings. Combined with a modest reduction in rate per footbath, his hasn't changed the total amount of Cu used, still about 1000 lbs/year, but the incidence of heel warts remains very low and the concentration of copper in our slurry manure has declined considerably. We've also increased our acres of harvested cropland, which combined with our current footbath protocol results in an annual copper application rate of about 1.5 lbs/acre. Manure Cu concentration is an easy and inexpensive way to measure Cu loading rates, though multiple manure analyses are necessary due to the (apparent) tendency of the copper to sink to the bottom of the manure storage.

Copper and forage crops: Research results

In a 2006 greenhouse trial a sandy loam soil from the Miner Institute farm was treated with 5 and 10 lbs of copper per acre as copper sulfate, plus an untreated control. Three cool-season forage grasses, timothy, orchardgrass, and reed canarygrass, were seeded at recommended rates, and the forage was harvested when there was 16" of growth for each species. The reed canarygrass harvested at a 2" cutting height didn't survive the first harvest, so results are only for orchardgrass and timothy (Table 1). Results for the two species were very similar, so the data were pooled.

Table 1. Copper treatment effects on grass growth and Cu concentration.

	0	5	10	*P*
No. seedlings	35	36	33	0.08
Harvest 1 shoots	35	36	33	0.06
Harvest 2 shoots	88	90	71	0.01
Tillering rate	53	55	39	0.05
Shoot wt g/plant	0.08	0.08	0.08	0.81
Regrowth g/d	0.18	0.19	0.15	0.08
Root dry wt. g	3.3	3.4	2.2	0.05
Tissue Cu, ppm	30	31	39	0.12

Miner Institute, 2006

The 5 lb. rate of copper had little effect on grass growth, but the 10 lb. rate significantly decreased first and second cut shoot numbers, tillering rate and root dry weight. There also was a trend toward lower regrowth rate and higher tissue copper concentration at the 10 lb. rate.

Copper and corn: Research Results

Corn was grown at Miner Institute for two years in a site that had no manure or copper applications for the previous 40+ years. Manure to which copper sulfate had been added was applied to each plot, with annual treatments of 8.1 and 16.3 lbs Cu/A plus an untreated control. Two corn hybrids (84 and 103 CRM) were planted in 30" rows; because the two hybrids performed similarly, the data were pooled.

Table 2. Copper treatment effects on corn yield, DM and Cu concentration, 2006-07

	0	8.1	16.3	*P*
Yield, T DM/A	6.4	6.8	6.8	0.48
Population/A	22,808	22,281	23,133	0.60
Harvest DM, %	36.7	37.1	37.1	0.30
Tissue Cu, ppm	4.1	3.7	3.5	0.07
Soil Cu, ppm, 0-6"	0.07	0.14	0.59	0.001

There was no apparent effect of either rate of copper application on corn yield or forage mineral concentration (data not included). We know of no explanation for the higher copper concentration in the untreated corn forage, but in all cases tissue Cu was very low. At about 4 ppm for each treatment (compared to at least 30 ppm for the grass forage), the differences certainly aren't biologically important. Perhaps a good example of the difference between statistical and biological significance?

Where do we go from here?

We can't afford to ignore the long-term effects of applying high rates of copper (via spent copper sulfate footbaths) to cropland. If, as the data in the above table indicates, a single application of about 16 lbs of copper per acre can increase soil copper concentration (Modified Morgan's extraction) from 0.07 to 0.59 ppm, what is the effect of repeated applications? (Although it should be noted that soil extraction using CaCl2 didn't find a statistically significant effect.) A field crop consultant in Western N.Y. reported several very high soil copper concentrations on fields that had been receiving repeated applications of manure containing copper sulfate. The soil test Cu level on several of these fields was so high that had the land been in British Columbia there would be restrictions on its sale for non-agricultural uses.

Alternatives to copper sulfate include zinc sulfate, antibiotics such as oxytetracycline, and formalin. Zinc sulfate has limited effectiveness on more serious heel warts, formalin is a serious health hazard, and antibiotics usually work better when included as a part of a multi-faceted treatment program. Copper sulfate, either in footbaths or as a topical application, will continue to be popular on many dairy farms. We still use copper sulfate at Miner Institute but at a reduced frequency of use, and by combining this with improved hoof care, hairy heel warts are no longer a significant problem in our dairy herd. Many of the legal issues surrounding the use of copper sulfate in dairy footbaths are yet to be dealt with. In at least one state (New Mexico), use of copper sulfate in milking parlors is a violation of the farm's wastewater discharge permit, and New Mexico State University discourages its use on dairy farms. There are a growing number of commercial products on the market, several which appear to have promise. However, what is lacking in most cases is independent research evaluating their effectiveness.

Burping Can Be Dangerous If You Are A Ruminant: Issues With High Sulfur Diets

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Introduction

Rumen microorganisms and the host ruminant animal require many macro and micro minerals for normal growth and development. Among these minerals, sulfur is a necessary component of the amino acids cystine and methionine that are building blocks of proteins. In ruminants, many inorganic forms of sulfur (e.g. potassium sulfate and calcium sulfate) can be used because sulfate is reduced in the rumen to sulfide by a group of bacteria referred to as the sulfur reducing bacteria and subsequently incorporated into microbial protein. However, excess production of sulfides in the rumen may be detrimental because high levels can cause polioencephalomalacia (PEM) (Lowe et al., 1996; Gould et al., 1991; McAllister et al., 1992). Polioencephalomalacia is a disease condition characterized by necrosis of the cerebrocortical region of the brain. A thiamine deficiency has been the most common cause of PEM in ruminants. Excess sulfur or sulfate in feed or water has been the second most reported condition associated with PEM. Consumption of excess lead (Christian and Tryphonas, 1971) and water deprivation (Sullivan, 1985) can result in the disease in some instances. High sulfur diets was the topic of a recent symposium at the 2008 ASAS Midwestern Section Meetings (http://ars.sdstate.edu/extbeef/). The objective of this paper is to review the relationships between the intake of high sulfur and PEM, and to discuss potential methods for control.

Sulfate Metabolism in the Rumen

Sulfur reducing bacteria (SRB) in the rumen utilize anaerobic respiration pathways for bioenergetic processes. The distinction between aerobic and anaerobic respiration is determined by the nature of the final reduced compound. In the process of aerobic respiration, electrons produced from reduced compounds are coupled to the reduction of oxygen, however, in anaerobic respiration electrons from oxidative reactions are used to reduce a variety of different compounds, e.g. SO_4-, NO_3-, or CO_2 (Liamleam and Annachhatre, 2007). Of particular interest is the reduction of SO_4- (sulfate). The SRB are grouped by the mechanism used to reduce sulfates; either an assimilatory process, or a dissimilatory process. In general, the dissimilatory reduction of sulfur compounds is used for energy production, while the assimilatory process reduces sulfur compounds for the incorporation of the sulfur into other biological compounds necessary for cell survival (Odom and Singleton, 1993). In the rumen, SRB from both the assimilatory and dissimilatory groups exist, and the latter are responsible for the reduction of sulfur to hydrogen sulfite and hydrogen sulfide. Although many bacteria can produce sulfides, organisms from the Desulfovibrio and Desulfotomaculum genus are most likely the predominant sulfate-reducing bacteria in the rumen (Cumming et al., 1995b).

In the rumen, the extent of dissimilatory sulfate reduction is proportional and limited to the amount of sulfur containing compounds. The sulfide compounds that are predominantly formed in the dissimilatory process are S_2-, S^o, HS-, or HSO_3- (Odom and Singleton, 1993). The pKa values for these compounds are around 7.0 (the pKa for H2S is 7.2). Because the pH range of a normal rumen is between 5.5 and 7.2, these reduced forms of sulfide are readily protonated. For this reason, most of the sulfide present in the rumen is found in the gas phase as hydrogen sulfide (H2S), and a small amount is left in the liquid phase in a variety of sulfide containing compounds.

Under normal feeding conditions, Hungate (1966) suggested that if equilibrated with rumen fluid, H2S concentration in ruminants was 0.1 umol per milliliter. High concentrations of sulfides in ruminal fermentations have been reported in vivo (Gould et al., 1997) and in vitro (Hession et al., 1995). The activity and dynamics of the sulfate-reducing bacteria in the rumen have been studied less than other major groups of bacteria, such as the cellulolytics and methanogens. Cummings et al. (1995a) did not detect a change in numbers of ruminal sulfate-reducing bacteria as percentages of sulfur in the diet increased. However, after being exposed to high levels of sulfur, ruminal organisms did have a greater capacity to produce sulfide after 10 to 12 days. Oliveira et al.

(1997) reported that high dietary sulfur resulted in a faster rate of sulfate reduction by ruminal bacteria after several weeks on that diet. Both reports are evidence that adaptive mechanisms for the increased activity by sulfate-reducing bacteria exists.

Added sulfur has improved ruminal fermentations, but only when the diet was deficient in this mineral. For example, Hegarty et al. (1994) reported improved dry matter digestion, increased total volatile fatty acids concentration, and more bacteria in the rumen of sheep fed a high versus a low sulfur diet (< 0.25%, dry matter basis). Patterson and Kung (1988) reported that added sulfur (0.3% of the dry matter) from methionine, methionine hydroxy analog, or sodium sulfate improved cellulose digestion threefold in in vitro fermentations that were void of sulfur. Moderately high percentages of sulfur (0.4 to 0.6%) in the diet have generally had no effects on ruminal volatile fatty acids and ammonia-nitrogen concentrations. However, the effect of extremely high percentages of sulfur (> 1% of the DM) in the diet of ruminants is equivocal. Kahlon et al. (1975) reported that 1.3% sulfur in the diet inhibited microbial protein synthesis in the rumen, but Kennedy et al. (1986) reported that a similar percentage of sulfur was not toxic to ruminal microorganisms. In calves, dietary sulfur as high as 1.72% had no effect on ruminal VFA or ammonia-nitrogen relative to calves consuming a diet with 0.34% sulfur (Slyter et al., 1988). Certainly, the biological availability of the sulfur source, ruminal pH, and interactions with dietary nutrients, such as divalent cations, may explain some of the conflicting results.

Sulfur Toxicity

In monogastrics, sulfur is relatively inert and can therefore be tolerated at relatively high levels. However, in ruminants, the ingestion of large amounts of sulfur can lead to acute sulfur toxicosis and death. The immediate signs of distress include thrashing, kicking at stomach, staggering, and moaning followed by subsequent death within 48 hours suggesting a fairly high capacity to produce sulfide without the need for adaptation. High concentrations of sulfide in ruminal gas have been reported (McAllister et al., 1992) and have resulted in respiratory distress, reduced feed intake, and reduced ruminal motility (Bird, 1972).

Sulfide is readily absorbed through the rumen wall into the blood stream (Bray, 1969). Once absorbed, sulfide inhibits the functions of carbonic anhydrase, dopa oxidases, catalases, peroxidases, dehydrogenases, and dipeptidases, adversely affecting oxidative metabolism and the production of ATP (Short and Edwards, 1989). Specifically, sulfide is also thought to block the enzyme cytochrome c oxidase. Sulfide also binds to hemoglobin creating sulfhemoglobin, reducing the ability of the blood to carry oxygen to tissues. In addition, sulfide also has a paralyzing effect on the carotid body and therefore may also inhibit normal respiration (Bulgin et al., 1996).

Bulgin et al. (1996) recently reported acute reactions in response to increased levels of ingested elemental sulfur in sheep. These animals had grazed on an alfalfa field that had been sprayed with elemental sulfur (60 kg/ha). Within two hours after being released onto this field, some of the animals began to show signs of distress, and quickly died. Upon necropsy, it was noted that the rumen pH was 6 - 6.5, there was an odor of rotten eggs, lead acetate paper blackened when exposed to rumen contents, and pulmonary edema was observed. Immediate deaths were probably from acute sulfide toxicity.

Role of Thiamine in Occurrences of PEM

Occurrences of PEM have been observed in animals which have access to plants containing high amounts of thiaminase, e.g. bracken fern (Merck, 1993), and in animals exhibiting thiamine deficiency (Gooneratne et al., 1989a; Olkowski et al., 1992). Lesions in affected brain tissue autofluoresce under UV light when prepared for histological observation. Clinical symptoms consist of blindness, head pressing, and circling, followed by recumbency, opisthonos, convulsions, and eventually death (Merck, 1993). Because thiamine is a necessary cofactor in the tri-carboxcylic acid cycle and the pentose shunt, lesions are seen in tissues of which these processes are vital to cell survival, in particular, the tissues of the brain and heart (Merck, 1993). An abrupt change in diet from forage to concentrates has also been suggested to affect thiamine status in ruminants (Merck, 1993). Levels of thiamine decrease because there is a shift in the rumen microflora. Gram positive bacilli, Gram negative cocci, and coccobacilli predominate, producing elevated levels of thiaminase type I activity. Thiaminase type I is deleterious for two reasons. First, it destroys thiamine and secondly, the actual destruction of thiamine produces a thiamine analog that inhibits the thiamine-dependent reactions of glycolysis and the tri-carboxcylic acid cycle (Brent and Bartley, 1984). In each of the ATP - producing, catabolic pathways, thiamine is a necessary cofactor. This cofactor (thiamine pyrophosphate or TPP) is necessary for the enzymatic actions of the alpha- ketogluturate and pyruvate dehydrogenase complexes in the tri-carboxcylic acid cycle. Olkowski et al. (1993) reported on thiamine destroying activity of ruminal fluid but Oliveira et al. (1997) could not demonstrate a negative effect of a high concentrate diet on thiamine metabolism.

Administering thiamine has been used as a treatment for some cases of PEM and as a

prophylactic agent against PEM (Merck, 1993; Low et al., 1996; and Olkowski et al., 1992). With the administration of thiamine other micronutrients should be considered. Gooneratne et al. (1989b) hypothesized that there is an interaction in the rumen between copper, sulfur, and thiamine. They suggested that, in the presence of excess sulfur, the addition of copper forms copper sulfate precipitates in the rumen, keeping the sulfur from maintaining its antagonistic relationship with thiamine. Olkowski et al. (1992) also suggests that elevated levels of thiamine are necessary to protect tissues from the clinical signs of sulfur toxicity, namely brain edema. In this scenario, thiamine would protect cells by decreasing the activity of the ATP-dependent sodium pump, and in this way maintaining osmolar balance.

High Sulfate Associated PEM

The National Research Council suggests that ruminants should not be fed more than 0.4% sulfur (DMB) to prevent reductions in intake (NRC, 1987). However, Bouchard and Conrads (1976) suggest that this level should not be higher than 0.26% for lactating cows. If high levels of sulfur inhibit intake, extreme caution should be taken during the close-up and early lactation stages of lactation where DM intake is lower than desired. Some common feeds and minerals that have moderate to high levels of sulfur are shown in Table 1. For example, corn gluten meal, molasses (cane and beet) and Brassicas (e.g., turnips) are high in sulfur. Other feeds worthy of mentioning that contain high concentrations of sulfur include fish, feather, meat and blood meals, that are common sources of rumen undegradable intake protein. Water can also be very high in sulfates with levels in excess of 5,000 ppm (Veenhuizen et al., 1992). Digesti and Weeth (1976) suggested that it was safe for cattle to consume water containing 2,500 ppm of sulfate. Recently, Wagner et al. (1998) reported lower intake and gains in steers fed water with 2,000 ppm sulfate (Table 2). Average daily gain was lower and feed efficiency was worse with increasing amounts of sulfate in water. Moderately high amounts of sulfur or sulfate consumption have resulted in reduced animal performance without acute symptoms of acute sulfur toxicity. For example, many years ago, in Cuba, cattle fed diets rich in molasses (and high in sulfur) developed symptoms of PEM and that were not responsive to thiamine. Feeds that are acidified with sulfuric acid as a preservative (H2SO4) and minerals (e.g. those used during balancing for DCAD balance during the dry period of dairy cows) also have high sulfur concentrations. One can easily envision a rather normal diet with alfalfa hay, beet pulp, distiller's grains and other feeds that would approach the upper limit of maximum sulfur intake. Coupled with a source of water with a high level of sulfate, this could easily lead to excessive sulfur consumption. Symptoms of PEM have been induced in cattle consuming diets with 0.4% (Gould et al., 1991) sulfur but in some studies calves have been fed more than 1.5% sulfur without signs of toxicity (Slyter et al., 1986). In younger animals, development of rumen microflora and size of the rumen may affect responses to high sulfur.

Table 1. A listing of some feeds with moderate to high sulfur content.

Feed	International Feed Number	Sulfur, % dry matter basis
Alfalfa hay, early bloom	1-00-059	0.28
Barley malt sprouts, dehydrates	5-00-545	0.85
Beet pulp, w/molasses, dehydrated	4-00-672	0.42
Brewers grains, wet	5-02-142	0.32
Corn, distillers grains, dehydrated	5-28-237	0.46
Corn gluten meal, 60%	5-28-242	0.72
Molasses, beet	4-00-668	0.60
Molasses, cane	4-04-696	0.47
Rapeseed meal	5-03-871	1.25
Whey, dehydrated	4-01-182	1.12
Turnip, root	4-05-067	0.43
Ammonium sulfate	6-09-339	24.10
Calcium sulfate	6-01-089	18.62
Copper sulfate	6-01-720	12.84
Potassium sulfate	6-06-098	17.35
Sodium sulfate	6-04-292	9.95

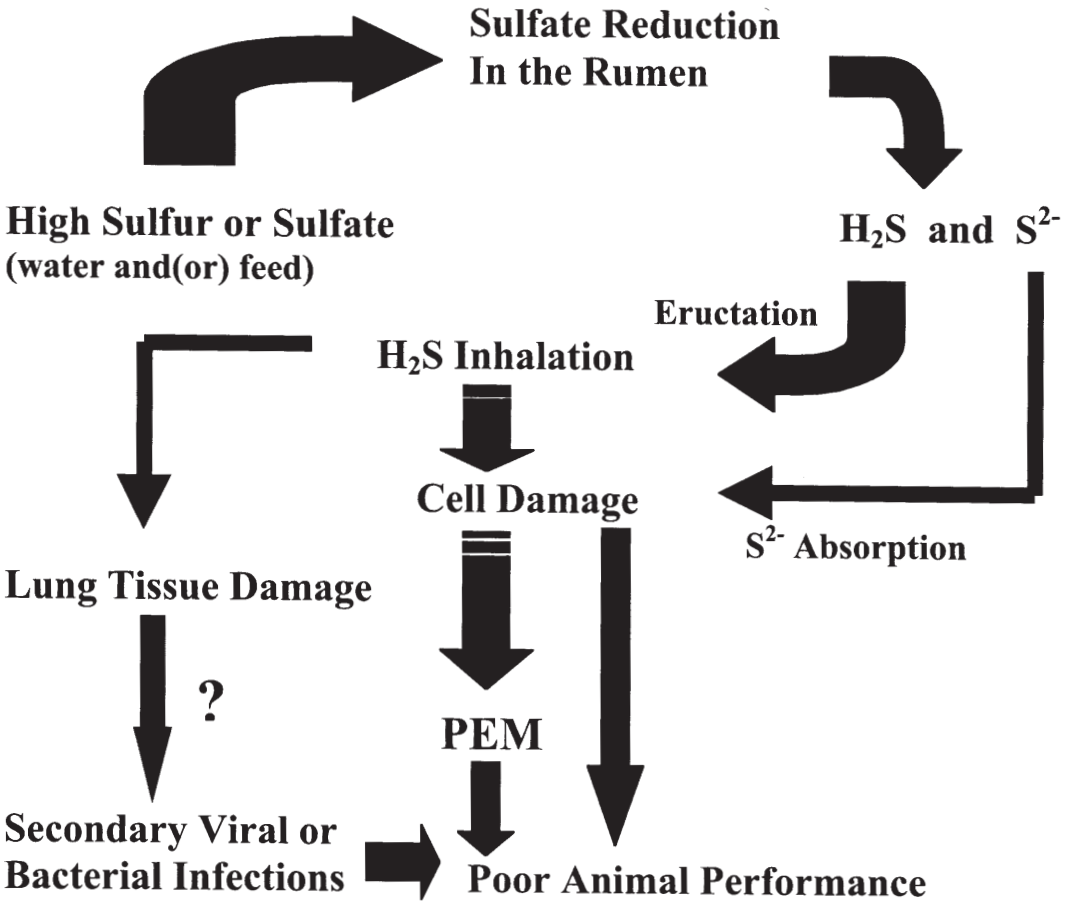
Table 2. Effect of sulfate content in water on performance of steers.

	Sulfate Concentration in Water (ppm)				
Item	125	250	500	1000	2000
DMI, kg/d	9.83	10.78	10.34	9.84	9.93
ADG, kg/d	2.15	2.11	2.14	2.10	2.04
Feed efficiency, DMI/gain	4.58	5.11	4.83	4.69	4.86
Water, liters/d	33.6	34.8	31.6	31.9	29.7

Wagner et al. 1997.

In ruminants, eructation (belching of gasses) is a normal process. However, as much as 60% of eructated gasses are inhaled and enters the respiratory tract (Bulgin et al., 1996). Thus, inhalation of H2S from diets high in sulfate has been implicated as a potential cause of PEM in ruminants. Exposures to higher concentrations of hydrogen sulfide (200 to 500 ppm) has resulted in the sudden onset of hemorrhagic pulmonary edema that often ends in death in humans (Green et al., 1991). Although little direct evidence exists, an association between inhaled H2S and respiratory diseases in ruminants cannot be dismissed. Because H2S is so toxic (Truong et al. (2006), damage to lung tissue could predispose animals to secondary bacterial or viral infections even if clinical symptoms of PEM do not exist. Some proposed mechanisms for high sulfate induced problems in ruminants are shown in Figure 1.

Figure 1. A proposed mechanism for high sulfate induced polioencephalomalacia.



Some controversy exists as to whether sulfide is the primary cause of sulfur- induce PEM because in some cases high levels of sulfur have been implicated in decreased levels of thiamine (Brent and Bartley, 1984). Animals fed a high sulfur diet were protected from clinical signs of PEM, while still exhibiting the clinical lesions of PEM (Olkowski et al., 1992). Excess sulfur may decrease the levels of thiamine, either through the direct action or through the stimulation of the production of thiaminase, or both. It has also been suggested that the transient sulfite that is produced during the reduction of sulfate to sulfide, could have a direct impact on the brain tissue itself (Oliveria et al., 1996; Brent and Bartley, 1984; Olkowski et al., 1992). Sulfite-derived radicals have been postulated to cause lipid peroxidation and damage to biological membranes. Because of the high lipid content of the brain, and its inability to be efficiently repaired, it becomes apparent why lesions are first seen in this tissue (Olkowski et al., 1992). Brent and Bartley (1984) suggested that sulfite can cleave thiamine at the methylene bridge. However, Oliveria et al. (1996) proposed that sulfite is not a large contributor to thiamine destruction because sulfite is transitory and therefore it does not accumulate in the rumen. Olkowski et al. (1992) suggested though, that sulfite may be a significant contributor because the sulfite produced is absorbed, oxidized to sulfate, and then recycled back to the rumen, available to be reduced again.

Table 3. Some references to outbreaks of high sulfur associated PEM.

Citation	Symptoms	Diagnosis
Kul et al., 2006	256 cattle died or slaughtered with signs of PEM.	PEM in cattle consuming barley malt sprouts. Total S content in diet was 0.45%.
Loneragan et al., 1998	16 of 150 calves on ranch A and 30 of 4,000 calves on ranch B with clinical signs of PEM.	PEM in calves consuming feeds with high S: grass hay (0.33% S), Canada thistle (0.9% S), turnips (0.63% S) and rape (0.91%S).
McAllister et al., 1997	Steers in a feedlot with visual impairment and ataxia. During hot summer months the incidence of PEM was 0.88%.	PEM in cattle drinking water containing 2,200 to 2,800 ppm sulfate corresponding to about 0.67% sulfur intake.
Hill and Ebbett, 1997	26 of 99 grazing heifers with signs of ataxia, recumbency, and blindness.	PEM in heifers consuming Brassica oleracea that contained 0.85% sulfur.
Bulgin et al., 1996	700 of 2,200 ewes with signs of incoordination and abdominal discomfort, death.	Sulfur toxicity and PEM from field acidified with 35% suspension of elemental sulfur.
Low et al., 1996	21 of 71 lambs with depression, blindness head pressing, and death.	PEM. Lambs consumed a diet with 0.43% sulfur for 15 to 32 days before symptoms appeared.

Some recent cases of high sulfur associated PEM are shown in Table 1. In the majority of studies reported in Table 3, thiamine status was normal and when administered, supplemental thiamine did not always solve the problem. In a group of potential animals, the incidence of PEM is very low even when animals display clinical symptoms. Data in the literature would also suggest that when sulfur levels are moderately high, an adaptive process takes place so that PEM is not manifested until 2 to 4 weeks after the beginning of consumption of high levels of sulfur. Gould et al. (1997) reported on the use of rumenocentesis coupled with the analysis of rumen gas for H2S and suggested that this may be a useful method for measuring pathological concentrations of H2S. Under controlled conditions, researchers have smelled the odor of H2S on the breath of cattle (Gould, personal communication).

Inhibiting Sulfide Production

Production of sulfides has deleterious effects in many biological and non-biological systems. For example, iron and steel structures are prone to corrosion in the presence of sulfides (Odom and

Singleton, 1993). In the work place, the presence of hydrogen sulfide gas at low concentrations (50 - 200 ppm) is an irritant to the human respiratory tract, and at higher concentrations (200 - 500 ppm) it can cause hemorrhagic pulmonary edema that is often fatal (Green et al., 1991).

Broad - spectrum biocides such as hypochlorite (Odom and Singleton, 1993), methylenebis thiocyanate (Zhou and King, 1995) and gentamicin (Tanimoto et al., 1989) have been used to control sulfide production from sulfate-reducing bacteria in industrial situations. For ruminants, balancing dietary ingredients to ensure optimal amounts of sulfur in the diet can be easily done. However, there are few options to choose from when faced with a source of water high in sulfate. Treating water by means of reverse osmosis is an expensive proposition. Most, if not all, biocides would be impractical to use in ruminant diets because of their broad antimicrobial spectrums that would have negative impacts on ruminal fermentation. In addition, many of these compounds would be highly toxic to the animal.

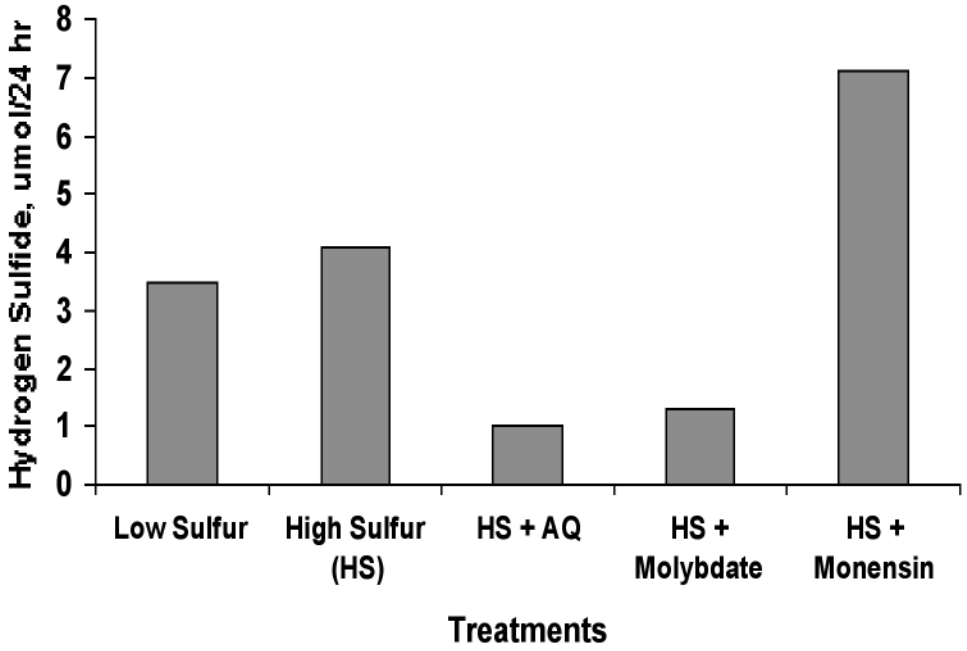
Rumen microbial populations have been manipulated in order to produce more desirable end products (e.g. VFA and microbial protein) and less undesirable end products (e.g. methane and hydrogen). The majority of non-ionophore antibiotics and ionophores administered to ruminants are effective against Gram-positive bacteria (Nagaraja, 1995). Since SRB are Gram-negative, we would not expect direct effects of these compounds on inhibiting sulfide production. However, indirect effects could occur. For example, one proposed mode of action of the ionophore monensin is that it selects against hydrogen and formate producing bacteria such as Ruminococcus albus, Ruminococcus flavefaciens, and Butyrivibrio fibrisolvens (Chen and Wolin, 1979) resulting in an indirect inhibition of methanogens that require hydrogen as a substrate. Selective targeting of sulfate-reducing bacteria may be a method to reduce excess sulfide production in the rumen.

In the literature, we have been able to identify only a few compounds that appear to be relatively specific for inhibiting sulfate-reducing bacteria that may be acceptable for use in ruminants. For example, molybdate (MoO4) has been proposed as an analog of sulfate that blocks the sulfate activation step that is catalyzed by ATP sulfurylase (Oremland and Capone, 1988). Taylor and Oremland (1979) showed that MoO4 specifically inhibits sulfate-reducing bacteria in pure culture and other investigations have also shown that MoO4 inhibits sulfate-reducing bacteria in sediments (Oremland and Silverman, 1979; Sorenson, et al., 1981). However, MoO4 may not be specific to inhibiting sulfate-reducing bacteria as Jones et al. (1982) demonstrated that MoO4 inhibited methanogenesis when sulfate was limiting. In contrast, Westerman and Ahring (1987) demonstrated that low levels of MoO4 (1 mM) slightly stimulated methane production. In light of these conflicting results, some have recommended caution in using MoO4 in ecological situations (Banat, et al., 1981; Jones, et al., 1982; Jacobson, et al., 1987). Odom and Singleton (1993) also suggested that although MoO4 was a useful research tool, its use as a commercial biocide was impractical because of the potential negative ecological impact. We have shown that molybdate (> 10 ppm of the fluid) can reduce H2S production in ruminal fermentations (Bracht and Kung, 1997). At concentrations that we tested (maximum of 25 ppm of the fluid) we observed no effect of molybdate on rumen VFA, methane or hydrogen. This amount of MoO4, caused a depression in both the liquid and gas sulfide and a slight decrease in total VFA, but no changes in any other culture conditions. Under our conditions, MoO4 appeared to be a specific inhibitor of sulfate-reducing bacteria because we found no effect on methane or hydrogen production. In ruminants, molybdenum is a trace mineral with a very narrow margin between the amount needed to fulfill the animal's requirements and toxic levels. Underwood (1981) reported that in cattle, molybdenum is toxic in the range of 20-100 ppm on a dry matter basis. However, Huber et al. (1971) reported that lactating dairy cows showed no signs of toxicity when fed a diet containing 100 ppm of molybdenum (1.7 g/d) for 6 months but toxicity occurred when cows were fed 200 ppm molybdenum. Intake of 1.7 g of molybdenum in a 625-kg cow with an 85-liter rumen would equate to a rumen concentration of 20 ppm, which is similar to the amount of MoO4 used in our study. Recently, Loneragan et al. (1998) reported that sodium molybdate was capable of reducing H2S concentrations in the gas cap of cattle fed a high sulfur diet, but the effect was not consistent for all cattle, and liver stores of Cu decreased dramatically.

The compound 9,10 anthraquinone (AQ) was first reported by our lab as a methane inhibitor in in vitro ruminal fermentations (Garcia-Lopez et al., 1996). We subsequently have reported the ability of AQ to also inhibit sulfate reduction in the rumen (Hession et al., 1995; Kung et al., 1996; Bracht and Kung, 1997, Kung et al., 1998). In Figure 2, addition of 10 ppm (fluid basis) of AQ reduced sulfide production in a diet containing 1.09% sulfur to levels below that found in a diet with only 0.29% S. Cooling et al. (1996) reported inhibition of sulfide production using 9,10 anthraquinone due to possible uncoupling of the electron transport chain. Decreased levels of ATP results in insufficient energy, which is needed for subsequent activation of sulfate for further sulfate reduction. Cooling et al. (1996) proposed that the uncoupling is due to the redox capabilities of anthraquinones. In our in vitro studies, we

surprisingly have found that monensin stimulated sulfide production in in vitro ruminal fermentations (Figure 2). The reasons for this finding are unknown but indirect inhibition of methanogens by monensin may decrease competition between methanogens and sulfate-reducing bacteria because both classes of organisms can utilize some common substrates such as acetate and H2. This finding may have far reaching implications because monensin is widely used in the feedlot. In vivo studies are needed to verify our initial findings.

Figure 2. Effect of high sulfur and various compounds on in vitro ruminal hydrogen sulfide production. Low sulfur = 0.29% S; Hig sulfur = 1.09% S. AQ = 10 ppm (fluid basis) of 9,10 anthraquinone; Molybdate = 25 ppm of molybdate; Monensin = 5 ppm. (Data from Bracht and Kung, 1997.)



In a recent publication, McAllister et al. (1997) reported that the incidence of PEM cases in a feedlot in Colorado was seasonal and related to days in the feedlot. The incidence of PEM peaked between 15-30 d after cattle had entered the feedlot and during summer months. Several factors could have contributed to these findings. First, increased consumption of water, high in sulfate, during hot summer months, coupled with increasing adaptation to high sulfur intake by sulfate-reducing bacteria in the rumen probably increased levels of H_2S in rumen of these cattle. Furthermore, the proportion of concentrate in the diet of incoming cattle was probably increased during the first 4 weeks in the feedlot. As the proportion of concentrate in the diet increased, rumen pH would decrease resulting in a greater proportion of sulfide to be protonated since the pka for H_2S is 7.2. In addition, we hypothesize that another contributing factor to high levels of H_2S production could be the fact that intake of monensin is also gradually increased during the first several weeks in the study. In our studies (Bracht and Kung, 1997), adding monensin to in vitro ruminal fermentations exacerbated H_2S production.

Conclusions

Many incidences of high sulfate-associated PEM that were independent of thiamine metabolism in ruminants have been reported in the last several years. Many common feeds and sources of water can contain high levels of sulfur/sulfate. Producers should be aware of all possible sources of sulfur in the diet. Although the incidence of clinical PEM is generally low, subtle decreases in intake and possible associations with respiratory diseases could be decreasing animal performance. More research is needed to study the association between high levels of sulfur in the diet and reduced animal performance in ruminants and to develop strategies to combat high sulfate-induced PEM.

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Understanding TMR Particle Size and the Effects on the Lactating Dairy Cow

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Introduction

Differences in feed particle size have long been known to affect milk production of lactating dairy cows (Cole and Mead, 1943). Over the past 10 years, several aspects which contribute to this effect have been more clearly established. Furthermore, the development of the Penn State TMR and Forage Particle Separator (**PSPS**) has facilitated practical application of these new understandings. Specific progress has been made in understanding the effects of ration particle size on feeding behavior, chewing activities, rumen fermentation and how these affect milk production and composition. The purposes of this paper are to highlight and discuss some of these recent findings and to underscore the importance of measuring TMR particle size.

Measuring Particle Size, The Penn State Particle Separator

The Penn State Particle Separator was originally introduced in 1996 (Lammers et al., 1996) and, largely because of the simplicity of the procedure, low cost of analysis and rapid determination of results, has become a routinely used device in particle size evaluation. The original device was constructed out of two sieves measuring 19.0 and 8.0-mm and was based on the S424 standard of the American Society of Agricultural Engineers (ASAE). Even though the original apparatus was widely accepted by nutritionists, TMR's typically contain 40 – 60% concentrate, most of which pass through the 8.0-mm sieve. As a result, an additional sieve containing a pore size of 1.18-mm was developed and is now used to more accurately describe the smaller particle fraction of TMR's (Kononoff et al., 2003a). The pore size for this sieve was selected because it is suggested that 1.18-mm is a critical length governing retention in the reticulo-rumen (Poppi et al., 1985).

Although no recommendation may apply adequately to all feeding systems, Table 1 outlines forage and TMR particle size recommendations according. When evaluating a TMR, the proportion of material retained on the top screen, or ≥ 19.0-mm is often considered. This is because the intake of DM from this portion of the diet is known to be positively correlated with ruminating activity and has been demonstrated to be negatively correlated with time rumen pH is below 5.8 (Kononoff and Heinrichs 2003a, b; Krause et al., 2002). The current recommendations indicate that the amount of TMR retained on the top screen of the PSPS is 2 - 8 % (Heinrichs and Kononoff, 2002). This recommendation is based on the collective observations of a series of experiments that evaluated diets within a wide range of particle lengths. The addition of the sieve measuring 1.18-mm allows a more accurate description of sample fineness, and a more accurate estimate mean particle length (MPL). As already noted, in some cases it might be impractical to feed rations that fall within the recommended range, such as the case when dry forages are incorporated into the TMR. In these cases, sorting activity may be avoided by management techniques such as increasing the frequency of feeding, pushing up feed frequently, or through the addition of water (Armentano and Leonardi, 2003).

Ration Particle Size and Feed Sorting Behavior

Employment of feeding and management strategies aimed to promote maximal feed intake, are critical in order to realize optimal milk production levels. In doing so, it is important to understand the diurnal feeding pattern of animals. Feeding patterns may be affected by a variety of nutritional and management factors. Cows usually consume their largest meals during the late night and early morning hours (DeVries et al., 2003 a, b). Lactating dairy cattle may spend 3 – 5 hours per day and consuming 8 – 14 meals per day (Grant, 2003). It is generally understood that increasing the particle size of forages results in an increase the amount of time spent eating and ruminating. It may also affect the nature of feeding behavior. In normal feeding patterns there is a consistent supply of nutrients into the rumen which leads to a constant environment for bacterial growth. Alternatively, if ingestion is rapid or selective, large diurnal variation in acid production and ruminal pH may result (Van Soest, 1994).

The PSPS has been used to evaluate feed sorting behavior of lactating dairy cows (Kononoff et al., 2003 b and Devries et al., 2007). There is increasing evidence that the amount of material retained on the 19.0-mm sieve of the PSPS is best correlated to sorting behavior and chewing activities (Johnson et al., 2003; Krause et al., 2002). It is likely that as ration particle size increases, so does the amount of time feeding and chewing. However the relationship

between particle size and chewing activity is not completely linear because coarse, longer, high fiber containing particles are easier for animals to select against, a situation which may also greatly affect rumen fermentation. Figure 1 illustrates the effects of corn silage particle size on the concentration of NDF remaining in the feedbunk over a 24 h period (Kononoff et al., 2003b). In this study diets were similar in NDF content but contained increasing amounts of material ≥ 19.0-mm. Animals consuming the diet of longest particle size refused more fiber particles, as demonstrated by the highest NDF content in the refusals. DeVries et al. (2007) evaluated the effects of sorting behavior in diets differing in forage to concentration (62:38 versus 51:49) ration and NDF content. As in previous experiments cows sorted mostly against particles ≥ 19.00mm. Surprisingly, cows consuming the low forage diet exhibited a greater degree of sorting against large particles and NDF. Clearly this behavior increases the risk of rumen acidosis. This research also suggests cows may not always regulate feeding based on their needs, and this underscores the importance of a well balanced ration.

Although reduction in chop length or particle size is one method that may reduce sorting activity, mechanical processing of corn silage has also been observed to be effective. In a study designed to evaluate the effects of feeding either processed or unprocessed corn silage, Ebling and Kung (2004) noted a high degree of sorting 18 and 24 hours after feeding. Although no deleterious effects were observed in feeding unprocessed corn silage, this was likely due to the relatively fine TMR fed (i.e. less than 10% was ≥ 19.0-mm). It should be noted that even if TMR's contain unprocessed corn silage, extensive sorting activity is usually not observed if the particle size is close to recommended ranges listed in Table 1. Thus, although finely chopping or processing corn silage increases the power requirements and harvesting costs, studies demonstrate that these practices reduce sorting behavior of dairy cattle.

Effective Fiber and Rumen Fermentation

For dairy nutritionists, NDF is the most commonly employed method to measure fiber (Mertens, 1997). The cow's need for long, coarse fiber from forage has long been recognized. This coarse fiber portion of the rations is believed to be *effective* in stimulating chewing activity and salivary buffer production that acts to buffer the rumen and maintain an optimal environment for rumen microbes. This idea has given rise to the term *effective* fiber even though measurement of this entity may be defined differently. Conversely, feeding rations low in fiber and of short particle size will decrease chewing activity, salivary buffer secretion, ultimately lowering rumen pH, rumen acetate production and milk fat percentage. Feeding diets low in effective fiber may precipitate and contribute to the cascade of factors associated with ruminal acidosis; but the interactive effects of dry matter intake, digestibility, ration nonstructural carbohydrate levels, and feeding behavior must also be considered. Unfortunately in many studies it is difficult to draw a clear link between peNDF and rumen pH. This is often the case when peNDF is decreased as grain is added to the diet. In this case, particle size is reduced but the portion or readily digestible carbohydrate is increased. Here rumen pH is almost always reduced but this may be a function of reduced saliva flow and increased VFA production with the later likely having the greatest effect.

The particle size and effective fiber recommendations for lactating cows was considered by the last NRC (2001) committee by they concluded that there was, "lack of standard, validated methods to measure effective fiber of feeds or to establish requirements for effective fiber limits application of this concept. The committee did not make a specific recommendation for measuring effective fiber but did including the suggestion of the NRC (1989) that lactating cow diets should contain at least 25% NDF with 19% NDF from forage.

The concept of physically effective NDF (peNDF) has been proposed to estimate the NDF portion of the diet that stimulates chewing activity and possibly the formation of the rumen mat (Mertens, 1997). A framework for routine measurement of ration peNDF concentration has also been proposed by Mertens, (1997). The peNDF content of an individual feed is calculated as the product of the NDF concentration and the physically effectiveness factor. Mertens (1997) has proposed that this factor may be estimated by measuring the proportion of dry matter retained on a 1.18-mm sieve after the sieve is vertical shaken and multiplying this by the NDF content. The 1.18-mm sieve was chosen because particles > 1.18-mm are believed to be resistant to passage out of the rumen (Poppi et al., 1985). Mertens (1997) has suggested that a TMR should contain a minimum of 22 % peNDF to adequately stimulate the amount of chewing activity required to maintain an average rumen pH of greater than 6.0. This system of has been adopted by a number of ration balancing programs including the Cornell Net Carbohydrate and Protein System and the CPM Dairy Model. Recently this index was re-evaluated using a dataset that contained data collected since 1997 (Zebeli et al., 2008). Results of this study were similar to that of Mertens (1997) in that a curvilinear response in pH is observed with increasing levels of NDF. However maintenance of rumen pH at 6.0 was observed to occur at a slightly lower level of peNDF (19.5 versus 22%). Another method to estimate the physically effective value is to sum the amount of dry matter retained on the 19.0

and 8.0-mm sieves of the PSPS (Beauchemin et al., 2003). An additional approach is to avoid an index system and simply evaluate effective fiber levels by considering the NDF content and particle size of the TMR separately.

TMR Particle Size, Feed Intake and Milk Production

The effect of forage and TMR particle size on feed intake is not always consistent. Difficulty in interpreting the response of particle size on DMI may in part be due to digestibility and specific gravity, factors independent of feed particle size. When detected, intake response to reduced forage particle size is usually positive with the magnitude depending upon the extent of particle size reduction as well as the type and digestibility of the forage fed (Kusmartono et al., 1996; Heinrichs and Kononoff, 2002). In summarizing 58 studies Zebeli et al (2008) noted that the relationship between DMI and peNDF is poor. However in this study it was clear that when peNDF measures were in recommended ranges (i.e. > 21%) increasing peNDF had a negative effect on feed intake and milk yield.

Increased feed intake is also observed when the particle size of the TMR is reduced with the increased inclusion of common byproduct feeds such as dried distillers grains plus solubles. An example of this was a study conducted by Janicek et al., (2008) in which DDGS were increased from 0 to 30% of the diet DM. In this experiment, the proportion of particles > 19.0-mm were reduced from 8 to 5% and the proportion of particles between 8.0-19.0mm were reduced from 37 to 27%, and an increase of both feed intake and milk yield were noted.

Summary and Conclusions

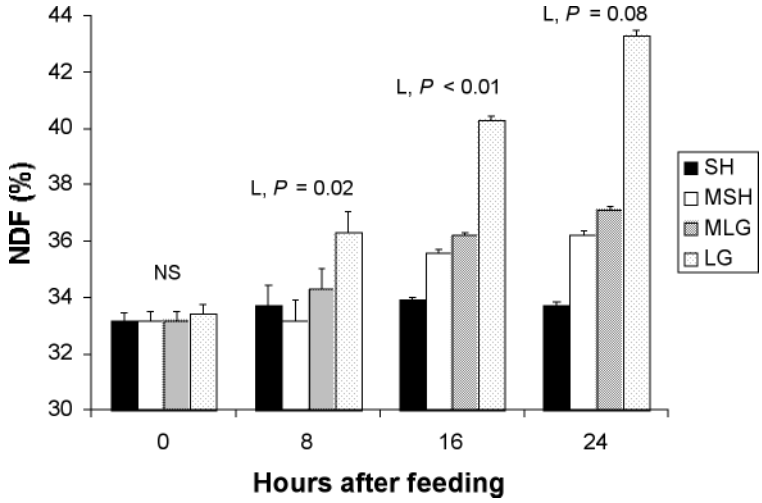
Ration particle size can be measured on-farm using PSPS. Reducing particle size may reduce the proportion of effective fiber in rations, and this may negatively affect rumen pH which may be problematic when peNDF is below 19.5%. Rations containing a greater proportion of longer forage particles (≥ 19.0-mm) are likely to have a larger difference between the feed originally offered and that consumed throughout the day due to sorting activity. Although chewing activity is closely related to particle size and may moderate effects on rumen pH (a function of increased salivary flow) other factors such as the amount of fermentable carbohydrates may be critical factors when ration NDF levels are near recommended levels. In formulating diets, nutritionists should be mindful of particle size and NDF independently of effective fiber recommendations, and it is important to understand that rapidly fermentable carbohydrates may have even greater effects on variation in rumen pH than ration particle size alone.

Table 1. Forage and TMR particle size recommendations as estimated by the Penn State Particle Size Separator.

	Feed Type		
	Corn Silage	**Haylage**	**TMR**
Sieve Size		**% DM retained**	
> 19.0 mm	5 ± 3	15 ± 5	5 ± 3
19.0 – 8.0 mm	55 ± 10	60 ± 15	40 ± 10
8.0 – 1.18 mm	40 ± 10	30 ± 10	40 ± 10
< 1.18 mm	< 5	< 5	≤ 20
MPL (mm)[a,b]	8 ± 2	10 ± 2	5 ± 2

[a]As estimated by the Penn State Particle Separator (Kononoff et al., 2003a)
[b]MPL = geometric mean length as calculated by the ASAE (2001)

Figure 1. The effect of reducing corn silage particle size on NDF content of feed (0 h) or orts 8, 16, and 24 h after feeding. Dietary treatments were as follows SH = SHORT, MSH = mostly short, MLG = mostly long LG = long. Treatments contained increasing amounts of TMR ≥ 19.0-mm: SH =2.8%, MSH= 6.7%, MLG=11.1%, LG= 15.5% (Kononoff et al., 2003b).



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Dealing with Sulfur Deficiency in Northeast Iowa Alfalfa Production

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Introduction

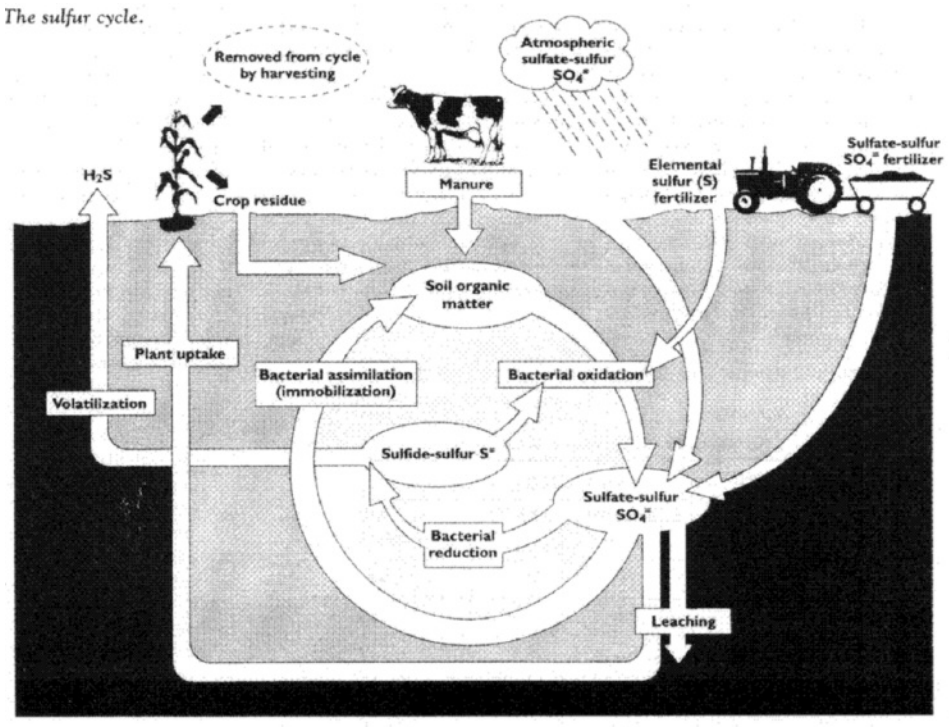
Historically, sulfur (S) deficiency has not been an issue for crop production in Iowa. Previous research documented sufficient plant available S for crop production on most soil associations (Alesii, 1982). Recent studies in corn and soybean production were consistent with results of previous research conducted across Iowa (Sawyer and Barker, 2002). The exception was a long-standing suggestion to apply S as commercial fertilizer or livestock manure for alfalfa production on sandy soils.

However, over the past decade, alfalfa grown on some silt loam and loam soils in northeast Iowa has exhibited a slowly worsening problem with areas in fields of stunted growth and poor coloration. Recent investigations determined the growth problems were largely due to S deficiency. The following provides reasons for the developing problem, how to identify S deficiency, a summary of the research in northeast Iowa, and S fertilizer recommendations for alfalfa.

Sources of Sulfur for Crop Production

Plant-available S can originate from several sources. These include soil mineralization of soil organic matter, subsoil sulfate, manure, decomposing crop residue, atmospheric deposition, irrigation water, and commercial fertilizer. These sources are illustrated in Figure 1.

Figure 1. The Sulfur Cycle, from Schulte and Kelling (1992).



Soil

Soil organic matter is an important source of plant available S. Over 95% of S in soil is in an organic form, and unavailable to plants. The form that plants take up is sulfate ($SO_4^=$). Organic compounds containing S must undergo bacterial oxidation to become plant available. Soil organic matter contains about 58 pounds of S/acre (Voss et. al., 1977), but less than 3 pounds/acre per year per one percent organic matter is estimated to become available to crops (Schulte and Kelling, 1992).

Manure

The amount of S from livestock manure varies with species and application rates (Table 1). About 55% of the total manure-S becomes plant available in the year applied (Schulte and Kelling, 1992).

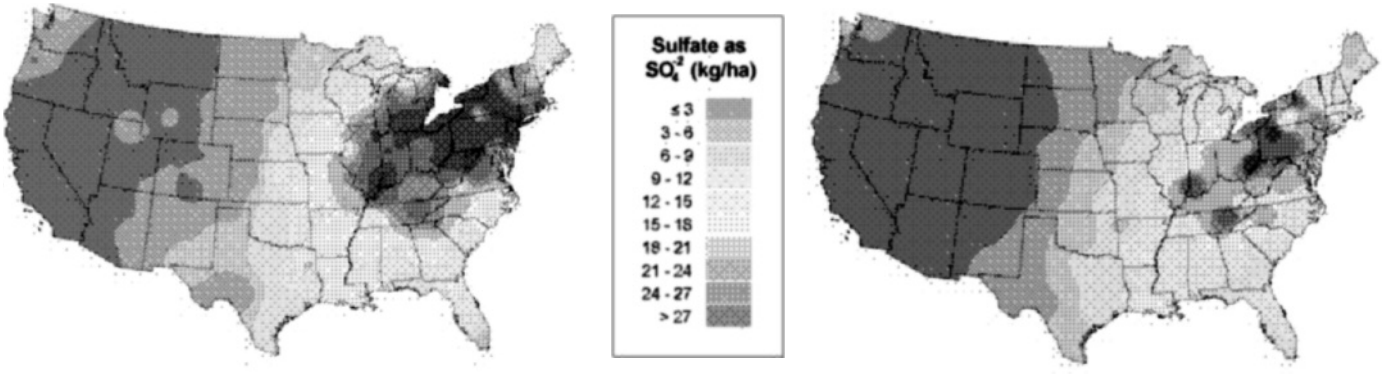
Table 1. Estimated available sulfur from manure (Schulte and Kelling; Voss et. al.)

Manure source	Solid manure		Liquid manure	
	Total	Available	Total	Available
	- - - lbs S/ton - - -		- lbs S/1,000 gal. -	
Horse	1.4	- -	- -	- -
Beef Cattle	1.7	0.9	4.8	2.6
Dairy Cattle	1.5	0.8	4.2	2.3
Sheep	1.8	- -	- -	- -
Swine	2.7	1.5	7.6	4.2
Chicken - old floor litter	3.2	1.8	9.0	5.0
Chicken - no floor little	6.2	- -	- -	- -

Atmospheric Deposition

A significant source of S comes from the atmosphere, or at least used to be. Sulfur contaminants from burning coal, oil, and gas are deposited to the soil by precipitation. Wisconsin Department of Natural Resources estimated that sulfur dioxide emissions decreased 50% from 1985 to 1994. The National Atmospheric Deposition Program records sulfate deposition across the United States (http://nadp.sws.uiuc.edu). Figure 2 illustrates the differences that have occurred from 1986 to 2003.

Figure 2. Atmospheric deposition of sulfate in 1986 (left) and 2003 (right). From the National Atmospheric Deposition Program, Cooperative Extension Service, USDA.



Irrigation

Irrigation water may contain significant concentrations of S. If S supply is a concern with irrigated crops, the irrigation water should be tested for S content.

Commercial Fertilizer

In the past, commercial fertilizers such as ordinary super phosphate, contained significant amounts of S, often greater than 10 percent. Currently used concentrated phosphate fertilizers like diammonium phosphate (DAP) and monoammonium phosphate (MAP), usually contain less than 2 percent S.

Table 2 lists some common S fertilizers. All fertilizers containing the sulfate form of S are considered equally effective. Elemental S, however, is initially insoluble and unavailable to plants. It requires oxidation by soil

bacteria to be converted to sulfate-S. Soil incorporation, weathering, temperature and moisture influence this transformation. So elemental S should be applied well in advance of the time the crop would need it.

Table 2. Common S containing fertilizers.

Material name	Chemical formula	Fertilizer analysis	S, %
Ammonium sulfate	$(NH_4)_2SO_4$	21 - 0 - 0 - 24	24
Ammonium thiosulfate	$(NH_4)_2S_2O_3+H_2O$	12 - 0 - 0 - 26	26
Calcium sulfate (gypsum)	$CaSO_4$	0 - 0 - 0 - 16	16-18
Potassium sulfate	K_2SO_4	0 - 0 - 50 - 18	18-20
Potassium-magnesium sulfate	$K_2SO.2MgSO_4$	0 - 0 - 22 - 23	23
Elemental sulfur	S	0 - 0 - 0 - 90	90-100

Crop Removal

With less S being supplied from the atmosphere, lack of manure application, potential leaching of sulfate-S not intercepted by crop roots, and S removal in crop harvest, the possibility for needing S fertilizer application to the land for crop production has increased over the years. Some crops remove more S than others, i.e. alfalfa, corn silage (Table 3). Also, some crops are more significantly affected by marginal S levels, requiring S for critical plant functions, i.e. nodule development in alfalfa (Barnes, et. al., 1995).

Table 3. Estimated removal of sulfur in harvested crops.

Crop	S content	Yield, unit/ac	S, lb/acre
Alfalfa hay	6.0 lb/ ton	6 ton	36
Corn grain	0.09 lb/ bu	180 bu	16
Corn silage	1.50 lb/ ton	20 ton	30
Oat grain & straw	0.16 lb/ bu	80 bu	13
Soybean grain	0.16 lb/ bu	50 bu	8
Soybean grain & straw	0.40 lb/ bu	50 bu	20

How to Identify Sulfur Deficiency

Symptoms

Sulfur is essential for protein synthesis in plants. For leguminous plants, it is also important in nodule development. Sulfur deficiency symptoms in alfalfa include a light green coloration of the whole plant, stunting, less shoot development, and reduced nodulation.

Soil Test

The soil test for S (measures sulfate-S) is not an effective means to determine S needs for crops. The estimated available S in a 6 to 8-inch soil core sample does not correlate to crop yield responses relative to S fertilizer applications. Reasons for this include: the subsoil can also provide various amounts of S to crops, S mineralization can quickly change plant-available sulfate in the soil, potential S mineralization is not measured by the test, and plant available sulfate-S can leach.

Plant Analysis

A plant analysis or plant tissue test for S is considerably more accurate than the soil test. However, it has its limitations. The test is correlated to sampling certain plant parts depending on the crop, and at a particular stage of plant growth. For example, alfalfa should be sampled in the bud stage by collecting the top six inches from about three dozens shoots. These shoots should be packaged and mailed to the laboratory. Do not sample plants under obvious stresses, i.e. severe drought, insect, or disease problems. Do not collect plants near field edges bordering gravel roads. The road dust could bias the results. The following is a partial list of Commercial Testing Laboratories that conduct plant analysis.

Agvise, Inc., 902 13th St. North, P.O. Box 187, Benson, MN 56215, (320) 843- 4109.
http://www.agviselabs.com
A & L Heartland Labs, Inc., 111 Linn St., Atlantic, IA 50022, (712) 243-6933.
http://www.al-labs.com
AgSource / Belmond Labs, 1245 Hwy 69 N, Belmond IA 50421, (641) 444-3384.
http://www.bellabsinc.com

Iowa Testing Laboratories, LLC, 1101 North Iowa Ave., Eagle Grove, IA 50533-0188, (515) 448-4741, WATS: 1-800-274-7645.
http://www.iowatestinglabs.com
Midwest Laboratories, Inc., 13611 B. Street, Omaha, NE 68144, (402) 334-7770.
http://www.midwestlabs.com
MVTL Labs, Inc., 35 West Lincolnway, Nevada, IA 50201-0440, (515) 382-5486.
http://www.mvtl.com
Servi-Tech Laboratories, 1602 Park West Drive, Hastings, NE 68901, (402) 463-3522.
http://www.servi-techinc.com/
Ward Laboratories, Inc., P.O. Box 788, Kearney, NE 68848, (308) 234-2418.
http://www.wardlab.com

Run a Simple Field Trial

Another method to check for S deficiency is to conduct a simple field trial. Get a few pounds of a sulfate product like calcium sulfate and spread it on several small areas of an alfalfa field. Target some of the pale areas if present. A 10 by 10-foot area works well. Mark these areas for later identification, i.e. flags, stakes, etc. If you use calcium sulfate, assuming the product is 16 percent S, one-half pound of this product spread over a 10 by 10-foot area is approximately 35 pounds of S per acre. Depending on rainfall and harvest schedules, it may take 4 to 6 weeks for a measured response. If there is no significant response (visual or measured canopy height), it is likely that field or that area of the field is not S deficient.

Summary of Sulfur Research in Northeast Iowa

Fertilizer Trials in 2005

In 2005, on-farm trials were conducted on established alfalfa fields near Elgin, Gunder and West Union. These sites were selected because there were large areas in these fields with both poor and good alfalfa plant coloration and growth. Within each poor and good coloration area, three fertilizer treatments were established and replicated 3 times. The treatments consisted of a zero application, 40 lb S/acre as ammonium sulfate, and 40 lb S/acre as calcium sulfate (gypsum). The treatments were applied after first cut. Alfalfa harvests included second cut and third cut in 2005 at all three sites, and first cut in 2006 at the Elgin and Gunder sites (Table 4).

Dry matter yields of S fertilized plots on the good coloration areas were not significantly different from that of the unfertilized treatment. However, S fertilized plots on the poor coloration areas more than doubled yields in 2005 and nearly double yields in 2006. The S fertilizer treatments in the poor coloration areas increased the dry matter yield nearly up to the level found in the good coloration areas.

Plant analysis for the untreated poor areas was 0.14 percent S, clearly well below the recommended sufficiency level of 0.25 percent S. Plant analysis for the untreated good areas was also considered deficient at 0.22 percent S, but just marginally so relative to 0.23 percent being adequate. The two sulfate containing fertilizers, ammonium sulfate and calcium sulfate, provided similar results.

Table 4. Alfalfa forage yield, S plant analysis, and S crop removal with topdress applications of S fertilizer in field areas with poor and good coloration of alfalfa.

	2005[1]						2006[2]	
	Cuts 2+3 Dry matter yield		Cut 2 Plant top Sulfur		Cuts 2+3 Sulfur removal		Cut 1 Dry matter yield	
Sulfur								
	Observed Growth Area							
Treatment[3]	Poor	Good	Poor	Good	Poor	Good	Poor	Good
	ton/acre - - - % S - - -		lb S/acre		ton/acre			
None	1.18[a]	2.99[a]	0.14[a]	0.22[b]	2.8[a]	10.6[b]	1.10[a]	2.04[a]
Am. sulfate	2.76[b]	3.26[a]	0.40[d]	0.35[c]	16.5[cd]	18.2[de]	2.18[b]	2.22[a]
Ca. sulfate	2.49[b]	3.21[a]	0.41[d]	0.37[c]	15.3[c]	18.1[e]	2.14[b]	2.19[a]

[1]Three field sites in 2005, Elgin, Gunder and West Union, Iowa.
[2]Two field sites in 2006, Elgin and Gunder, Iowa.
[3]Sulfur (ammonium sulfate and calcium sulfate) were applied at 40 lb S/acre after first cut in 2005.
[4]Treatment means followed by the same letter are not significantly different, 90% probability level.

Other soil characteristics, soil type, P and K soil test levels, pH, sulfate-S soil test levels, organic matter, and cation exchange capacity were largely similar within the sites (Table 5). Any differences that did exist, such as soil test phosphorus (STP) at the Elgin and Gunder sites and soil test potassium (STK) at the West union site, did not explain differences found with the S fertilizer treatments. The S soil test results did not correspond to the coloration differences in the fields, the percent S differences found in the plant analysis, or yield responses to applied S.

Table 5. Soil characteristics for 2005-2006 research trials, Elgin, Gunder, West Union.

		Observed Growth Area					
		Poor	Good	Poor	Good	Poor	Good
Site	Soil	STP		STK		pH	
		- - - - - - - - - ppm - - - - - - - - -					
Elgin	Fayette silt loam	30	15	144	155	7.0	7.2
Gunder	Fayette silt loam	43	21	240	220	7.0	6.9
West Union	Downs silt loam	24	26	164	92	7.2	7.1

		Observed Growth Area					
		Poor	Good	Poor	Good	Poor	Good
Site	Soil	SO_4-S		OM		CEC	
		- - - ppm - - -		- - - % - - -		meq/100g	
Elgin	Fayette silt loam	6.3	7.0	2.3	2.3	20.2	16.4
Gunder	Fayette silt loam	7.3	8.3	2.7	2.9	19.3	16.7
West Union	Downs silt loam	6.3	7.0	2.3	2.6	17.8	14.1

Samples collected after first cut, 0 to 6 inch depth.

Fertilizer Trials in 2006

In 2006, on-farm trials were conducted on established alfalfa fields near Wadena, Waucoma, Nashua, Waukon, West Union and Lawler. These trials compared different rates of S. Sites were selected to offer a wide range of responses, in that they were established on different soil types and exhibiting different degrees of poor to good coloration. Calcium sulfate was applied in the spring at 0, 15, 30 and 45 lb S/acre with four replications in each trial. Most sites were harvested at second and third cut, the Nashua site was harvested for 4 cuts, and some harvest coordination issues resulted in loosing the second cut at West Union and the third cut at Lawler.

The sites with poor coloration had lower percent S plant analysis (Table 6) and greater dry matter yield responses to S fertilizer (Table 7). The two sites with plant S above 0.23 percent S with no applied S did not have statistically significant yield increases from applied S. The S soil test did not correspond to percent S plant analysis, yield response to applied S, or soil organic matter. Those sites with significant yield responses to S fertilizer leveled off in the response at about 25 pounds of S/acre (Table 7, maximum rate, lb S/acre).

Table 6. Alfalfa plant S concentration and site characteristics, 2006.

	Site					
Sulfur rate[1]	Wadena	Waucoma[2]	Nashua	Waukon	West Union	Lawler
lb S/acre	- - - - - - - - - - - - - - - - - - % S[3] - - - - - - - - - - - - - - - - - -					
0	0.14	0.21	0.33	0.18	0.18	0.27
15	0.20	0.30	0.35	0.29	0.24	0.36
30	0.30	0.43	0.34	0.40	0.29	0.39
45	0.39	0.36	0.37	0.41	0.28	0.37
[4]Soil SO_4-S, ppm	7	3	7	1	6	3
[4]Soil OM, %	3.1	2.1	4.2	3.8	3.3	2.6
[5]Soil	Fayette	Wapsie	Floyd-Clyde	Fayette	Fayette	Ostrander

[1]Sulfur applied as calcium sulfate in April at Nashua and in May at the other sites.
[2]Waucoma site had 10 lbs of elemental S applied in spring across the entire field.
[3]Sulfur concentration (% S) for 6-inch plant tops collected before second cut.
[4]Soil samples collected after first cut, 0 to 6 inch depth.
[5]Soil texture: Fayette silt loam, Wapsie loam, Floyd-Clyde loam, Ostrander loam.

Table 7. Alfalfa total dry matter for the harvests collected in 2006.

	Site					
Sulfur rate[1]	Wadena	Waucoma[2]	Nashua	Waukon	West Union	Lawler
lb S/acre	- - - - - - - - - - - - - - - - - - ton/acre - - - - - - - - - - - - - - - - - -					
0	1.32	1.85	6.73	1.39	0.78	2.14
15	2.59	3.06	6.98	2.97	1.05	2.11
30	2.76	3.14	6.85	3.33	1.07	2.11
45	2.92	3.24	7.14	3.58	1.07	2.07
Significance (90%)	*	*	NS	*	*	NS
Max rate, lb S/acre	25	22	0	29	12	0
Cut harvested	2+3	2+3	1+2+3+4	2+3	3	2+4

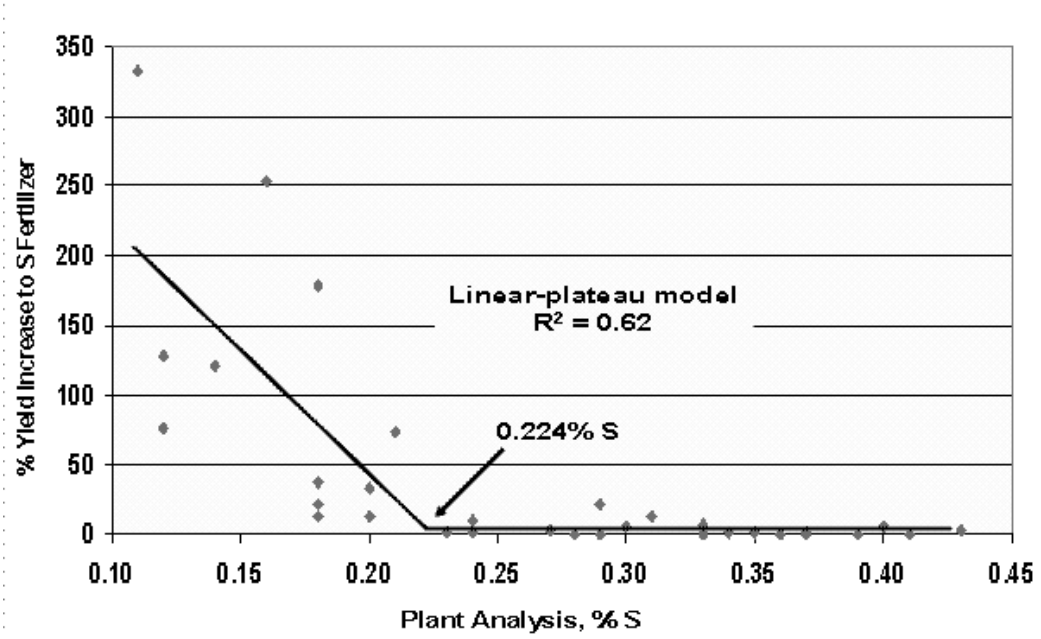
[1]Sulfur applied as calcium sulfate in April at Nashua and in May at the other sites.
[2]Waucoma site had 10 lbs of elemental S applied across the entire field in spring.

Discussion

Sulfur deficiency problems exist in northeast Iowa alfalfa production fields. The majority of S deficiency problems occur in areas within fields, not entire fields. However, this non-uniformity can still account for large economic losses on a field scale. Most of the soils involved are lower organic matter, side-slope position, silt loam soils, i.e. Fayette silt loam and Downs silt loam. However, lighter textured loam soils have also responded to S fertilizer in these trials, i.e. Wapsie loam in 2006, Winneshiek loam and Saude loam in 2005 (data not included in this proceedings). Problems with S deficiency have not been observed on heavily manured fields.

Plant analysis is currently the best available analytical method to test for S deficiency. Figure 3 represents the percent yield response in these trials relative to S plant analyses. This research supports other work that suggests S sufficiency is reached around 0.23 to 0.25 percent S (Schulte and Kelling, 1992).

Figure 3. The percent yield increase from S fertilization relative to the alfalfa plant S concentration with no S applied.



Economic response follows the same relationship. With sulfur fertilizer and application costs estimated at $20 per acre, the overall net economic return in these trials averaged $50 per acre.

Currently, if a S deficiency is found (i.e. through plant analysis or field trial), the amount of S fertilizer recommended is 20 to 30 pounds S/acre. Where deficiencies occurred in the 2006 trials, the first 15 pounds of S/acre gave the largest incremental increase in yield, but the next 15 pounds of S/acre was still profitable in most trials. Additional research would help to refine these recommendations.

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Evaluation of Corn Response to Sulfur Fertilization in Northeast Iowa

Project Report for 2006 and 2007 Research

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Brian Lang, Field Agronomist, Iowa State University Extension, Northeast Area

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Introduction

Over forty years of prior research in Iowa had rarely noted improved corn yield with sulfur (S) fertilization. Statewide and regional studies conducted in Iowa from 2000-2005 had not found corn yield increase from S fertilizer application. Recently, S deficiency was document through forage yield and plant S increase from applied S fertilizers in northeast Iowa alfalfa fields (Lang et al., 2006), especially in field areas with low soil organic matter and side-slope landscape position. On similar soils and on coarse textured soils, early corn growth has been exhibiting strong visual S deficiency symptoms. The objectives of this research were to determine corn response to S fertilization and evaluate specific soils and extent of northeast Iowa affected by S deficiency.

Materials and Methods

Three studies were conducted in northeast Iowa in 2006 and 2007 to evaluate S fertilization response in corn. The first study was designed to evaluate a new phosphorus (P) and S containing fertilizer product. Only treatments related to evaluation of S response are presented here. The second study was targeted to determine if S deficiency was responsible for visual plant yellowing (chlorosis) in early corn growth, and if so, the response to early sidedress applied S fertilizer. The third study was designed to evaluate corn response to S fertilization rate and the extent of S deficiency in northeast Iowa. All of these studies provide insight into the potential for corn yield response to S application and the magnitude of S deficiency in northeast Iowa.

Study 1 - Sulfur Fertilizer Product Evaluation

Two sites were chosen on producer fields in Allamakee and Winneshiek counties in 2006, a Seaton silt loam and a Renova loam soil. The previous year crops were soybean and long-term grazed grass pasture, respectively. Other than grazing, neither site had a history of manure application. Tillage following soybean was shallow disking in the spring and no-till corn planted into the grass pasture.

Treatments were arranged in a randomized complete block design with four replications at each site. Fertilizer treatments were applied broadcast by hand prior to spring tillage or corn planting for the no-till site. For this report, only the following selected treatments are presented: S control (S-CON), ammonium sulfate (AMS) at 10 (AMS-10) and 30 (AMS-30) lb S/acre, and a Simplot 13-33-0-15S product (SEF) at 10 (SEF-10) and 30 (SEF-30) lb S/acre. The SEF product contained half of the S as sulfate and half as elemental. Nitrogen (N) and P application was equalized on all plots.

Soil samples (0-6 inch depth) were collected in spring prior to any tillage and treatment application. Extractable sulfate-S was 8 ppm at both sites. Corn ear leaf samples were collected at the silking (R1) corn growth stage and analyzed for total S. Grain yields were determined for each plot and adjusted to 15.5 % moisture content. Means and statistical analyses were combined across sites, with site as a random effect.

Study 2 - Corn Response to Sulfur Application with Visual Deficiency Symptoms

In 2006, six sites were selected based on expectation of S deficiency, either through visual observation of early plant S deficiency symptoms being present or previous experience indicating that soil conditions and previous crop would be conducive to S deficiency. Therefore, sites were considered specifically "chosen", and therefore not a set of sites with random potential of response to S application. Sites did not have recent or known manure application history.

Calcium sulfate was surface broadcast applied sidedress after early corn growth at 40 lb S/acre, with a control treatment for comparison. A non-limiting S rate was chosen to allow measurement of S response, with expectation the 40 lb S/acre rate would maximize any potential yield increase. Treatments were arranged in a randomized complete block design with four replications at each site. Soil samples (0-6 inch depth) were collected before S application. Grain yields were determined for each plot and adjusted to 15.5 % moisture content. Means and statistical analyses were computed across sites, with site as a fixed effect.

Study 3 - Corn Response to Sulfur Fertilization Rate

An expanded study was conducted in 2007 at twenty sites to determine corn response to S rate of application. The sites were selected to represent major soils and cropping systems (Table 3), and were chosen to represent a range in potential S response. Sites did not have a recent or known manure application history. Calcium sulfate was surface broadcast applied with no incorporation shortly after planting at 0, 10, 20, and 40 lb S/acre. Each rate was replicated four times at each site in a randomized complete block design. Soil samples (0-6 inch depth) were collected before S application. At the silking (R1) growth stage corn ear leaf samples were collected and analyzed for total S. Grain yields were determined for each plot and adjusted to 15.5 % moisture content. Means and statistical analyses were computed across sites, with site as a random effect. Quadratic-plateau regression models were fit to the grain yield response for the fine and coarse textured soil sites. Economic optimum S rate was determined with S fertilizer at $0.50/lb S and corn grain at $4.00/bu.

Results

Study 1 - Sulfur Fertilizer Product Evaluation

The yield difference between the control (S-CON) and 10 lb S/acre (AMS-10 and SEF-10) was 15 bu/acre, which was statistically significant (Table 1). There was no yield increase to additional S application with the 30 lb S/acre rate. Corn ear leaf S concentration was significantly increased with application of AMS and SEF fertilizers (Table 1). Grain yields and leaf S concentrations with AMS and SEF were the same, indicating similar plant-available S supply from both S sources. Leaf S concentration with no S applied was low, and below the 0.21% S level considered sufficient (Neubert, et al., 1969). Application of 30 lb S/acre increased leaf S concentration compared to the 10 lb S/acre rate, and raised the concentration just to the sufficient level. Despite this increase in leaf S, yield was not increased with the higher S rate.

Study 2 - Corn Response to Sulfur Application with Visual Deficiency Symptoms

Corn yield was increased with the sidedress calcium sulfate application at five of six sites. The yield increases were quite large, especially considering the surface fertilizer application after plant early growth. However, the sites were chosen based on expected S deficiency, with many sites showing severe plant yellowing. Therefore, substantial yield increase might be expected. With rainfall after application, plant response (increase in greenness) was observed in a short time period. This would also indicate an expected plant growth and yield increase. The site with no statistically significant response to S application (and high yield with no S) also had the highest extractable soil sulfate-S concentration.

Across all sites, the yield increase from S application was 38 bu/acre. This yield increase would easily cover the required S fertilization cost. Since only one non-limiting S rate was applied, it is not possible to determine an economic application rate. These results indicate that a substantial corn yield increase to S application is possible when soil conditions are conducive to low S supply and severe S deficiency exists. In this study, those conditions were coarse textured soils and soil/landscape position similar to that with documented S deficiency in alfalfa.

Study 3 - Corn Response to Sulfur Fertilization Rate

Corn grain yield was increased (statistically significant) with S application at seventeen of the twenty sites in 2007 (Figure 1) and leaf S concentration was increased at sixteen sites (Figure 2). Across all sites, the average yield increase was 18 bu/acre. When grouped by soil texture, the yield increase was 15 bu/acre for the fine textured soils (loam and silt loam) and 25 bu/acre for the coarse textured soils (loamy sand and sandy loam). These are large yield increases to S fertilization. The yield levels were quite high in 2007, with an average yield (with S application) of 201 bu/acre at the fine textured soil sites and 190 bu/acre for the coarse textured soil sites.

When analyzed across S rate, the maximum response rate for the fourteen fine-textured soil sites was 15 lb S/acre, with an economic optimum rate at 14 lb S/acre (Figure 3). For the six coarse-textured soil sites, the maximum response rate was 26 lb S/acre, with an economic optimum rate at 24 lb S/acre (Figure 3).

Corn ear leaf S concentrations were below the 0.21% S critical level (Neubert, et al., 1969) at all sites. The application of S increased leaf S concentration, but was not a large increase (across sites, an increase of 0.03% S with the 40 lb S/acre rate). Even with the 40 lb S/acre rate, the leaf S concentration was below 0.21% S at all but one site. Two of the non-responding sites did not have a statistically significant increase in leaf S concentration with S application. The 3 non-significant yield responsive sites (Figure 1) all had leaf S concentrations well below 0.21% S without S application (Figure 2).

Ear leaf S concentration in the control (zero applied S) can be used as a guide for potential corn response to S application. Figure 4 shows this relationship for relative yield of the control (relative to yield with the 40 lb S/acre rate). All sites had leaf

S concentrations below the 0.21% S critical level established by Neubert et al. (1969). That critical level was established years ago and may not be valid with today's hybrids. The current work, however, does not refute that level. No site had a leaf S concentration greater than 0.19% S (without S application), and sites with that leaf S concentration did respond to S (yield increase). Therefore, it is not possible to define a critical level in this study or determine if the 0.21% S level is still valid. The data does indicate that the critical level is greater than 0.19% S.

The extractable soil sulfate-S concentrations in the control (Table 3 and Figure 5) were not well related to yield response to applied S. Also, several sites had concentrations above the 10 ppm S level considered sufficient (Hoeft et al., 1973), but still responded to S. This has been found in other studies where the sulfate-S soil test has not been reliable for predicting crop responses to S application on soils in the Midwest USA (Hoeft et al., 1985; Sawyer and Barker, 2002). Supply of crop-available S is related to more than the sulfate-S concentration in the top six inches of soil, thus the poor relationship between relative yield and soil test.

Summary

Corn grain yield increase to S fertilization has occurred with high frequency in these studies. Also, the magnitude of yield increase has been large. Across the two years and three studies, 82% of the sites had a statistically significant yield increase to applied S fertilizer. By study, statistically significant across-site yield increases averaged 15, 18, and 38 bu/acre. Analyzed across S rate, the economic optimum S rate was 14 lb S/acre for fine-textured soils and 24 lb S/acre for coarse-textured soils. This research indicates a dramatic change in need for S fertilization in northeast Iowa, and that S application is an economically viable fertilization practice on many soils.

In addition, this work indicates that more research is critically needed, not only to continue study on soils in northeast Iowa, but also for a larger geographic area extending into central and southeast Iowa. If the responses found in these studies are indicative of potential S fertilization need in other geographic areas, then yields of corn and other crops could be suffering due to S deficiency. The only way to know is to expand research efforts. In addition, additional information is needed regarding plant and soil S tests, plant S stress sensing, site characteristics, and S deposition in order to develop better predictive indices of S deficiency and need for S fertilization. These tools will provide better decision making and enhance positive economic return to S fertilization for producers.

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Table 1. Effect of S fertilizer product application on corn ear leaf S concentration and grain yield combined across sites, 2006.

Treatment†	Ear Leaf S Concentration	Grain Yield
%		bu/acre
S-CON	0.15	196
SEF-10	0.18	211
AMS-10	0.18	211
SEF-30	0.21	204
AMS-30	0.20	207
Contrast	Statistics (p>F)	
SEF-10 & SEF-30 vs. AMS-10 & AMS-30	0.6620	0.7433
S-CON vs. AMS-10	0.0001*	0.0467*
AMS-10 vs. AMS-30	0.0166*	0.5796

† S-CON, S control; SEF, 13-33-0-15S product; AMS, ammonium sulfate product; 10 or 30 indicates the rate of S applied.

* Indicates statistical significance of the contrast, $p \leq 0.10$.

Table 2. Effect of S fertilizer application on corn grain yield, 2006.

Site	County	Previous Crop†	Map Unit	Soil	Soil Test S‡	Grain Yield, bu/ac Yield - S	Yield + S§
L1	Buchanan	S	41B	Sparta lfs	6 ppm	123	151*
L2	Buchanan	S	41B	Sparta lfs	7 ppm	154	198*
T1	Delaware	S	63C	Chelsa lfs	9 ppm	88	108*
T2	Delaware	S	83B	Kenyon l	13 ppm	196	204NS
WK	Allamakee	A	163C	Fayette sil	3 ppm	96	172*
WT	Allamakee	A	163C	Fayette sil	--	118	171*
Across Sites		129	167*				

† S, soybean; A, first-cut alfalfa harvested.

‡ Extractable sulfate-S in the 0-6 inch soil depth.

§ Sulfur applied at 40 lb S/acre. Symbol indicates statistically significant (*) or non-significant
(NS) yield increase with S application ($p \leq 0.10$).

Table 3. Site information for the S rate study, 2007.

Site	County	Previous Crop†	Soil OM%‡	Soil Test S, ppm‡	Map Unit	Soil
B	Black Hawk	S	1.9	5	408B	Olin fsl
C	Buchanan	S	2.7	3	399	Readlyn l
D	Buchanan	S	0.8	2	41B	Sparta lfs
E	Buchanan	S	1.4	3	284	Flagler sl
F	Buchanan	S	0.9	13	41B	Sparta lfs
G	Delaware	S	2.0	5	241B	Burkhardt-Saude sl
H	Delaware	S	2.5	5	391B	Clyde-Floyd l
I	Delaware	S	2.6	7	177	Saude l
J	Delaware	S	1.1	6	175B	Dickinson fsl
K	Delaware	S	0.9	4	408B	Olin fsl
L	Delaware	S	3.4	4	83B	Kenyon l
M	Fayette	S	2.6	5	163D2	Kenyon l
O	Clayton	C	1.5	14	158	Dorchester sil
Q	Clayton	S	2.9	5	162C	Downs sil
R	Clayton	S	2.7	10	163C2	Fayette sil
U	Clayton	A	2.1	1	163B	Fayette sil
W	Winneshiek	S	2.8	4	162D	Downs sil
X	Allamakee	C	2.1	12	163C2	Fayette sil
Y	Allamakee	C	2.3	6	162C2	Downs sil
Z	Allamakee	C	2.1	11	162C2	Downs sil

† S, soybean; C, corn; A, alfalfa.

‡ Soil organic matter (OM) and extractable sulfate-S in the 0-6 inch soil depth.

Figure 1. Corn grain yield response to S application (no S vs. plus S), 2007. The average across all sites is designated by [a], * indicates statistically significant response to S, and NS indicates non-significant response to S ($p \leq 0.10$).

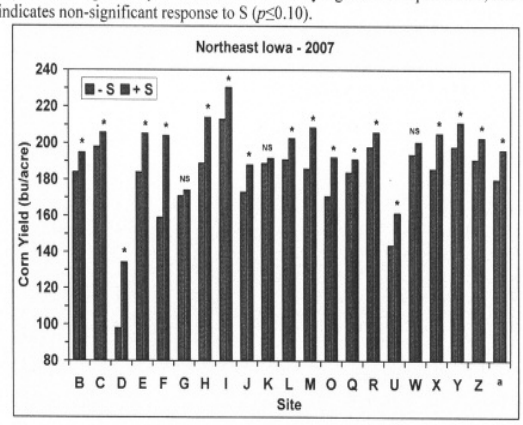


Figure 2. Corn ear leaf S concentration response to S application (no S vs. plus S), 2007. The average across all sites is designated by [a], * indicates statistically significant response to S, and NS indicates non-significant response to S ($p \leq 0.10$).

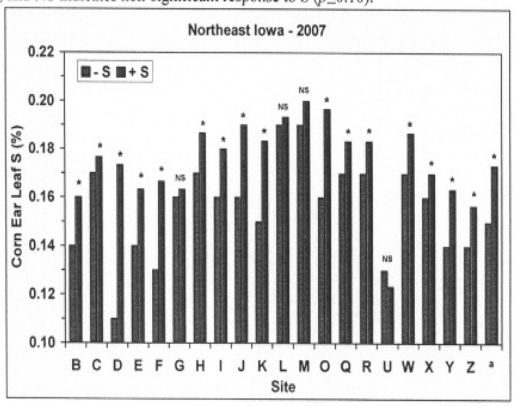


Figure 3. Corn grain yield response to S rate of application, 2007.

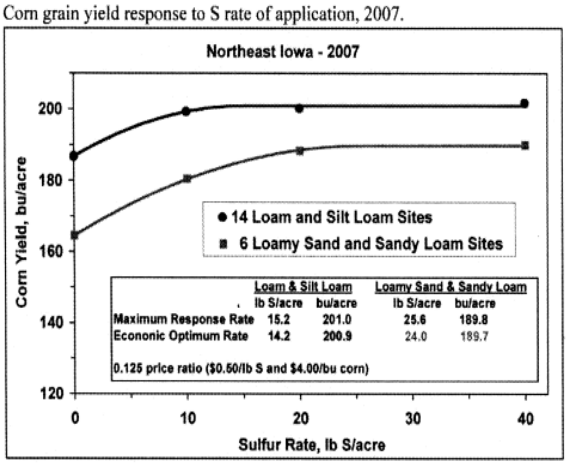


Figure 4. Corn grain relative yield as related to ear leaf S concentration, 2007.

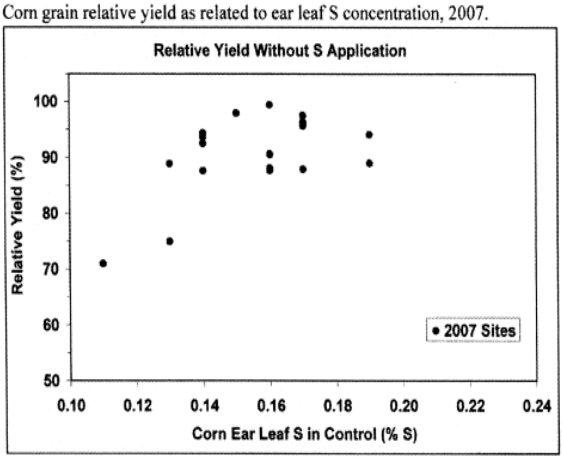
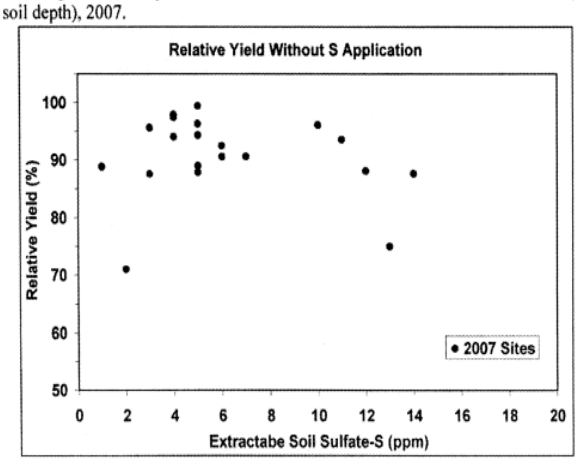


Figure 5. Corn grain relative yield as related to extractable soil sulfate-S concentration (0-6 soil depth), 2007.



Evaluation of Milk Components, Fatty Acid Profile, and Production of Cows Fed Rolled Flaxseed on Two Commercial Dairies

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Abstract

The objective of this field trial was to study the effects of supplementing early lactation dairy cow diets with rolled flaxseed on milk composition, fatty acid profile, and yield. Conducted on 2 commercial dairies with cows naive to flaxseed, the treatments consisted of either their existing post-fresh ration (CON; n = 408) or a similar diet re-formulated with rolled flaxseed (FLX; n = 507; 0.85 kg DM/cow daily). Cows were assigned randomly to treatment upon leaving the fresh-cow pen (approximately 10 d postpartum) within parity (primiparous or multiparous). Cows on both dairies remained in the study until confirmed pregnant or were culled from the herd. Milk, TMR, and feedstuffs were collected monthly. Analyses included 915 cows. Milk production was collected and monitored using monthly DHIA records. Milk yield was analyzed as a split-plot with cow as the experimental unit and treatment by parity by farm as the whole-plot error term. Treatment did not interact with farm or parity. Milk from cows fed FLX had a greater ($P \leq 0.06$) proportion of C18:0 (11.21 vs. 10.50 ± 0.13 g/100g), C18:1 (24.60 vs., 22.59 ± 0.20 g/100g), and C18:3n3 (0.85 vs. 0.53 ± 0.03 g/100g) fatty acids in the milk fat and a lesser ($P \leq 0.01$) proportion of C16:0 (26.88 vs. 29.33 ± 0.17 g/100g) compared to CON cows. Treatment did not affect milk yield (36.49 ± 1.11 kg/d), milk protein (2.77 ± 0.02 %), protein yield (1.01 ± 0.03 kg/d), milk fat (3.34 ± 0.04%), or milk fat yield (1.22 ± 0.05 kg/d). Feeding 0.85 kg DM of flaxseed daily can alter the fatty acid profile of milk while maintaining milk yield and composition in on-farm dairy applications.

Introduction

The composition of milk is an important determinant of profitability for a dairy enterprise. Modifying milk composition has gained considerable interest among a public that has become more health conscious. Modifying milk components can increase the efficiency of manufacturing dairy products as well as lead to the formulation of dairy products that conform to growing needs in the field of functional foods. The objective of this field trial was to study the effects of supplementing early lactation dairy cow diets with rolled flaxseed on milk composition, fatty acid profile, and yield.

Materials and Methods

Criteria for Selecting Field Trial Dairy Sites

Criteria used to select the dairies for participation in this field trial included the ability to collect and record desired data, strength of management team and practices, size of the herd (a targeted range of 300-800 lactating cows), and the willingness to participate in the project given the incentives in place to conduct the research. The participating dairies used similar reproductive hormonal synchronization protocols (necessary for a companion trial) and similar computerized record keeping systems (DairyCOMP 305®, Valley Ag Software, Tulare, CA). Adherence to these requirements aided in the implementation of the protocol and the interpretation of the data.

Cows and Diets

All procedures were approved by the North Dakota State University Institutional Animal Care and Use Committee. This study was conducted on two commercial dairies: Minglewood Dairy (MWD), Deer Park, WI (herd size = 750 lactating cows), and County Line Dairy (CLD), Edgerton, MN (herd size = 500 lactating cows). The trial was initiated at MWD in December, 2006, whereas the trial was initiated at CLD in June, 2007. Each site consisted of cows naive to flaxseed before initiation of the trial. Cows were assigned randomly to treatment upon leaving the fresh-cow pen (approximately 10 d postpartum) within parity (primiparous or multiparous). For both dairies, cows remained in the study until confirmed

pregnant or culled from the herd. Treatment did not interact with farm or parity, and therefore, the proceeding discussion will describe the comparison between the main effect of diet while combining parity and farm. Treatments consisted of either their existing post-fresh diet (control, CON; n=408) or a similar diet re-formulated with rolled flaxseed (flax, FLX; n=507; 0.85 kg DM/cow daily). Analyses presented herein included a total of 915 cows. Diets were formulated by each dairies' nutritionist and were approved by the study authors (Tables 1 & 2). Fatty acid profiles for each treatment and parity are shown in Table 3.

Sample Collection

The milk, base feed component, and TMR samples along with exportation of the DairyCOMP 305 data were collected monthly throughout the duration of the trial. For each treatment pen at each site, milk samples were collected via string sampling kits (CA DHIA, Clovis, CA). Milk samples were placed on dry ice immediately following collection and frozen until analysis at the University of Wisconsin, Dairy Science Nutrition Laboratory. Data regarding milk production and milk composition were collected at each site via DHIA records. All TMR and base feed component samples were collected in plastic bags, frozen, and stored until the trial concluded. DairyCOMP 305 data was transferred and stored on a common storage device (USB).

Table 1. Diets for cows fed supplements of no flax (Control) or flax seed (Flax)

Site – Minglewood Dairy	Control		Flax	
Ingredients, % of DM	**P[1]**	**M[1]**	**P[1]**	**M[1]**
Forage[2]	59.78	59.78	60.96	60.96
Concentrate[3]	38.95	38.96	34.87	34.84
Fat source:				
Flax seed	-	-	3.26	3.49
Tallow	0.79	0.79	0.16	0.16
Rumen inert fat[4]	0.48	0.48	0.55	0.55
Chemical Composition:				
Fat (ether extract), %	5.42	5.42	5.35	5.35
NEL, Mcal/kg of DM	1.72	1.72	1.72	1.72
Crude protein, %	18.50	18.50	18.50	18.50
Acid detergent fiber, %	20.20	20.20	20.10	20.10
Neutral detergent fiber, %	29.10	29.10	28.90	28.90
Calcium, %	0.91	0.91	0.95	0.95
Phosphorus, %	0.42	0.42	0.42	0.42

[1] P = Primiparous, M = Multiparous

[2] Forage includes: corn silage, haylage, and beet pulp

[3] Concentrate includes: corn, roasted soybeans, sodium bicarbonate, extruded soybeans, distillers grain, calcium carbonate, blood meal, urea, salt, magnesium oxide, dicalcium, magnesium sulfate, and OmniGen-AF (Prince Agri Products, Inc., Quincy, IL)

[4] Energy Booster 100 (Vita Plus Corp., Madison, WI)

Table 2. Diets for cows fed supplements of no flax (Control) or flax seed (Flax)

Site – County Line Dairy	Control		Flax	
Ingredients, % of DM	**P[1]**	**M[1]**	**P[1]**	**M[1]**
Forage[2]	46.52	46.52	47.47	47.47
Concentrate[3]	48.59	48.59	48.89	48.89
Fat source:				
Flax seed	-	-	3.35	3.35
Cottonseed	4.03	4.03	-	-
Rumen inert fat[4]	0.71	0.71	0.30	0.30
Choice white grease	0.16	0.16	-	-
Chemical Composition:				
Fat (ether extract), %	5.00	5.00	5.00	5.00
NEL, Mcal/kg of DM	1.54	1.54	1.57	1.57
Crude protein, %	16.90	16.90	17.10	17.10
Acid detergent fiber, %	17.80	17.80	17.10	17.10
Neutral detergent fiber, %	32.40	32.40	31.20	31.20
Calcium, %	0.95	0.95	0.99	0.99
Phosphorus, %	0.46	0.46	0.44	0.44

[1] P = Primiparous, M = Multiparous

[2] Forage includes: corn silage, haylage, dry alfalfa hay

[3] Concentrate includes: corn, corn gluten, rolled corn, soybean meal, soy hulls, canola meal, blood meal, urea, magnesium oxide, salt, sesquicarbonate, vitamin E, Omnigen-AF (Prince Agri Products, Inc., Quincy, IL), UltraMet (Vita Plus Corp., Madison, WI), Vi-COR Amax Yeast, (ViCOR Varied Industries Corp., Mason City , IA), Sel-Plex (Altech, Flemington, NJ), Rumensin (Elanco Animal Health, Greenfield, IN), and Zinpro Availa-4 (Eden Prairie, MN)

[4] Energy Booster 100 (Vita Plus Corp., Madison, WI)

Table 3. Diet fatty acid composition for cows fed supplements of no flax (Control) or flax seed (Flax)

	Minglewood Dairy				County Line Dairy			
	Flax	Con	Flax	Con	Flax	Con	Flax	Con
Fatty Acid[1]	Primi.	Primi.	Multi.	Multi.	Primi.	Primi.	Multi.	Multi.
C6:0	0.00	0.03	0.00	0.00	0.00	0.37	0.19	0.00
C8:0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C10:0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C12:0	0.00	0.44	0.00	0.00	0.00	0.00	0.14	0.00
C14:0	0.47	0.36	0.00	0.00	0.75	1.04	0.93	1.18
C14:1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C15:0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C16:0	15.72	18.61	14.89	17.59	16.58	20.53	17.62	21.21
C16:1	0.00	0.20	0.00	0.00	0.00	0.43	0.39	0.45
C17:0	0.00	0.24	0.00	0.00	0.16	0.35	0.38	0.21
C17:1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C18:0	6.81	8.23	5.19	6.72	6.15	7.17	8.71	7.99
t11 C18:1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
c9 C18:1	17.24	15.52	15.78	14.62	14.78	14.23	14.83	14.43
c6, c11 C18:1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
t6 C18:2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
c6 C18:2	27.30	31.26	30.99	33.76	31.30	34.53	27.53	34.70
C20:0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C18:3n6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C20:1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C18:3n3	18.65	8.93	17.66	9.51	16.18	7.40	14.54	7.19
c9, t11 C18:22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
t10, c12 C18:22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C21:0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C20:2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C22:0	0.18	0.24	0.00	0.00	0.16	0.15	0.32	0.00
C20:3n6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C22:1n9	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00
C20:3n3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C20:4n6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C23:0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C22:2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C24:0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C20:5n3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C24:1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C22:6n3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Other	3.29	3.93	1.08	1.35	1.73	2.44	6.61	1.79
Short-chain[3]	58.33	51.61	61.44	64.54	44.09	37.04	31.84	47.50
Monounsaturated	17.24	15.72	15.78	14.62	14.78	14.66	15.27	14.89
Polyunsaturated	45.94	40.19	48.65	43.27	47.48	41.92	42.07	41.89
Total unsaturated	63.18	55.92	64.44	57.88	62.26	56.58	57.34	56.77

[1] Expressed as number of carbons:double bonds.

[2] Conjugated linoleic acid.

[3] Short-chain fatty acids (C6 to C12).

Laboratory Analyses

Base feed component and TMR samples were dried at 55°C in a forced-air oven for 48h. Dried samples were ground in a Whiley mill to pass through a 2 mm screen. Samples of components and TMRs were composited within parity, treatment, and farm for analysis. Base feed component and TMR samples were analyzed for DM, OM, CP, ADF, NDF, Ca, K, and N.

Diet fatty acid analysis was performed at the Northern Great Plains Research Laboratory, USDA-ARS, Mandan, ND. Diets were prepared for fatty acid analysis via direct transesterification (Whitney et al., 1999) with methanolic-HCl (Kucuk et al., 2001). Separation of fatty acid methyl esters was achieved by GLC (Model CP-3800, Varian Inc., Palo Alto, CA) with a 100 m capillary column (SP-2560, Supelco, Bellefonte, PA) and H2 as a carrier gas at 1.0 mL/min. Oven temperature was maintained at 120° C for 2 min and then ramped to 210° C at 6° C/min. Oven temperature was then ramped to 250° C at 5° C/min. Injector temperature was 260° C and flame ionization detector temperature was 300° C. Identification of peaks was accomplished using purified standards (Sigma-Aldrich, St. Louis, MO; Nu-Chek Prep, Elysian, MN; Matreya, Pleasant Gap, PA). Fatty acids which were not identified by identification peak standards were grouped together and reported as "other".

Milk analysis was performed at the University of Wisconsin Dairy Science Nutrition Laboratory. Initial procedure was the isolation of the fat cake (Chouinard, P.Y. et al., 1999). Thirty mL of milk was centrifuged at 17,800 x g for 30 min at 8°C followed by the removal of the fat cake and continued with lipid extraction (Hara, A. and Radin, N.S., 1978). For the lipid extraction, 300 mg of fat cake was weighed in glass tubes (16 x 125 mm, Teflon-lined, screw capped). 18 mL of HIP per gram of fat was added, vortexed, and allowed to sit for 10 min. 12 mL of sodium sulfate solution per gram of fat was added and vortexed for 1 min. The top hexane layer was removed, and dried under nitrogen to produce the butter oil. Methylation procedures included methylating a butterfat standard with each set of samples to determine the response factors for calculating fatty acid relative percentages. 2 mL of hexane and 40 µl of methyl acetate was added to 50 mg of fat, vortexed and dissolved. 40 µl of methylation solution was added, vortexed, and allowed to cool for 10 min. 60 µl of oxalic acid was added to terminate reaction, and then centrifuged for 5 min. at 2000 x g at 5°C. The top hexane layer was removed and placed in a GC vial. Fatty acids were then analyzed by GLC after methylation (Chouinard, P.Y. et al., 1999).

Statistical analyses

Data was analyzed using MIXED procedures (Littell et al., 1996) of SAS (SAS Inst., Cary, NC), and means separated as least square means when differences were significant ($P < 0.05$). Milk components and production were analyzed as a split-plot with cow as the experimental unit and treatment by parity by farm as the whole-plot error term (St-Pierre, 2007).

Results and Discussion

Milk Components and Production

Our study showed no effect of diet on peak milk, milk yield, milk fat, milk fat yield, milk protein, or milk protein yield ($P \geq 0.16$; Table 3). Few studies have reported peak milk changes in response to supplemental fats. In a previous study with diets based on barley silage mixed with either Megalac® with flax seed meal (Diet = 9.3% EE) or whole flax seed treated with formaldehyde (Diet = 10.0% EE), milk production was decreased for flax seed fed cows (Petit, 2001). In this trial, basal diets were comprised of only barley silage and level of milk production for the early lactation multiparous cows was low (19.8 vs. 18.6 kg d^{-1}). The authors suggested this was likely due to lower silage quality. Khorasani and Kennelly (1994) found reduced milk production for cows fed whole flax seed (28.5 kg d^{-1}) compared to that of cows fed rolled flax seed (31.5 kg d-1), and rolled flaxseed/rolled canola seed (50:50) (31.6 kg $^{d-1}$). Their basal diets had a 40:60 forage:concentrate ratio with the forage being 50% barley silage and 50% alfalfa haylage. The authors assumed the reduction in milk production was likely due to the decreased digestibility of the whole flax seed.

As with the present study, Petit (2001), Kennelly and Khorasani (1992), and Khorasani and Kennelly (1994) reported no changes in milk fat, however, Petit found milk fat percentages tended ($P = 0.06$) to be lower for whole flax seed fed cows. The authors suggested increased fat mobilization may have contributed to these findings. In addition, Petit's study reported increased milk protein percentages with feeding flax seed, however, protein yield was not affected due to the reduced milk production. The authors indicated the percentage response was aided through the protection of the flax seed protein from ruminal degradability by the formaldehyde. Kennelly and Khorasani (1992) observed decreased protein percentages, but no differences in a the latest (1994) study.

The present study used rolled flax seed, which likely led to increased biohydrogenation of the unsaturated fats as well as increased ruminal degradation of the flax seed protein. Diets were formulated to contain 5% EE with the intent of following recommendations by the 2001 Dairy NRC which suggests not exceeding 6 to 7 % EE on a DM basis. It has been well documented (Allen, 2000; Devendra and Lewis, 1974) that dietary fat levels exceeding 5% will lead to decreased DMI, and reduced fiber digestibility. Clearly, a loss of DMI and fiber digestibility leading to decreased milk production and a reduced slope for the elevating energy status of the cow would diminish a protein response induced by feeding flax seed. Other studies have shown reproductive improvements when feeding flax seed with proposed mechanisms indicating independence from the improvement in energy status, while specifically increasing levels of omega-3 FA in diet to contribute to less series-3 prostaglandins (Mattos, 2001). Future studies may lead to increased dietary fat levels leading to a milk protein response while also decreasing early embryonic mortality. These complementing responses may lead to increased dietary fat levels which may prove to be beneficial regardless of slight DMI intake depression.

Table 3. Milk production and components for cows fed supplements of no flax (Control) or flax seed (Flax)

	Treatment		Statistics	
Item	**CON**	**FLX**	**SE**	***P*-values**
Number of cows	408	507	-	-
Peak milk, (kg)	45.50	46.46	0.917	0.49
Milk yield, (kg/d)	36.25	36.72	1.114	0.78
Milk fat, (%)	3.39	3.29	0.038	0.16
Milk fat yield, (kg/d)	1.23	1.21	0.045	0.76
Milk protein, (%)	2.75	2.78	0.016	0.27
Milk protein yield, (kg/d)	1.00	1.02	0.031	0.67

Milk Fatty Acid Profiles

Concentrations of C16:0 were significantly reduced for cows fed rolled flaxseed (Table 4). This result is in agreement with Khorrasani and Kennelly (1994) which reported increased C16:0 for the control diet compared to that of diets including whole flaxseed or rolled flaxseed. Our study also showed increased concentrations of C18:0, C18:1, C18:3n3, and C20:0 with the inclusion of rolled flax seed in the diet. These increases in C18 fatty acids are products of biohydrogenation in the rumen from the linolenic acid supplied by the rolled flax seed. The increase in C18:3n3 shows some unsaturated fatty is escaping ruminal biohydrogenation thereby increasing milk concentrations of omega-3 fatty acid. In addition, medium-chain length and saturated fatty acids were decreased in the present study for cows fed rolled flaxseed, while inclusion of rolled flaxseed increased the proportions of long-chain and monounsaturated fatty acids. Total omega-3 fatty acids were also increased with rolled flaxseed. Rolled flaxseed also decreased the omega-6 to omega-3 ratio which has been postulated to positively affect human nutrition.

Implications

Feeding 0.85 kg DM of flax seed daily can alter the fatty acid profile of milk while maintaining milk yield and composition in on-farm dairy applications. These results support supplementing dairy cow diets with flax seed to increase milk value by increasing omega-3 fatty acids.

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Table 4. Milk fatty acid composition for cows fed supplements of no flax (Control) or flax seed (Flax)

	Treatment		Statistics	
Fatty acid1	CON	FLX	SE	P-values
	---% of total fatty acids---			
C4:0	4.72	4.90	0.11	0.36
C5:0	0.04	0.04	0.003	0.53
C6:0	2.57	2.55	0.02	0.50
C7:0	0.04	0.03	0.002	0.26
C8:0	1.46	1.42	0.02	0.22
C9:0	0.04	0.04	0.002	0.32
C10:0	3.09	2.93	0.04	0.13
C10:1	0.29	0.28	0.005	0.15
C11:0	0.07	0.06	0.003	0.22
C12:0	3.53	3.43	0.12	0.62
C13:0	0.09	0.08	0.004	0.14
C14:0	11.03	10.67	0.10	0.12
C14:1	0.64	0.53	0.03	0.13
C15:0	1.00	0.95	0.01	0.14
C15:1	0.02	0.02	0.01	0.88
C16:0	29.33	26.88	0.17	0.01
C16:1	0.98	0.79	0.08	0.22
C16:2n4	0.03	0.01	0.01	0.42
C17:0	0.49	0.47	0.01	0.21
C17:1	0.18	0.16	0.006	0.17
C18:0	10.50	11.21	0.13	0.06
C18:1	22.59	24.60	0.20	0.02
c6 C18:2n6	2.47	2.44	0.09	0.83
t6 C18:2n6	0.21	0.21	0.06	0.98
t10, c12 C18:2[2]	0.08	0.07	0.03	0.83
c9, t11 C18:2[2]	0.35	0.42	0.02	0.12
C18:3n3	0.53	0.85	0.03	0.02
C18:3n6	0.05	0.04	0.007	0.30
C19:0	0.0004	0.01	0.005	0.23
C20:0	0.02	0.05	0.004	0.04
C20:1	0.01	0.01	0.004	0.72
C20:2	0.02	0.03	0.006	0.52
C20:3n3	0.009	0.009	0.003	0.98
C20:3n6	0.09	0.06	0.02	0.35
C20:3n9	0.01	0.01	0.002	0.24
C20:4	0.07	0.07	0.01	0.83
C20:5	0.02	0.03	0.005	0.38
C21:0	0.01	0.01	0.002	0.18
C22:0	0.05	0.04	0.005	0.26
C22:1	0.03	0.04	0.009	0.65
C22:2	0.01	0.02	0.003	0.19
C22:6	0.06	0.03	0.02	0.48
C23:0	0.009	0.00002	0.003	0.15
C24:0	0.001	0.0002	0.001	0.40
C24:1	0.00	0.00	-	-
Unknown	1.29	1.44	0.09	≥ 0.11
Short-chain[3]	15.96	15.77	0.22	0.60
Medium-chain[4]	45.54	42.52	0.23	0.01
Long-chain[5]	37.53	40.85	0.29	0.02
Monounsaturated	24.12	25.91	0.24	0.03
Polyunsaturated	4.01	4.32	0.07	0.09
Saturated	68.19	65.90	0.28	0.03
Total omega-3	0.54	0.85	0.03	0.02
Total omega-6	2.82	2.75	0.06	0.47
Omega-6:omega-3	5.46	3.23	0.24	0.02
Total CLA	0.43	0.50	0.02	0.10

[a-b]Means within rows with different superscripts differ ($P < 0.06$).

[1] Expressed as number of carbons:double bonds.

[2] Conjugated linoleic acid.

[3] Short-chain fatty acids (C_6 to C_{12}).

[4] Medium-chain fatty acids (C_{14} to C_{17}).

[5] Long-chain fatty acids ($\geq C_{18}$).

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Cow Comfort: What Have We Learned Lately?

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Introduction

Cow comfort and behavior continues to be a topic of interest among dairy producers. Research in North America is somewhat limited, but growing. Research in this field is relatively difficult to conduct and a very limited number of research facilities are available. The University of British Columbia in Canada, for example, has a research facility that allows the investigation of behavior and well-being of dairy cows and calves in a group setting. Group sizes are small, but they can provide an indication on how facilities can affect the animals and it is expected that results would be applicable to an on-farm situation. Other facilities are beginning to be used at some universities and institutes in the U.S. too. In our group in Minnesota, we have conducted field studies with commercial dairies, which perhaps corresponds more to the 'real world', but research manipulations are almost impossible to achieve. Those studies, therefore, are of an observational nature. We probably need both types of studies in order to better understand cow comfort. This article will summarize some of the recent findings in cow comfort and behavior in the U.S. and Canada.

Heat stress and its relationship to resting behavior

Cook et al. (2007) investigated the lying behavior of 14 cows housed in a 3-row freestall pen at temperature-humidity (THI) indexes of 56.2 to 73.8. They observed a reduction in lying time from 10.9 to 7.9 hours/day from the coolest to the hottest filming session. Cows expressed this reduction in lying time predominantly between 6 a.m. and 6 p.m. The time cows spent standing in the alley increased from 2.6 to 4.5 hours/day from the coolest to the hottest filming session. Because changes in behavior were noted at THI of 68, authors suggested more aggressive heat abatement strategies, perhaps an activation temperature of 70 F for turning fans and sprinklers.

Endres and Barberg (2007) compared lying time of cows housed in 12 compost dairy barns when the THI ≥ 72 (60% of all hourly observations) or < 72 (40% of all hourly observations) during a period of seven days per farm and a total of 25,734 hourly observations. Less time was spent lying when the THI was ≥ 72. The time lying/hour was 53.6 ± 38.5% or, 12.7 hours/day when THI < 72. In contrast, the time lying/hour was 32.8 ± 37.1%, or 7.9 hours/day when THI ≥ 72. This study also shows the importance of heat abatement in dairy cow facilities in order to improve cow comfort and optimize productivity.

Management effects on feeding behavior

Hosseinkhani et al. (2008) measured the feed sorting, feeding behavior and feed intake of close-up cows to find out whether these behaviors were affected by competition for feed space. Treatments were non-competitive access (one cow per feeding bin) or competitive access (two cows per feeding bin). They monitored behaviors on four separate days during weeks two and three prior to anticipated calving date. Competition at the feed bunk did not have an effect on dry matter intake, sorting behavior, or feeding time, but dramatically increased feeding rate. Cows assigned to the competitive treatment also had fewer meals per day, and tended to have larger and longer meals. These changes could potentially affect the composition of the diet consumed. It is recommended that at least one feeding space per cow be provided during the close-up period with at least three feet of feed bunk space per cow.

Huzzey et al. (2007) reported that prepartum feeding time and dry matter intake were best able to identify cows at risk for metritis. Odds of severe metritis increased by 1.72 for each 10-minute decrease in feeding time during the week before calving, and for each 2.2 lb reduction in DMI during this time, cows were about three times more likely to be diagnosed with metritis. It was also observed that cows more prone to become sick had fewer aggressive interactions at the feed bunk than cows that remained healthy. Management of this critical group of cows to allow easy access to feed without the need for much competition is warranted.

Mentink and Cook (2006) investigated feed bunk utilization patterns of dairy cows in freestall pens with either two or three rows of stalls. They utilized 24-h videos of the high cow group in five herds with 2-row pen designs and five herds with 3-row pen designs that were provided fresh TMR once a day after the morning milking. From the video observations they noted the feed bunk utilization score (proportion of feed bunk spaces in the pen that were filled) for each pen. Data were aligned according to peak feed bunk utilization score following fresh feed delivery (primary peaks), return

from the afternoon milking (secondary peaks), and return from the night milking (tertiary peaks). Bunk utilization score was highest for primary peaks, and scores were similar between 2- and 3-row pens (0.65 vs. 0.71, respectively). Differences in bunk utilization between peak type and pen row type were observed; tertiary bunk utilization with 2-row pens was significantly lower than bunk utilization with 3-row pens and significantly lower than either primary or secondary bunk utilization in 2-row pens. The feed space allowance provided by a 2-row pen design potentially allows cows to demonstrate other important feeding behaviors, such as avoidance of conflicts and maintenance of greater inter-cow distances between neighbors while feeding.

The effects of regrouping on feeding behavior, social behavior and short term milk production change were investigated by von Keyserlingk et al. (2008). Behaviors and milk production were monitored from three days before until three days after regrouping. Cows were individually introduced into established groups. Feeding time was 15 minutes less in the first hour after regrouping compared to the three days before regrouping. Displacements from the feed bunk were more than 25 times on the day of regrouping compared to 10 times per day before regrouping. The number of displacements gradually declined after the first day of regrouping. Number of lying bouts and lying time were also affected by regrouping. On the day of regrouping, the number of allogrooming effects was reduced from 7.5 to 1.3 events per day. Milk production was reduced on the day of regrouping by about 8 lbs, but returned to premixing levels on the following days. They suggest that management changes that could reduce the negative effects of regrouping should be investigated.

Cow comfort aspects and their effect on lameness

Espejo and Endres (2007) measured lameness prevalence in 50 randomly selected freestall herds in Minnesota. Of all the herd-level management risk factors investigated, daily time away from the pen for milking was positively associated with the prevalence of lameness, whereas cow comfort quotient (number of cows lying in stalls/number of cows touching a stall) was negatively associated with prevalence of lameness. Prevalence of lameness was greater when farms performed hoof trimming only when the manager decided cows needed it because of hoof overgrowth or lameness compared with all cows in which feet were trimmed on a maintenance schedule once or twice annually. Brisket board height of more than 6 inches and presence of the area behind the brisket board filled with concrete were associated with greater prevalence of lameness. Most of these herd-level factors could possibly be managed in order to reduce lameness prevalence in commercial dairy farms.

Hernandez-Mendo et al. (2007) investigated whether providing cows a four-week period on pasture would improve locomotion and change lying behavior. Groups of cows that were initially housed in a freestall barn, were assigned to either continued housing in the same freestall barn, or moved to pasture to provide changes in both physical environment and diet. To assess lameness, they recorded locomotion scores (1 to 5) weekly for four weeks. Locomotion improved (0.22 units per week) for cows kept on pasture. They also noted that tracking up and reluctance to bear weight evenly on all four feet improved during the pasture period. They noted that cows on pasture spent less time lying down than cows kept indoors (10.9 vs. 12.3 hours/day), although this lying time was spread over a larger number of bouts (15.3 vs. 12.2 bouts). Endres and Barberg (2007) also noted a reduced lying time for cows that had access to pasture compared to cows that stayed in bedded packs the entire time. By having a soft surface to stand on (pasture or bedded pack), standing time does not appear to correlate with increased prevalence of lameness. Hernandez-Mendo et al. (2007) suggest that a period on pasture may be used to help lame cows recover from foot and leg injuries.

Flower et al. (2007) studied dairy cows walking on concrete or on a soft, high-friction composite rubber surface to examine how flooring influenced locomotion and how this differed for cows with hoof lesions. They used video recordings of the cows while walking to calculate stride variables (length, height, overlap, duration, proportion of triple support, and speed). Locomotion was scored by a subjective scoring system (1 = sound to 5 = severely lame) and by a continuous visual analog scale for each of seven locomotion attributes. Results indicated that cows with sole ulcers walking on a rubber surface had longer strides, higher stride heights, more stride overlap, shorter periods of triple support (three legs in ground contact), walked faster, had lower overall locomotion scores, better tracking-up, better joint flexion, more symmetric steps, and less reluctance to bear weight on their legs compared with walking on concrete. Similar results were found for cows without sole ulcers. Cows with higher locomotion scores (more severe lameness) showed the greatest improvement in stride length, triple support, swing duration, overall locomotion score, and reluctance to bear weight when walking on the rubber surface compared with cows with lower locomotion scores. It can be concluded from these results that rubber flooring is more comfortable to walk on and offers a more secure footing, especially for lame cows.

Stocking density

Krawczel et al. (2008) evaluated the effects of increasing stocking density on cow comfort indices measured over a 24-h period, between 12 midnight and 4 a.m. (peak lying period), and at one hour after the afternoon milking using Holstein cows housed in one of four pens. Stocking densities were 100, 113, 131 or 142% (based on number of stalls). Using video recordings, authors measured percentage of cows lying in stalls, standing in stalls, standing in the alley, and eating at the feedbunk. More cows were standing idly in the alley as stocking density increased above 113%. Cow comfort index (cows lying down in stalls/cows touching a stall) and stall standing index, were similar across stocking densities, whereas stall usage index (cows lying in stalls/cows in pen not eating) decreased with stock densities greater than 113%. Indices did not vary by stocking density when measurements were taken at one hour after milking.

Fregonesi et al. (2007a) investigated the effect of overstocking on the lying and standing behavior of lactating dairy cows. Stocking densities were 110, 109, 120, 133, and 150% (based on number of stalls). They used groups of 12 cows for their study. Each group was exposed to each density for a week, with a return to 100% density after exposure to the other treatments. They also measured the ability of each cow to displace other cows from the stall. Cows spent less time lying down when they had fewer stalls available. Cows stood longer in the alley. Cows were more likely to be displaced from the stalls at higher stocking densities. Cows lay down sooner after milking at 150% than 100% and they used stalls more uniformly as density increased.

What could be the potential impact of reduced lying time on productivity? The effect of stocking density (100, 115, 130 or 145%) on milk production and behavior was investigated at the Miner Institute (Grant, 2006). They found that production dropped from 94.6 to 91.3 lbs per day as density increased. Lying time was reduced 1.1 hours/day when density increased from 100 to 145%. They looked at a data set from previous behaviors studies at Miner and reached the conclusion that each hour change in resting time was associated with a 3.5 lb difference in milk production. It is unknown yet what that number really is, but there is probably a relationship between lying time and production. Grant suggested limiting overcrowding in 2-row freestall pens to 120% or less. More research on this topic is warranted to better quantify the resting time effect on milk yield.

Stall design and management

Tucker et al. (2006) reported that cows preferred to lie down in stalls without a brisket board, spending 68% of their time lying down in those stalls when given a choice. Cows spent 1.2 hours/day more lying down in stalls without a brisket board. They positioned themselves relatively forward in the stalls 98% of lying bouts when the brisket board was absent compared to 67% of bouts when the board was present. Longer cows were more likely to move forward than shorter cows. Lying bouts were longer in stalls without brisket board. Their results indicate that brisket boards make stalls less comfortable to cows.

It has been shown that cows prefer to lie down in stalls with sufficient amounts of bedding, but what about bedding moisture? Fregonesi et al. (2007b) looked at the effects of sawdust bedding quality on stall preference and use. Groups of cows were tested sequentially with access to stalls that were either dry (86.4% DM) or wet (26.5% DM), each for two days. They followed the non-choice phase with a free-choice phase where cows had access to both types of stalls. Ambient temperature during the study period was a minimum of 38 F and a maximum of 44 F. Lying time was 8.8 hours per day when they had access only to stalls with wet bedding and lying time increased to 13.8 hours per day when stalls with dry bedding were provided. More perching (two feet in the stall) was observed with wet bedding than dry bedding. During the free-choice phase, cows spent more time lying down in the dry stalls (12.5 hours per day vs. 0.9 hours/day in stalls with wet bedding). The study demonstrated that cows have a greater preference for a dry lying surface. As we always say, dry, clean, comfortable lying surface is what cows need for cow comfort and udder health.

Conclusion

These studies indicate the importance of improving cow comfort in dairy operations. A lot more needs to be learned about cows' behavior and well-being. The availability of research facilities in the U.S. that allow for application of treatments to groups of cows is still very limited, but progress is being made. Field studies also contribute to the understanding of cow comfort. Other studies have been conducted in Europe and not reported in this article, but they also add to the body of knowledge in the field.

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Modulation of Immune Function in Ruminant Livestock

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The purposes of this short manuscript will be to review some of the standard nutritional approaches by which producers may maintain immunity in their livestock and to review some results of our recent studies which have shown that a feed additive which we recently developed is also able to modify several important aspects of immunity. First, however, some general background on immunity is provided.

General Aspects of Immunology

Higher animals (i.e., vertebrates) are endowed with two aspects of their immune systems. These are the innate system and the acquired (antibody-mediated) system (Janeway et al., 2005). The innate system is an evolutionarily ancient system found in invertebrates as well and consists of a variety of strategies to prevent an infection. Elements of innate immunity include:

- Epithelial barriers. The skin and epithelial surfaces of the lungs, gastrointestinal tract and mammary gland provide a first line of defense against pathogens of all types (bacteria, viruses, fungi and parasites).
- Digestive stomach acid. The hydrochloric acid of the stomach (or abomasum) reduces the likelihood that a pathogen may pass through this digestive sac into the lower gastrointestinal tract.
- Complement. The liver produces a variety of proteins, collectively known as "complement", which are able to bind to pathogens and to thereby mark those pathogens for destruction. Complement proteins may assemble on the cell wall of a pathogen and form a "membrane attack complex" or they may recruit cells of the innate immune system to assist in killing.
- White blood cells. Some of the white blood cells (monocytes and their derivative cell type [i.e., the macrophage], neutrophils, eosinophils and basophils are endogenously produced in the bone marrow and are able to identify and kill pathogens which have crossed the epithelial barriers. To detect the presence of pathogens within the body, these cells express on their cell surface (as well as extracellularly and intracellularly) a repertoire of germline-encoded pathogen receptors. These receptors include the Toll-like receptors (of which 11 have been identified in humans), Dectin-1, CD14, NOD-like receptor, peptidoglycan recognition proteins (PGRPs), and mannose-binding lectin (Lippolis, 2008, in press). It is important to underscore the point that this collection of pathogen recognition receptors is able to recognize a limited subset of pathogen molecules because they are "germ-line encoded".

In most cases, the innate system provides adequate protection from an infection. In cases where the innate immune system is "breached", the acquired (antibody-mediated) system becomes activated.

Another type of white blood cell which is part of the innate system is the "dendritic cell". When pathogen invades a tissue, the dendritic cell, via its pathogen receptors, is able to identify it as "foreign" (Janeway et al., 2005). The pathogen is phagocytosed by the dendritic cell after which it is partially digested intracellularly. During this digestion, the dendritic cell migrates the nearby lymphoid tissue (e.g., lymph nodes) and presents portions of the ingested pathogen on its cell surface associated with a group of proteins called the "major histocompatibility complex [MHC]". In lymphoid tissue, naïve B and T lymphocytes come into contact with antigen-presenting dendritic cells and those which display antibodies which bind to the presented antigen become "activated". This process of activation initiates a process of clonal selection whereby those lymphocytes displaying antibodies specific for the membrane-bound antigen begin to rapidly divide. The B lymphocytes activated in this manner become antibody-secreting plasma cells and the selected T-cells exit the lymph node with antibodies tethered to their cell surface. The binding of secreted antibody (i.e., from plasma cells) or of T cells via tethered antibody initiates processes whereby the targeted pathogen is marked for killing. Additional reading of Janeway et al (2005) is recommended for a thorough overview of immunology.

Nutritional Support of Immunity

Nutrition impacts all aspects of an animal's physiology; hence, it should not be surprising that deficiencies of most nutrients bring about some form of immune impairment. Calder and Kew published a survey in 2002 which listed all nutrients known to support immunity. In non-ruminants, this list included essential amino acids, linoleic acid, vitamin A, folic acid, vitamin B_6, vitamin B_{12}, vitamin C, vitamin E, zinc, copper, iron and selenium. More recently, studies have shown that calcium and vitamin D also play important roles in supporting immunity (Cantorna, 2006). A challenge in integrating all that is known in how nutrition supports immunity is that there is not a standard method to assess "immunity". Dozens of methods exist and are acceptable in peer-reviewed journals. Hence, it is often difficult to compare the roles of individual nutrients to other nutrients as no single method of assessing immunity exists.

One of the most intriguing ways in which individual nutrients support immune function is via provision of antioxidants (Chew and Park, 2004). Immune cells such as neutrophils utilize the generation of reactive oxygen species (ROS) in killing of pathogens (Chew and Park, 2004). This high generation of ROS in immune cells places these cells at high risk for oxidative damage. Further, the membranes of immune cells are typically higher in polyunsaturated fatty acids because these are used in formation of signaling molecules used by the immune system (e.g., leukotrienes, thromboxanes, etc). As a result, the high level of ROS generation has potential to also damage membranes through free radical-induced damage. Therefore, any nutrient with anti-oxidant properties is thought to play immune supportive roles. Examples of nutrients which function as anti-oxidants are well known and include vitamin E, selenium, vitamin A and various carotenoids. Minerals also support the immune system as components of enzymes involved in normal immune function. For example, both copper and zinc are used in the generation of ROS. Deficiencies in Cu and Zn thereby bring about immunodeficiency.

In recent years, more specific molecular mechanisms by which the nutrients support immunity have been elucidated. For example, vitamin B6 is required for the formation of lymphocyte receptor which is involved in lymphocyte trafficking between blood, lymphoid tissues and peripheral tissues.

Use of novel feed additives to regulate immune function in livestock

In 2002, we developed a feed additive for livestock (OmniGen-AF) which is now commonly used in the US dairy industry. Since that time, we have conducted approximately two dozen studies in a variety of species (sheep, dairy cattle, beef cattle, swine, poultry and laboratory species [mice and rats]) which have examined the hypothesis that the additive had the ability to augment immune function. We do not have enough room to present all data collected in this short review paper and, so, we with present a synopsis of what we now know about this additive's ability to regulate immune function.

a. Effects of the additive on molecular markers of neutrophil function

Neutrophils represent the most abundant white blood cell type and are the first cell to arrive at a site of infection. Their arrival to an infection site is mediated by tissue macrophages which secrete chemoattractants (e.g., interleulin-8 [IL8]). To date, we have examined three markers of neutrophil function following the addition of the additive to the diets of various species. These markers include L-selectin (CD62L), interleukin 8 receptor (IL8R) and interleukin 1β (IL1β). Studies have been completed in animals which have been immunosuppressed by daily injection of dexamethasone (Azium) and in non-immunosuppressed animals. In general, the additive increases molecular markers of neutrophil function by 50% to two-fold in normal animals but caused marked increases in these markers in immunosuppressed animals.

L-selectin is an extracellular neutrophil adhesion molecule which enables the neutrophil to adhere to the endothelial lining of blood vessels and to thereby find sources of infection following macrophage signaling. Earlier work by others (Weber et al., 2006) has shown that L-selectin is a "plastic" molecule: i.e., that in stressful situations (e.g., parturition) it is down-regulated. This represents a form of immunosuppression in that neutrophils with less L-selectin expression have reduced ability to seek out and find sources of infection.

In a recent study, we assessed effects of the additive on immune function in immunosuppressed sheep (Wang et al., 2007). The additive increased expression of L-selectin protein concentration and this effect was more evident when sheep were co-stimulated with a moldy feed.

IL1β is a cytokine released at a site of inflammation which brings about a variety of actions. It increases vascular permeability thereby increasing movement of fluids (which contain complement) from the blood into the tissue infection site. Further, it provides a feed-forward mechanism from the innate to the adaptive immune system by stimulating

lymphocyte differentiation (Janeway et al., 2005). Similar to its effects on L-selectin, the additive increased IL-1B protein concentration and this effect was pronounced when a co-stimulatory additive (moldy feed) was also provided.

More recently, we studied the effects of the additive on a broad range of genes which are expressed in bovine neutrophils using microarray analysis (gene profiling). To accomplish this study, we used the bovine total leukocyte array (BoTL-5) which has been developed by the Center for Animal Functional Genomics at Michigan State University. This study (Wang *et al.,* 2008) revealed that, in addition to the above-mentioned markers of neutrophil function, several additional genes were differentially-regulated in neutrophils recovered from periparturient dairy cattle. These included interleukin converting enzyme (ICE) and interleukin 4 receptor (IL4R). These changes explain the increase in expression of IL1β protein reported in Figure 1 (as ICE is a rate-limiting enzyme in IL1β formation) and also explain an observation which we have seen in several studies; that the additive increased concentrations of neutrophils in blood by 20%. IL4R signaling controls apoptosis in neutrophils and the differential expression of this receptor in neutrophils presents one plausible mechanism for this (Wang et al., 2008).

b. Effects of the additive on neutrophil physiology

While it may be exciting to find that a feed additive can bring about changes in molecular markers of neutrophil function, we needed to determine whether these changes brought about meaningful changes in the biology of the white blood cell. To test this, we examined effects of the additive on two markers of neutrophil physiology: phagocytosis and ROS generation. Effects of the additive on phagocytosis of *E. coli* and *Strep uberis* were assessed in neutrophils of immunosuppressed sheep and in neutrophils of commercial dairy cattle, respectively. In both cases, consumption of the additive increased the rate of phagocytosis (whether *E. coli* or *S. uberis*) by 50-60% ($P<0.05$).

Effects of the additive on ROS generation in neutrophils of immunosuppressed sheep have also been studied. The additive caused an approximately doubling ($P<0.05$) in ROS generation indicating that it increases the killing potential of individual neutrophils.

c. Effects of the additive on development of titer

We reasoned that if IL1β secretion by neutrophils is increased by the additive, that this could feed forward and activate the production of antibodies by the adaptive immune system (i.e., as noted earlier, one function of IL1β is to activate adaptive immunity). To test this hypothesis, we conducted a study with Angus beef cattle where were followed the development of J5 titer in IgM, IgG1 and IgG2 fractions following a vaccination program with a J5 bacterin vaccine. Animals were fed three levels of the additive (0, 15 and 30 g/day) for 56 days after which all animals were placed on the 0 g/head/day dose until Day 82 of the study. Animals were vaccinated with J5 vaccine on Days 7, 21 and 35 and blood samples were taken periodically throughout the trial for assessment of titer. We found that the additive had no effect ($P>0.05$) on development of J5 titer in the IgM fraction; however, it brought about significant improvements ($P<0.05$) in titer within IgG1 and IgG2 fractions. Specifically, animals fed the additive maintained J5 titer in the IgG1 fraction following removal of the additive from the ration through to Day 82 of the study. Animals which did not receive the additive lost J5 titer during this time. Furthermore, animals which received the higher level of the additive (30g/head/day) had elevated levels of J5 titer within the IgG2 fraction on Day 56 compared to animals which did not receive the additive. Further studies with different vaccines are now on-going.

d. Effects of the additive on animal health

Within the past year, we have embarked on a novel research program aimed at understanding mechanisms by which the additive may bring about improvements in animal health. Our primary focus has been on the incidence of mastitis and, to accomplish this, we have adapted a mouse model of bovine mastitis. Bovine isolates of *S. uberis, E. coli* and *S. aureus* have been obtained from field veterinarians in Iowa and Washington and have been deliberately infused into the teat canals of lactating mice (control and additive fed). Results have been promising. It is premature to provide all of the information on these studies in this review; however, results will be presented in detail at the upcoming meeting in Iowa.

Summary

Published (Wang et al., 2007, 2008) and unpublished studies have given us a fairly clear idea of the actions of the product in vivo. The main properties of the product include the following:

- The product increases neutrophil function (increased molecular markers, increased functional properties and increased numbers)
- The product also brings about improvements in titer following vaccination.
- Actions of the product take time to develop (about a month, perhaps longer).
- When the product is removed from a ration, its effects on immunity are lost over a period of about one week.
- Actions are detected in all mammalian species tested to date (ruminants, swine, rodents).
- The mechanism(s) by which the product brings about these changes is not entirely clear. However, our hypothesis is that it is a gastrointestinal-driven event (i.e., the product is detected by receptors lining the GI tract which sets up a cascade of events resulting in immune modulation). Various aspects of this hypothesis are under investigation.

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Feeding Pre-Weaned Calves for Future Production

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Introduction

Traditional goals of calf-rearing programs have centered on decreasing mortality and weaning to solid feeds as early as practically feasible on farms. Little thought has been given to the possibility that early feeding practices could influence subsequent productivity when these calves grow into lactating cows. Exciting developments in human biomedical research have shown conclusively that both prenatal and postnatal nutrition can influence metabolic characteristics as adults and the likelihood that adults will contract chronic diseases such as diabetes, hypertension, and atherosclerosis. Might early life nutrition of dairy calves also impact metabolism and the capacity to produce milk as adult cows?

The most recent USDA National Animal Health Monitoring System survey reported that preweaning mortality of heifers alive at 48 h of age was 7.9% (USDA, 2007). Although slightly lower than previous survey results, industry-average morbidity and mortality of preweaned dairy calves remains unacceptably high in the US. Disease agents and environmental stressors interact with nutrition to determine disease susceptibility (Davis and Drackley, 1998). Labor for care and individual feeding of calves before weaning is the major cost of calf production, but nutritional inputs are also more costly during this period. Therefore, nutrition of young calves remains of paramount importance for calf health and profitability of dairy operations.

Conventional calf-rearing systems historically have restricted the amount of milk or milk replacer fed during the first few weeks of life in an effort to encourage solid feed intake and allow early weaning. Over the last several years, demonstrations of the remarkable improvements in growth and feed efficiency that are obtained by feeding greater quantities of milk (Flower and Weary, 2001; Jasper and Weary, 2002; Khan et al., 2007a,b) or milk replacer (Bartlett, 2001; Diaz et al., 2001; Tikofsky et al., 2001; Blome et al., 2003; Brown et al., 2005; Bartlett et al., 2006) have stimulated renewed interest in early calf nutrition. Such systems have been called by various names, including "accelerated early nutrition", "accelerated growth", "enhanced nutrition", "intensified nutrition", and "biologically appropriate growth". While interest in these systems has been high, a major limitation in adoption has been the unknown economic benefits of improved early nutrition. To develop a full economic model of the effect of such systems on dairy enterprise profitability, necessary inputs include effects on growth rates and cost per unit height or weight increase, effects on subsequent growth after weaning, effects on health, and effects on subsequent milk production. While data continue to accumulate in each of these areas, it is not yet possible to prepare a complete economic assessment. The objective of this paper is to provide an overview of the current state of knowledge on accelerated early nutrition programs and data that show negative or positive biological effects.

Nutrient Requirements

The rationale for so-called accelerated feeding is simple to appreciate if one considers nutrient requirements for growth in young calves. Like other animals, calves require nutrients for maintenance and for growth. Moreover, like other animals, amounts of nutrients required are not fixed but vary with body weight (BW) and average daily gain (ADG) of BW. The National Research Council (NRC) in its most recent publication of nutrient requirements for dairy cattle (NRC, 2001) established energy requirements for young calves in terms of metabolizable energy (ME). Recent growth experiments at the University of Illinois and Cornell University have provided data to develop modified NRC equations that better predict growth performance by dairy heifer and bull calves under typical US rearing conditions (Table 1).

Table 1. Nutrient requirements and estimated gain:feed for a 50-kg calf fed milk replacer under thermoneutral conditions, using the Cornell-Illinois modifications of NRC (2001) equations (Van Amburgh and Drackley, 2005)

Rate of gain, kg/d	Dry matter intake, % BW	ME, Mcal/d	CP, g/d	CP, % of diet DM	Estimated gain: feed
0.2	1.05	2.34	94	18.0	0.38
0.4	1.30	2.89	150	22.4	0.63
0.6	1.57	3.49	207	26.6	0.77
0.8	1.84	4.40	253	27.4	0.86
1.0	2.30	4.80	318	28.6	0.87

Several important principles can be demonstrated from data in Table 1. First, the amount of milk solids required to meet maintenance ME requirements is not small. The ME requirements for maintenance under thermoneutral conditions are approximately 1.75 Mcal/d for a 100-lb (45 kg) calf. Whole milk contains about 5.37 Mcal ME/kg of solids, which means that a 45-kg calf requires about 325 g of milk solids, or 2.6 kg of whole milk (about 2.5 L) just for maintenance. Because most milk replacers are lower in fat content than whole milk, they have less ME per unit of solids (4.6 – 4.7 Mcal/kg). Consequently, a 45-kg calf requires about 380 g (0.84 lb) of milk replacer (about 3.0 L as fed) for maintenance. Amounts of milk solids consumed above maintenance can be used for growth.

Second, for calves to grow faster, they need to be fed more milk or milk replacer, or, in older calves, they must consume more starter. Calves clearly respond to greater intake of milk or milk replacer with greater BW gains (Huber et al., 1984; Richard et al., 1988; Diaz et al., 2001; Jasper and Weary, 2002; Brown et al., 2005; Bartlett et al., 2006; Khan et al., 2007a,b). Third, the amount of crude protein (**CP**) required in the calf's diet as a percentage of dry matter (**DM**) is very low for maintenance but increases as rate of gain increases. Fourth, CP content of the diet appears to approach a plateau at about 28% of the DM, which is not unlike the CP content of whole milk solids (about 26% on a DM basis). Finally, these relationships highlight the importance of matching dietary protein and energy intakes with the expected growth performance of the calf. For example, feeding twice as much of a conventional milk replacer with 20% CP does not provide enough protein for lean tissue growth, and the surplus energy will be converted to fat. Conversely, feeding a high-protein milk replacer (e.g., 28% CP) designed for "accelerated growth" at conventional feeding rates of 1 to 1.25 lb/d (454 to 568 g/d) provides excess protein to the calves, which cannot be used for additional growth because energy is limiting. In this case the excess protein will be degraded and the nitrogen excreted in urine.

Requirements discussed to this point assume that calves are in thermoneutral conditions, which means that they do not need to expend energy to maintain body temperature. The thermoneutral zone for calves less than 21 d of age is 59 to 77 °F (NRC, 2001). Consequently, calves in the 4-state region spend a considerable portion of their time outside of the thermoneutral zone. Above or below this range, calves must expend more energy to maintain body temperature; in hotter temperatures they will pant and sweat, and in colder temperatures they will shiver and use other means to increase heat production. This increase in energy expended becomes part of the maintenance energy requirement. For calves older than 21 d, the lower critical temperature falls to about 41 °F, which means they are more able to withstand colder temperatures because of increases in body fat content and hair coat. The increased maintenance energy requirement in cold temperatures is built into the NRC model (NRC, 2001). As environmental temperature decreases, maintenance requirements for ME increase. A 100-lb calf at -20 °C requires about 563 g/d of milk replacer powder just to meet maintenance requirements and maintain body temperature, compared with about 382 g/d of powder under thermoneutral conditions. If calves are fed the same amount of milk or milk replacer as in thermoneutral conditions, less energy will be available to fuel growth.

Heat stress also increases the maintenance energy requirements of calves, although the exact amount needed for cooling has not been as well quantified as the effects of cold stress. Estimates based on data for older growing cattle (NRC, 2001) would indicate increased maintenance requirements of 20 to 30% (about 0.15 to 0.25 lb more milk replacer powder) during heat stress. Free choice water availability and shade are critical to maintain body temperature in young calves. Sand bedding also helps calves dissipate heat better than straw or wood shavings.

Based on data from an Israeli study (Arieli et al., 1995), an additional maintenance requirement may be needed by young calves undergoing transport. On average, this amount is about 100 g of powder for calves weighing 43-50 kg. Calves should be fed this increased amount (in addition to any needed for temperature allowance) for 14 d following transport (Van Amburgh and Drackley, 2005).

Conventional Vs. Accelerated Feeding Systems

Traditionally, calves have been fed limited amounts of milk or milk replacer (typically 8 to 10% of birth BW) with starter offered for ad libitum consumption from the first week of life. This amount of liquid feed is much lower than ad libitum intakes,

which are in the range of 16 to 20% of BW or 2 to 2.5% of BW as dry solids (Hafez and Lineweaver, 1968). The restricted liquid feeding approach arose in an attempt to stimulate early intake of starter and to minimize input costs of higher-value feed. In addition, early milk replacers were of poor quality and were not well utilized by calves at higher feeding rates (Davis and Drackley, 1998). Restricted feeding allows only for maintenance requirements and up to about 0.5 lb/d ADG under thermoneutral conditions (Table 1). As starter intake increases, typically doubling every week, enough nutrients are consumed to allow calves to begin to grow rapidly (Kertz et al., 1979).

A contrasting approach is the accelerated feeding system, which allows calves much greater intakes of liquid feed during early life, closer to "natural" conditions in which calves would have ad libitum access to milk. Milk feeding rates are approximately twice those of conventional systems. An easy thumbrule is to provide 1.5% of BW as milk solids during the first week of life, then 2% of BW from the second week of life until the week before weaning, when one feeding is dropped (Stamey et al., 2005). Intake of starter will lag behind calves fed on conventional systems, but increases at approximately the same rate once the amount of liquid is cut back (Stamey et al., 2005; Hill et al., 2006, 2007)]. To avoid or minimize growth slumps around weaning, calves should not be weaned until they are consistently eating 2 lb of starter daily. As shown in Figure 1, the major difference in growth rate is in the first 2-3 wk of life, and after that growth rates generally are parallel. Accelerated feeding programs using whole milk also can be successful, particularly when implemented with step-down (Khan et al., 2007a,b) or gradual weaning programs (Jasper and Weary, 2002).

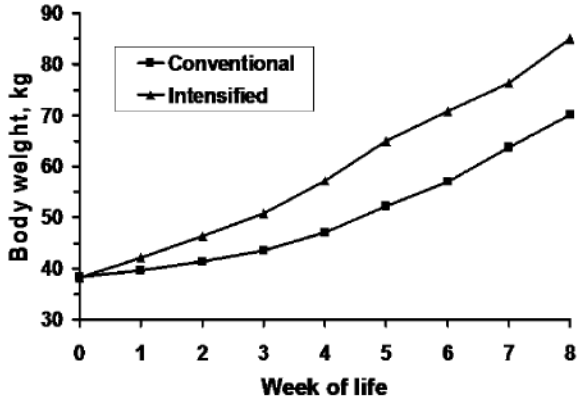

Figure 1. Example of differences in early growth between calves fed on a conventional limit-feeding program (milk replacer powder fed at 1.25% of birth BW; calves weaned at 35 days) or on an accelerated (intensified) program where milk replacer was fed at 2% of birth BW for wk 1, then 2.5% of BW at wk 2 during wk 2-5. Calves had access to water and starter from wk 1 of life and were weaned at d 42. (B.C. Pollard and J.K. Drackley, unpublished data, 2002)

Feeding programs have been developed that are intermediate in nature to accelerated and conventional programs. These moderately aggressive programs call for liquid intakes between those in conventional and accelerated programs (Stamey et al., 2006; Hill et al., 2006). These programs are reported to result in less slump in growth around weaning and fewer digestive upsets in calves than more aggressive liquid feeding programs (Hill et al., 2006), while still providing improved nutritional status during the critical first 2-3 wk (Stamey et al., 2006). Milk replacers designed for use in intermediate programs usually contain 24 to 26% CP and are fed at 1.5 to 1.75% of BW. While easier to implement, they do not fully capitalize on the early growth potential. These programs may be more easily implemented with transported or colostrum-deprived calves than are more aggressive accelerated programs (Hill et al., 2006).

Benefits of Accelerated Early Nutrition

Benefits of improved nutritional status in the first 2-3 wk may include reaching breeding age (and thus calving age) sooner, an improved ability to withstand infectious challenges, and increased subsequent milk production (Drackley, 2005).

Increased growth and earlier first calving

The increased early growth of heifers easily translates into 2 wk earlier calving age if typical BW or height differences at weaning are maintained. If heifers continue to grow more rapidly the advantage may increase to more than 1 mo. Of course, to realize this decrease in calving age, heifers must be bred according to body size rather than age. It is important to note that calves must have adequate early colostrum intake to be able to efficiently use additional nutrients from milk intake. In addition, calves undergoing adaptation to stressors such as transport also may be less able to utilize high amounts of milk solids intake in early life (Hill et al., 2006; Quigley et al., 2006).

Improved health

Poor health during early life is believed to have long-lasting effects on milk production and herd life. Epidemiological studies relating specific neonatal illnesses to later productivity generally have not found strong relationships between any specific illness or condition and subsequent survivability or productivity, although respiratory disease in calves increased the age at first calving (Correa et al., 1988). Early-life "dullness" in calves was a significant risk factor for shorter herd life. Calves that were

characterized as having dullness before 90 d of age (defined as dull appearance, listlessness, droopy ears, and off feed) were 4.3 times more likely to die after 90 d of age (Curtis et al., 1989) and 1.3 times more likely to leave the milking herd than herdmates (Warnick et al., 1997). The authors speculated that this condition might reflect the combined effects of poor health and suboptimal nutrition.

Considerable evidence points to inadequate nutrition during early life as a major factor in decreased resistance to disease and compromised health and well being. Williams et al. (1981) compared calves fed two amounts of milk replacer solids (600 g/d and either 300 or 400 g/d) with either ad libitum or restricted access to calf starter. Calves fed the higher amount of milk replacer with ad libitum access to starter had the greatest ADG and least mortality. More recently, Khan et al. (2007b) showed a reduction in fecal scores for calves fed at an accelerated rate with whole milk.

The available evidence suggests that improvements in health seen with calves fed greater amounts of milk or milk replacer likely are due to improved overall nutritional status rather than to any specific alterations in immune system characteristics or function. Studies that have examined functional aspects of components of the immune system generally have found small differences between calves fed conventionally or on accelerated programs (Griebel et al. 1987; Pollock et al., 1993, 1994; Nonnecke et al. 2003; Foote et al., 2005, 2007). Unfortunately, studies are not available in which calves have been grown on different planes of nutrition and then challenged with a disease organism to assess the impact of plane of nutrition on the ability to prevent disease or recover more quickly from disease.

The health status of young calves is impacted by interactions of early nutrition and the environment. Nutritional insufficiency may be especially problematic for immune function during cold or heat stress, when maintenance requirements for temperature regulation are increased. For example, we conducted an experiment to determine the value of supplementing milk replacer with energy sources for Jersey calves raised in hutches during winter (Drackley et al., 1996). To do so required establishment of an appropriate baseline feeding regimen. Jersey heifer calves fed a conventional milk replacer at 8% of BW did not maintain BW and had a high incidence of health problems. Calves fed the same milk replacer at 10% of BW gained small amounts of BW but still were unhealthy. Only when calves were fed at a rate of 12% of BW were they able to maintain health and modest rates of BW gain.

A study conducted in Minnesota (Godden et al., 2005) compared equal volumes of pasteurized non-saleable milk and a conventional milk replacer. Because whole milk contains about 17% more energy than milk replacer at equal amounts, indirectly these authors were comparing two planes of nutrition. Calves fed the pasteurized non-saleable milk had greater ADG than those fed milk replacer. In summer, mortality of calves did not differ between those fed milk (2.2%) or milk replacer (2.7%). However, for calves born in the winter, mortality was much greater for calves fed milk replacer (21.0%) than for those fed milk (2.8%). Much of this difference is likely attributable to the marginal nutrient status of the calves fed milk replacer because of the greater maintenance energy requirements during cold stress.

Greater subsequent milk production

One of the most exciting current areas of research concerning accelerated feeding is to document long-term effects of early nutrition on subsequent productivity. As more and more lactation data become available for calves fed differently after birth it is becoming clear that improved growth rates and early nutrition translate into greater milk production. Several earlier studies suggested improvements in subsequent milk production when calves were fed greater amounts of milk (Foldager and Krohn, 1994; Foldager et al., 1997; Bar-Peled et al., 1997). Average improvements in first-lactation milk yield are in the range of 1,000 to 2,000 lb milk.

We compared an accelerated milk replacer feeding system with a conventional limit-feeding system for calves born in spring and summer over two subsequent years (Pollard et al., 2003). The same milk replacers were fed in each year but the feeding rate of the accelerated program varied slightly in the two years; consequently each year represents a separate trial. Calves fed the acclerated treatments had greater ADG during the milk feeding period (Table 2), but stalled markedly around weaning. By 12 wk of age, differences in BW and stature had narrowed between groups. First-lactation 305-day actual milk yields (Drackley et al., 2007) are shown in Table 2. Early life enhanced feeding resulted in greater milk production during the first lactation, although the tendency for the diet by trial interaction indicates that the difference was greater for Trial 1 than Trial 2. "Accelerated" heifers from Trial 1 calved about 1 mo later on average, were slightly larger, and had greater milk yields. Heifers from both diets in Trial 2 calved at the same average age and BW, and milk yields differed less. Regardless of diet, heifers from Trial 2 did not perform as well as those from Trial 2. This points out the importance of variation from year to year, which complicates on-farm determination of effects of management changes. Correlation analysis revealed that ADG was correlated negatively with subsequent milk production within the conventional treatment but was correlated positively with milk production in the

accelerated treatment (M. E. Van Amburgh and J. K. Drackley, unpublished).

Table 2. Growth and first-lactation data for heifers fed either conventional or intensified milk replacer programs as calves in two trials (Drackley et al., 2007)

Variable	Conventional	Accelerated
ADG to weaning (lb)		
Trial 1	1.14	1.65
Trial 2	1.23	1.56
Age at calving[a] (mo)		
Trial 1	25.4	26.5
Trial 2	24.0	24.3
Calving BW (lb)		
Trial 1	1,238	1,284
Trial 2	1,243	1,238
305-d milk[abc] (lb)		
Trial 1	20,340	23,269
Trial 2	19,351	20,104

[a]Trial, $P < 0.01$.

[b]Diet, $P < 0.01$.

[c]Diet _ trial, $P = 0.13$.

We currently are completing analysis of a large experiment with heifer and bull calves born on the University of Illinois dairy farm (Stamey et al., 2005, and unpublished). The experiment compared a traditional restricted-feeding program of a 20% CP, 20% fat milk replacer with an intensified step-up feeding program using a 28% CP, 15% fat milk replacer. Both groups of calves had starter and water available free choice and were weaned at 6 wk of age. The ADG through 8 wk of age were 20% greater (777 g/d vs. 648 g/d) for the intensified calves. Of greater importance is that gains of withers height were also about 24% greater for the intensified calves. We have followed these heifers through subsequent growth and first lactation, and the data should allow a complete economic evaluation of the program.

Conclusions

The concept of "accelerated feeding" for young milk-fed calves is now well-accepted as an alternative to traditional restricted feeding. Research and field experience have highlighted many important aspects that are important for successful implementation. Calves must be fed a properly formulated milk replacer or whole milk at approximately twice the conventional rate. A step-down or gradual weaning process facilitates a smoother transition to dry feed. Colostrum-deprived calves or calves that are undergoing transport stress will not respond as well to increased amounts of milk and may in fact be impacted negatively. Benefits to accelerated milk-feeding programs include decreased age at first calving, improvements in health, and increased milk production. Ongoing research will provide the necessary input variables to model the overall economic impact of accelerated milk feeding programs.

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Novel Nutrition for Dairy Replacement Heifers

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Introduction

The goals of a dairy replacement management program are to rear heifers at a low economic and environmental cost without compromising future lactation performance. To meet these objectives, increased sophistication dairy heifer nutrition programs may be required. Research evaluating more sophisticated dairy heifer nutrition programs however does not always result in a relevant field application. For example, numerous research trials have evaluated protein degradability in dairy heifer diets. Neither negative nor positive effects on improving milk yield, growth or decreasing feed cost have been observed. In contrast, dairy heifers have commonly been fed diets containing low cost, high fiber forages (MPS, 2003), which meet the low energy requirement (NRC, 2001) of replacement heifers. Feeding bred heifers low energy, high fiber forages minimizes over-conditioning at calving which can be detrimental to lactation performance (Hoffman et al., 1996) but feed efficiency and feed cost of this feeding practice is seldom considered. Recent research, while limited has demonstrated that heifers can be limit-fed to control over-conditioning resulting in reduced feed cost without effect on lactation performance. Thus, limit feeding is potential management practice that meets the goals for field application as defined above. This paper will review limit feeding and other new and potential innovations in dairy heifer nutrition.

Ancillary Review of Heifer Management Research

An ancillary review of published heifer research and field application relevance to improve milk yield or decrease rearing cost is presented in Table 1. The review is not limited to nutrition research rather it encompasses published heifer research topics for the years 1990-2006. A completed listing of all published references would be exhaustive and thus are not listed. The author's intent was not to provide a detailed summary of published heifer research but rather to provide an ancillary view of research as it pertains to field application. Table 1 provides a general categorization of whether a heifer management practice has been demonstrated by research to improve future milk yield, or decrease rearing cost using a simplified +,-, or 0 rating system. An index of each management practice category is also provided using a +,- or 0 system. Management practices with a + index indicate the management practice may improve milk yield or decrease rearing cost. A management practice with a – rating may decrease milk yield or increase cost. A management practice with a 0 rating is an ambiguous management practice in which net benefit to the heifer management program is difficult to ascertain. The reader is cautioned that information in Table 1 is qualitative.

In an example, improvement in milk production by utilizing proven AI sires is predictable and well documented (Kelm, et al., 2000) with annual milk production improvement estimates from 150 to 250 lbs/year. In contrast, our laboratory (Drendel et al., 2005) demonstrated that a heifer having an event of lameness during the rearing phase was 27.7 - 15.1 more times likely to have a lameness event in the first 2 months post-partum which if occurs, reduces milk yield approximately 3500 lbs/lactation. Therefore, to improve future performance of dairy heifers some best management practices would logically include selection of high merit AI sires and management practices that prevent events of lameness in dairy heifers.

In contrast, acutely adopting a nutritional management practice to reduce the calving age from 24 to 20 months of age is an ambiguous management practice (Table 1). Reducing the calving from 24 to 20 months of age may decrease feed cost by reducing the days on feed. However research (Hoffman et al., 1996, Hoffman, 1998) has also demonstrated a chronic reduction in first lactation milk yield when heifers calve at ages < 22 months. These data are supported by industry observations. Kelm et al, 2000 reported a dynamic shift in age at first calving between 1980 and 2004 with the majority of first calvings (2000) now occurring at 23-24 months of age. The dairy industry however calves less than 1 % of all dairy heifers (2000) at less than 22 months of age indicating some general bottleneck in field application is observed.

A complete review of the idiosyncrasies of all of heifer management practices listed in Table 1 is beyond the scope of this paper. The information in Table 1 is simply designed to highlight management practices of greater or lesser potential to improve heifer management. Of the management practices listed there are three nutrition management practices that are relatively novel, limit-feeding, controlled bunk management and feeding low cost forage or byproduct feeds. The remaining portion of this paper will review these particular heifer nutrition practices.

Feeding Low Cost Byproduct Feeds

Often, distillers grains can be purchased at highly competitive prices, making it a highly attractive feed to include in dairy replacement heifer diets. Typically, nutrients in distillers grains make it a very desirable feedstuff, but positioning distillers grains in heifer diets can be challenging. There are no known biological or nutritional advantages or disadvantages associated with feeding distillers grains to dairy heifers. Research trials, which fed distillers grains to heifers, have observed normal growth rates, normal reproduction and normal subsequent milk production.

The challenges associated with feeding distillers grains to dairy heifers are:

1) Distillers grains are high in energy and excessive supplementation may result in over-conditioned heifers.

2) Distillers grains are rich in free, largely unsaturated oil of which the effects to feeding heifers are largely unknown.

3) Distillers grains are high in phosphorus and the phosphorus requirement of dairy heifers are low.

4) Distillers grains are low in lysine and the dynamics of lysine supply has not been extensively studied in dairy heifers.

There are a moderate number of research trials that have successfully fed distillers grains to dairy heifers, but most trials were not designed to specifically evaluate distillers grains as a protein supplement per se. In most trials, researchers limited distillers grains to <20% of the dietary dry matter. Researchers at South Dakota State University have fed up to 40% of the diet as distillers grains which resulted in excessive heifer growth rates (>2.4 lbs/d). High supplementation rates of distillers grains result in diets high in dietary fat (7-9%) and the effects of high supplementation rates of unsaturated fat to dairy heifers has not been investigated. The fatty acid composition of distillers is primarily C18:2 which is bio-hydrogenated in the rumen to C18:0. Under certain dietary conditions (high intake, fast passage rate, low ruminal pH, etc.) not all C18:2 will be bio-hydrogenated resulting in some C18:2 being absorbed. Research with lactating cows and steers has demonstrated some isomers of C18:2 (conjugated linoleic acid) can be absorbed and these C18:2 isomers may have highly active metabolic effects. Research data with growing steers fed high distillers grains diets have observed increased pelvic fat deposition and increases in C18:2 composition of adipose tissue. Because heifers are fed high forage, low energy diets with moderate ruminal passage rates, bio-hydrogenation of moderate amounts of C18:2 to C18:0 should readily occur. Because very little information is available on the possible negative or positive aspects of feeding unsaturated fats to dairy heifers, it is prudent to take a conservative approach and limit unsaturated fat content in heifer diets to approximately 5.0% of dietary DM (Table 2). This guideline results in limiting distillers grains in heifers diets to < 20.0% of DM.

An irreconcilable nutritional issue with feeding distillers grains to dairy heifers up to 20% of dietary DM is excessive levels of phosphorus will be fed (Table 2). Feeding phosphorus at 100-200% of requirements has not been demonstrated to affect animal health, but nutrient management programs may be compromised, as excess phosphorus will be excreted in the feces.

Distillers grains with solubles may also be high in sulfur (0.35-0.55% DM) and high dietary sulfur levels may be linked to polioencephalomalacia in rapidly growing heifers. There is no direct evidence feeding distillers grains results in an increased incidence polioencephalomalacia, but dietary sulfur levels should be carefully monitored as a prudent nutritional management practice.

Limit-Feeding

Another immerging innovation in feeding dairy heifers to control over-conditioning, and improve feed efficiency, would be to limit-feed a more nutrient dense diet which provides an alternative management strategy to reduce feed cost and nutrient excretion both of which are becoming a greater concern in the dairy industry. Lammers et al., 1999 used a limit-feeding strategy to control growth rates of pre-breeding Holstein heifers and observed no negative effects on first lactation performance. Limit-feeding strategies have also been employed successfully with other livestock species such as beef cows, (Loerch, 1996), ewes (Susin et al. 1995) and beef heifers (Wertz et al. 2001). In dairy replacement heifer management systems limit-feeding of bred heifers may yield the maximum management benefit because bred heifers have high feed intakes (NRC, 2001) and excrete more manure DM (Wilkerson, et al., 1997) as compared to pre-breeding heifers.

Recently we explored a simple limit-feeding feeding system for replacement heifers (Hoffman et al., 2006). Bred Holstein heifers (1000 lbs) were fed diets (C-100, L-90 and L-80) containing 67.5, 70.0 and 73.9 percent TDN respectively but heifers fed the 70.0 and 73.9 percent TDN diets were limit-fed at 90 and 80 percent of their intake potential. The experimental feeding system resulted in heifers being fed less dry matter per day but the total amount of calories consumed per day was equal (Table 3). We did not observe any differences in the size or body condition scores of the heifers after a 111 day feeding period (Table 4). The limit fed heifers had numerically higher average daily gains as compared to control fed heifers. The limit-feeding regimen did however result in a 30 % improvement in feed efficiency (Table 4), and heifers excreted significantly less manure (Table

4). We observed no long term effects of limit feeding heifers and lactation performance was similar between control and limit-fed heifers (Figure 1). Recent research at the Pennsylvania State University observed similar responses when heifers were limit fed. Zanton and Heinrichs, (2006) limit fed 300 lb Holstein heifers for 35 weeks a diet containing 25 percent forage as compared to feeding a greater DM allocation of a diet containing 75 percent forage and observed no differences in average daily gain or skeletal growth of the heifers.

There are some limitations to implementing a limit-feeding strategy. First, heifers do vocalize to minor extent for approximately one week with vocalization ending thereafter. Second, adequate bunk space is required to assure all animals have full access to feed because heifers fed to 80 percent of their intake potential will consume all feed available within short periods of time. Lack of adequate bunk space could result in un-even rates of gain. Despite disadvantages the positive aspects of limit-feeding such as increases in feed efficiency, decrease manure output and ability to control over-conditioning without long term effects make limit-feeding and attractive management alternative but more data is required.

Bunk Management Systems

When feeding high fiber forages or corn silage diets, heifers will sort feed very similar to lactating dairy cows. Heifers like lactating dairy cows will preferentially consume smaller feed particles as compared to larger feed particles. This feeding behavior can be used as an innovation in feeding dairy heifers to improve feed efficiency and reduce feed cost. In a recent study (Hoffman et al., 2006) we fed heifers five different physical methods of feeding hay to explore possible differences in nutrient intake and feed sorting behavior. Diets were fed to eighty Holstein heifers, and included (1) incorporation of long hay (**LH**) in a total mixed ration (**TMR**) mixer (**TMR-LH**); (2) incorporation of bale cut hay (**BC**) in a TMR mixer (**TMR-BC**); (3) incorporation of chopped hay (**CH**) in a TMR mixer (**TMR-CH**); (4) top-dressing (**TD**) long hay (**TD-LH**) without TMR incorporation, and (5) top-dressing BC hay (TD-BC) without TMR incorporation. Top dressing LH or BC hay to heifers resulted in a suppression (0.5 kg/d) of DM intake as compared to heifers fed TMR diets in which hays were incorporated in the TMR. Heifers heavily refused long particles (>12.5 mm) on all diets. In particular, heifers refused 70 to 80 percent of corn cobs fed. Because long forage particles and or corn cobs generally contain more NDF or less energy than small feed particles, such as grain, data suggest heifers may consume diets higher in energy than formulated. Likewise data suggest bunk management of heifer diets is critical to assure heifers are consuming high fiber low energy feeds as intended.

Understanding this behavior affords the opportunity of producers and heifer growers to direct heifers to consume all feed particles. Precisely monitoring and controlling feed intakes and feeding heifers to exact intakes will reduce feed wastage and increase feed efficiency. The combination of proper bunk design and feeding heifers to exact intakes may result in a 10 percent improvement in feed efficiency. To feed heifers to exact intakes a bunk scoring management system should be utilized. A simplified bunk scoring system is 0) no feed remaining, 1) a few small scatter particles of feed remaining, 2) many feed particles remaining but concrete still visible and 3) large amounts of feed remaining with no bunk concrete visible. The objective of a controlled bunk management feeding system is to feed to a bunk score of 1 every day directing heifers to consume remaining large feed particles. If bunks are empty (Score 0) or excessive feed is remaining (Scores 2 and 3) then feed intakes are moved up or down in very small increments (2 %) to facilitate feeding heifers to a bunk score of 1. This type of feeding systems also helps assure that heifers consume all large feed particles and feeds such as corn cobs. Full consumption of diet also assures the formulated diet is actually being totally consumed.

Novel Forage Feeding

Dairy producers and heifer growers commonly have utilized legume-grass hays and silages to cut the energy content of corn silage in heifer diets and supply needed protein. Because of improvements in corn silage (grain yield) and improved heifer housing systems (reduced energy requirements) cutting the energy content of corn silage in heifer diets with legume-grass hays and silages is becoming more challenging. Dairy producers and heifer growers are currently seeking and utilizing more aggressive dietary approaches to cutting energy contents of corn silage based heifer diets. Forages such as straw, corn stover, tropical corn silage and soybean stubble are now being included in heifer diets because of their high NDF content and low NDF digestibility. These forages are desirable because they can reduce the amount of dietary energy in a heifer diet at a lower inclusion rate as compared to legume-grass hays and silages effectively reducing the cost of the heifer diet.

Conclusions

Limit feeding, intensified bunk management and feeding low cost byproducts or forages appear to offer some innovation in dairy heifer nutrition programs.

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Table 1. Ancillary review of published heifer research and field application relevance to improve milk yield or decrease rearing cost.

Research/Management	Research Base[1]	Relationship to Milk Production[2]	Milk[3]	Cost[4]	Index[5]
Genetics - Genetic Improvement	+++	D	++	+	++
Disease Prevention - Vaccination	+++	I	++	+	++
Grazing	+	N	0	- -	++
Colostrum Management	+++	I	+	-	++
Feed Restriction	+	D	+	-	++
Limit Feeding	+	N	0	-	+
Intensive Neonatal Nutrition	++	D/I	+	+,0,-	+
Control Feed Intake	+	N	0	-	+
Breeding Efficiency	+++	N	0	-	+
Feeding Lost Cost Byproducts/Feeds	+	N	0	-	+
Grouping Strategies-Transition	+	I	+	+,0	+
Early Weaning	++	N	0	-	+
Pasteurized Waste Milk	+	N	0	-	+
Ionophores For Disease Prevention	+++	N	0	-	+
Ionophores For Feed Efficiency	+	N	0	-	+
Increasing Calving BW	++	D/I	+,0,-	0	+,0,-
Increasing Growth Rate	+++	I	+,0,-	+,0,-	+,0,-
Crossbreeding	+	D	-	--	0,+
Feeding Bypass Protein	++	N	0	+,0,-	0
Decrease Calving Age <22 months	++	D	-	+,0,-	0
Dietary Energy to Protein Ratios	+	N	0	0	0
Ionophores For Growth	+++	N	0	0	0
Milk Replacer CP Type Manipulation	+++	N	0	+,0,-	0
Forage Type	+	N	0	+,0,-	0
Calf Starter CP Manipulation	+	N	0	+,0,-	0
Increasing Dietary CP (above requirements)	+	N	0	+	-
Excess Postpuberty Gain	+	I	-	0	-
Excess Prepuberty Gain	+++	D	-	0	-
Scours	+++	N	0	+	-
Over-conditioning	++	I	-	+	--
Pneumonia	++	D	--	+	--
Lameness-Hoof Disease	+++	I	--	+	--

[1] +++ = abundant research, ++ some research, + limited research.

[2] D = direct relationship to milk yield, I = indirect relationship to milk yield, N = no established relationship to milk yield

[3] ++ positive influence on milk yield, + = moderate influence on milk yield, 0 = little influence on milk yield, - = moderate negative influence on milk yield, -- = negative influence on milk yield.

[4] ++ cost increase, + = moderate cost increase, 0 = little or no cost increase, - = moderate cost derease, -- = cost decrease.

[5] ++ = excellent management practice, + = good management practice, 0 = abiguous management practice, - = avoid, -- = strongly avoid.

Table 2. Guidelines for feeding distillers grains with solubles to dairy heifers

Item	Heifer body weight, lbs			
	300	600	900	1200
Intake				
Dry Matter Intake, lb DM/d	8.4	15.1	20.3	23.1
Estimated Maximum				
Distillers Grains, % of DM	20	20	20	20
Distillers Grains, lb DM/d	1.68	3.02	4.06	4.62
Diet Density				
Dietary Fat, % of DM	5.0	5.0	5.0	5.0
Dietary Phosphorus, % of DM	0.37	0.37	0.37	0.37
Phosphorus Requirment				
Dietary Phosphorus Requirement, % of DM	0.25	0.25	0.20	0.18

Table 3. Nutrient and energy intake of heifers fed treatment diets.

Item	Treatment[1]				Effect(P>)[4]		
	C-100	L-90	L-80	SEM	Treatment	Linear	C vs R
Nutrient intake, lbs/d							
DM	21.3	19.9	18.3	0.4	0.01	0.003	0.006
CP	2.42	2.54	2.57	0.03	0.07	0.03	0.03
NDF	10.06	8.29	6.50	0.16	0.0003	0.0001	0.0002
Digestible NDF[2]	6.11	4.90	3.87	0.09	0.0002	0.0001	0.0001
Non-fiber carbohydrate	7.26	7.60	7.85	0.17	…	0.07	0.09
P	0.057	0.058	0.058	0.001	…	…	…
Ca	0.086	0.090	0.089	0.001	…	…	0.08
Energy intake[3]							
TDN, lbs/heifer/d	14.4	13.9	13.5	0.3	…	0.08	0.09
ME, Mcals/d	23.8	23.0	22.3	0.4	…	0.07	0.09
NE_g, Mcals/d	9.4	9.4	9.5	0.2	…	…	…
NE_m, Mcals/d	13.7	13.3	13.0	0.2	…	…	…

[1] C-100, control heifers fed ad libitum, L-90, limited to 90.0 percent of intake, L-80, limited to 80.0 of intake. Treatment means expressed on a per heifer basis.

[2] In vitro digestible NDF as determined by a 48 h incubation.

[3] Where ME = metabolizable energy, NE_g = net energy gain, NE_m = net energy maintenance.

[4] C=Control (C-100) vs L=limited (L-80,L-90). Entries without values are not significant (P>0.10).

Table 4. Effect of dietary regimen on body size and growth of replacement heifers.

		Treatment[1]				Effect(P<)[2]		
Item		C-100	L-90	L-80	SEM	Treatment	Linear	C vs R
Intial								
	Weight, lbs	1036	1021	1011	21	...	...	...
	Hip height, in	54.20	54.60	54.90	0.3	...	...	...
	Body condition score	3.1	3.0	2.9	0.1	...	...	...
Final								
	Weight, lbs	1220	1234	1217	19	...	...	...
	Hip height, in	56.0	56.3	56.4	0.3	...	...	...
	Body condition score	3.2	3.2	3.2	0.1	...	...	...
Growth								
	Average daily gain, lbs/d	1.66	1.92	1.84	0.14	...	...	...
	Hip height, in/111 d	1.8	1.7	1.5	0.3	...	...	...
	Body condition score, units/111d	0.1	0.2	0.2	0.1	...	...	...
	Feed efficiency, lbs DM/lb gain	13.2	10.7	11.1	0.9	...	...	0.09
Excretion								
	DM, lbs/d	7.7	6.9	5.8	0.6	...	0.10	0.10
	N, g/d	140.2	141.7	146.8	9.7	...	...	...
	P, g/d	24.7	25.2	27.2	2.3	...	...	...

[1] C-100, control heifers fed ad libitum, L-90, limited to 90.0 percent of intake, L-80, limited to 80.0 of intake. Treatment means expressed on a per heifer basis.

[2] C=Control (C-100) vs L=limited (L-80,L-90). Entries without values are not significant (P>0.10).

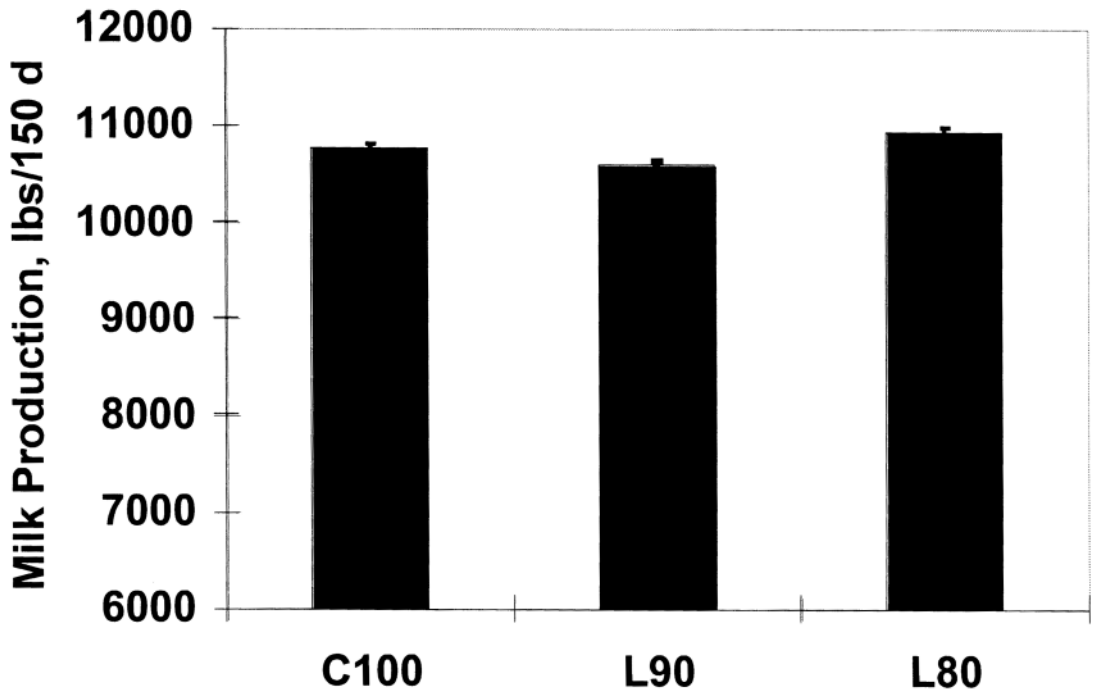

Figure 1. Milk production (150 d) of first lactation cows which were limit-fed prior to parturition, (Hoffman et al. 2006.)

Costs of Raising Dairy Calves and Replacement Heifers

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The full report of dairy calf and heifer rearing cost is published on the Dairy Science website at the University of Wisconsin-Madison: http://www.wisc.edu/dysci/.

UW Extension

Economic Cost and Labor Efficiencies Associated with Rearing Dairy Herd Replacements on Wisconsin Dairy Farms and Custom Heifer Rearing Operations

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Report Background

Due to inflation and changing economic dynamics in the dairy industry, the cost of raising dairy calves and heifers increases with time. As a result, a field project was initiated at the University of Wisconsin-Extension in 2007 which evaluated the cost of production of dairy calf (n=40) and dairy heifer (n=44) enterprises on commercial dairy and custom heifer raising operations. Operations were divided into two dairy operation categories, (tie-stall dairy, free-stall dairy) and one custom calf and heifer grower category in an attempt to represent a broad spectrum of the Wisconsin calf and heifer industry. The two dairy operation categories were selected solely on the basis of how lactating cows were milked on the operation. Field input data were collected by 21-county based University of Wisconsin-Extension Agriculture Agents. Data were edited for practical errors and entered into the computer model by a single technician to avoid errors. Calf and heifer enterprise summary statistics, including comparisons to 1999 cost of production data, were developed for the entire data set (49 operations total) and for each operational category.

Selected findings of the 2007 project include the following:

1) The total cost of rearing a replacement heifer from birth to calving was $2150.00.

2) The cost of rearing a dairy calf (without calf value) was estimated to be $325.00 or $4.64/day.

3) The largest percentage increase in cost for rearing dairy calves was milk replacer and labor cost.

4) Custom calf and heifer growers commonly had lower rearing cost as compared to commercial dairy producers.

5) Labor efficiencies were higher for custom calf and heifer growers because custom growers generally raised more calves and heifers.

6) Large variation in the cost of rearing calves was observed indicating calf rearing cost can be altered substantially if desired.

Efficacy of Essential Oils as Dietary Supplements for Dairy Cows[1]

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Summary

Effects of essential oils (EO) on rumen microbial fermentation in vitro are well established in the literature, but the impact of dietary EO supplementation on ruminant animal performance has been equivocal (Calsamiglia et al., 2007). Seven reports on the effects of EO supplemented in diets fed to lactating dairy cows were reviewed herein. Averaged across all treatment comparisons, EO increased DMI and yields of milk, FCM, fat and protein by 0.4, 0.9, 1.4, 0.07, and 0.03 kg/cow/d over control; these responses to EO increased milk income minus feed cost $0.27 to $0.42/cow/d depending on the milk component and feed prices evaluated. Milk fat and protein percentage and feed efficiency responses to EO were positive on average. Other reported ($P < 0.10$) in vivo responses were increased ruminal OM and N digestibility (Yang et al., 2007), increased ruminal pH and reduced total VFA (Benchaar et al., 2007), and increased total tract ADF digestibility and ruminal pH (Benchaar et al., 2006). Unpublished results of a recent UW-Madison trial to evaluate transition cow and 15-wk postpartum lactation performance responses to dietary EO supplementation were reported herein. Treatments were a control diet and an EO diet supplemented with 1.2 g/cow/d EO mixture (CRINA Ruminants) fed to 20 multiparous Holstein cows per treatment from 4 wk prepartum through 15 wk of lactation. Transition cow measurements were unaffected by EO. Lactation DMI was 1.8 kg/cow/d lower for EO ($P < 0.04$). Milk yield was numerically lower for EO during lactation wk 1-5 (-2.4 kg/cow/d), similar during wk 6-10, and numerically higher (+2.1 kg/cow/d) for EO during wk 11-15. Average feed efficiencies (Milk/DMI and FCM/DMI) tended to be greater for EO ($P < 0.08$ and $P < 0.07$, respectively). Feed efficiency was unaffected by treatment during lactation wk 1-5, but was greater for EO during wk 6-10 and wk 11-15 ($P < 0.04$ and $P < 0.02$, respectively). In a meta analysis performed on combined data from the literature review and the UW-Madison trial, milk, fat and protein yields were 1.2 ($P < 0.04$), 0.06 ($P < 0.03$) and 0.05 ($P < 0.06$) kg/d, respectively, higher for EO. More dairy cattle research regarding potential interactions between basal diet, stage of lactation and dietary EO supplementation is warranted.

Introduction

Newbold et al. (2006) and Calsamiglia et al. (2007) described EO as follows: volatile aromatic compounds with an oily appearance extracted from plant materials typically by steam distillation; alcohol, ester or aldehyde derivatives of phenylproponoids and terpenoids; some of the more common EO compounds available include thymol (thyme and oregano), eugenol (clove), pinene (Juniper), limonene (dill), cinnamaldehyde (cinnamon), capsaicin (hot peppers), terpinene (tea tree), allicin (garlic), anethol (anise), etc.; antimicrobial activity; modify rumen microbial fermentation. With regard to EO as modifiers of rumen microbial fermentation, Calsamiglia et al. (2007) from an extensive review of the literature (primarily in vitro, in situ or continuous culture based) concluded the following: inhibition of deamination and methanogenesis, which results in lower ammonia-N, methane and acetate and higher propionate and butyrate concentrations; effects may vary depending on the specific EO or combination of EO supplemented; effects of some EO are pH and diet dependent. Readers are referred to Calsamiglia et al. (2007) for an in depth review of EO and effects on rumen microbial fermentation. The purpose of this paper is to review and summarize the available reports involving EO as dietary supplements for dairy cows and effects on lactation performance.

Literature Review

Seven reports on the effects of EO supplemented in diets fed to lactating dairy cows were reviewed. Six of these reports involved the CRINA ruminants

(CRINA S.A., Gland, Switzerland) mixture of natural and synthesized EO including thymol, eugenol, vanillin, guaiacol, and limonene. The other report involved EO (Axiss France SAS, Bellegarde-sur-Valserine, France) from garlic (allicin) and juniper berry (pinene) fed separately. The seven experiments are described in Tables 1 (EO tested, experimental design, and cows), 2 (Diet ingredient and nutrient composition and control DMI and milk yield), and 3 (Experimental measurements). There were 9 and 10 treatment comparisons, respectively, for intake and production related measurements across the seven experiments.

DMI, milk yield, composition and component yield, and feed efficiency responses to EO relative to control are presented in Table 4. Averaged across all treatment comparisons, EO increased DMI and yields of milk, FCM, fat and protein by 0.4, 0.9, 1.4, 0.07, and 0.03 kg/cow/d over control. Milk fat and protein percentage and feed efficiency responses to EO were positive on average.

To calculate the economic value derived from EO at the average response, the following milk and feed prices were used: $3.10/kg fat, $9.18/kg protein, $0.51/kg other solids, and an add-on premium of $0.036/kg milk (based on pay period ending 10/31/07 for a Wisconsin dairy), $0.18/kg TMR DM, and $0.06/cow/d cost for 1.2 g/cow/d supplemental EO (Will Seymour, DSM, personal communication). At the average response and under this milk and feed price scenario, dietary supplementation with EO increased milk income minus feed cost $0.42/cow/d. To calculate the average economic value derived from EO under a lower milk and feed price scenario, the following milk and feed prices were used: $2.91/kg fat, $4.69/kg protein, $0.42/kg other solids, and an add-on premium of $0.030/kg milk (based on 2006 average pay prices for a Wisconsin dairy), $0.15/kg TMR DM, and $0.06/cow/d cost for supplemental EO. At the average response and under this milk and feed price scenario, dietary supplementation with EO increased milk income minus feed cost $0.27/cow/d. Responses to EO were average or above average for 7/10, 5/10 and 6/10 of milk, fat and protein yield treatment comparisons, respectively.

Other significant ($P < 0.10$) in vivo responses found in these seven reports are summarized in Table 5. These responses include increased ruminal OM and N digestibility (Yang et al., 2007), increased ruminal pH and reduced total VFA (Benchaar et al., 2007), and increased total tract ADF digestibility and ruminal pH (Benchaar et al., 2006).

UW-Madison Trial

Our objective was to evaluate transition cow and 15-wk postpartum lactation performance responses to dietary EO supplementation. Forty multiparous Holstein cows were used in a completely randomized design. Treatments were a control diet supplemented with a placebo premix (57 g/cow/d) and an EO diet supplemented with 1.2 g/cow/d CRINA Ruminants (CRINA S.A., Gland, Switzerland; mixture of natural and synthesized EO including thymol, eugenol, vanillin, guaiacol, and limonene) provided through a premix (57 g/cow/d). Treatment diets were fed from 4 wk prepartum through 15 wk of lactation. Prepartum and lactation TMR ingredient and nutrient composition are presented in Table 6. Cows were fed individually a TMR once daily in tie-stalls and the amounts fed and refused were recorded daily. Body weights and condition scores will were recorded weekly throughout the trial. Blood samples from each cow obtained prior to feeding on d -21, -7, -1, 1, 8, 15, 22, and 29 were analyzed for glucose, BHBA, NEFA, and urea-N. Milk yield was recorded daily on individual cows from throughout the lactation trial. Milk samples obtained from all cows weekly on two consecutive days of the week from am and pm harvests throughout the lactation trial were analyzed for fat, true protein, lactose and MUN concentrations.

Results are presented in Table 7 and Figures 1-3. There was no affect of EO on prepartum DMI. Lactation DMI was 1.8 kg/cow/d lower for EO ($P < 0.04$). Milk and component yields were unaffected by treatment. Milk true protein was 0.15%-units lower for EO ($P < 0.03$). Milk yield was numerically lower for EO during lactation wk 1-5 (-2.4 kg/cow/d), similar during wk 6-10, and numerically higher (+2.1 kg/cow/d) for EO during wk 11-15 (Figure 1). Unfortunately, the feeding trial was not continued any further into the lactation. Average feed efficiencies (Milk/DMI and FCM/DMI) tended to be greater for EO ($P < 0.08$ and $P < 0.07$, respectively). Feed efficiency (Milk/DMI) was unaffected by treatment during lactation wk 1-5, but was greater for EO during wk 6-10 and wk 11-15 ($P < 0.04$ and $P < 0.02$, respectively; Figure 2). Average lactation energy balance tended to be lower for EO ($P < 0.06$). Energy balance was unaffected by treatment during lactation wk 1-5, but was lower for EO during wk 6-10 and wk 11-15 ($P < 0.04$ and $P < 0.03$, respectively; Figure 3). Control cows returned to positive energy balance during lactation wk 6-10 (+1.5 Mcal/d), while EO cows remained in slightly negative energy balance even during wk 11-15 (-0.4 Mcal/d; Figure 3). Prepartum and lactation body weight, body condition score, and blood sample measurements were unaffected by treatment.

Meta Analysis

Combined data from the literature review and the UW-Madison trial were analyzed using the MIXED procedure of SAS to evaluate animal response to dietary EO supplementation for DMI and milk, fat and protein yields. The model included the fixed effect of EO supplementation and the random effect

of trial (St. Pierre, 2001). Each response was weighted according to the number of animals used to test for it using the WEIGHT statement. DMI was unaffected by treatment ($P > 0.10$). Milk, fat and protein yields were 1.2 ($P < 0.04$), 0.06 ($P < 0.03$) and 0.05 ($P < 0.06$) kg/d, respectively, higher for EO.

Conclusions

Averaged across all treatment comparisons from the reports reviewed, EO increased DMI and yields of milk, FCM, fat and protein; these responses to EO increased milk income minus feed cost $0.27 to $0.42/cow/d depending on the milk component and feed prices evaluated. Milk fat and protein percentage and feed efficiency responses to EO were positive on average. In a recent UW-Madison trial: transition cow measurements were unaffected by EO; lactation DMI was lower for EO ($P < 0.04$); milk yield was numerically higher (+2.1 kg/cow/d) for EO during lactation wk 11-15; average feed efficiencies tended to be greater for EO; feed efficiency was greater for EO during lactation wk 6-10 and wk 11-15 ($P < 0.04$ and $P < 0.02$, respectively). In a meta analysis performed on combined data from the literature review and the UW-Madison trial, milk, fat and protein yields were 1.2 ($P < 0.04$), 0.06 ($P < 0.03$) and 0.05 ($P < 0.06$) kg/d, respectively, higher for EO. More dairy cattle research regarding potential interactions between basal diet, stage of lactation and dietary EO supplementation is warranted.

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Table 1. Literature review: Essential oils tested, experimental design, and cows.

Trial	Essential Oils Product	Experimental Design	Cows
Yang et al., 2007	Garlic[1] 5 g/cow/d Juniper Berry[1] 2 g/cow/d	4x4 LS[3] 21-d periods	n=4 >113 DIM[4] Parity>1
Benchaar et al., 2007	Crina[2] 0.75 g/cow/d	4x4 LS 28-d periods	n=4 >61 DIM Parity>1
Benchaar et al., 2006	Crina 2 g/cow/d	4x4 LS 28-d periods	n=4 >98 DIM Parity>1
Offer et al., 2005	Crina 0.5, 1, and 2 g/cow/d	4x4 LS 28-d periods	n=16 >50 DIM Parity>1
Schmidt et al., 2004	Crina 1.2 g/cow/d	RCB[5] 56-d period	Parity=1 n=4 Parity>1 n=26 >50 DIM
Varga et al., 2004	Crina 1.2 g/cow/d	Unreplicated pens 120-d period	n=170 High group Parity 1& >
LaCount, 1997	Crina 1.5 g/cow/d	CRD[6] 70-d period	n=33 >42 DIM Parity>1

[1]Axiss France SAS, Bellegarde-sur-Valserine, France; Garlic standardized at 1.5% of allicin; Junniper Berry standardized at 35% of pinene.
[2]CRINA Ruminants, CRINA S.A., Gland, Switzerland; Mixture of natural and synthesized essential oils including thymol, eugenol, vanillin, guaiacol, and limonene.
[3]Latin square design. [4]Days in milk. [5]Randomized complete-block design. [6]Completely randomized design.

Table 2. Literature review: Diet ingredient and nutrient composition and control DMI and milk yield.

Trial	Diet Ingredient Composition (DM basis)	Diet Nutrient Composition (DM basis)	Control DMI kg/d	Control Milk kg/d
Yang et al., 2007	40:60 F:C[1] Barley silage & grain	16% CP, 32% NDF, & 33% Starch	20.7	29.0
Benchaar et al., 2007	50:50 F:C AS[2] or CS[3] Corn & barley grain	16% CP, 38% NDF, & 21% Starch	17.5	28.9
Benchaar et al., 2006	48:52 F:C 75:25 Grass silage:CS Corn grain -/+ 350 mg/d monensin	19% CP, 36% NDF, & 20% Starch	22.6	34.3
Offer et al., 2005	Grass silage ad lib 12 kg/d (as fed) DC[4]	19% CP & 35% NDF	20.8	31.1
Schmidt et al., 2004	50:50 F:C 50:30:20 CS:AS:AH[5] Corn grain	16% CP, 35% NDF, & 19% Starch	26.4	39.8
Varga et al., 2004	42:58 F:C 70:30 CS:AS High in byproducts	18% CP, 31% NDF, & 27% Starch	NA[6]	40.1
LaCount, 1997	51:49 F:C 50:50 CS:AS Pelleted complete feed	18% CP & 35% NDF	22.5	44.0

[1]Forage:Concentrate Ratio. [2]Alfalfa silage. [3]Corn silage. [4]18% CP (as-fed basis) Dairy concentrate. [5]Alfalfa hay. [6]Not available.

Table 3. Literature review: Experimental measurements.

Trial	Measurements
Yang et al., 2007	Ruminal fermentation parameters; Ruminal & total tract nutrient digestibility; Duodenal nutrient flows; intake & production
Benchaar et al., 2007	Ruminal microbial counts & fermentation parameters; Total tract nutrient digestibility; N balance; intake & production; milk fatty acid profiles
Benchaar et al., 2006	Ruminal fermentation parameters & protozoa counts; Ruminal in situ nutrient degradation; Total tract nutrient digestibility; N balance; intake & production; milk fatty acid profiles
Offer et al., 2005	Intake & production
Schmidt et al., 2004	Intake & production
Varga et al., 2004	Production field trial; Continuous culture fermenters
LaCount, 1997	Intake & production

Table 4. Literature review: DMI, milk yield, composition and component yield, and feed efficiency responses relative to control.

Trial	DMI kg/d	Milk kg/d	FCM kg/d	Fat %	Fat kg/d	Protein %	Protein kg/d	Milk/ DMI	FCM/ DMI
Yang et al., 2007									
Garlic	-0.3	+0.9	+2.5*	+0.32*	+0.14*	-0.08	0	+0.07	+0.14
Junniper Berry	-0.2	+0.4	+1.8*	+0.26*	+0.11*	-0.03	0	+0.03	+0.10
Benchaar et al., 2007	-0.1	-0.9	-0.7	-0.05	-0.02	+0.01	-0.04	-0.03	-0.03
Benchaar et al., 2006	+0.1	-1.3	-1.3	+0.04	-0.04	-0.01	-0.05	-0.07	-0.07
Offer et al., 2005									
0.5 g/cow/d Crina	+0.3	+1.4*	+1.2*	-0.03	+0.04*	+0.03	+0.06*	+0.04	+0.04
1.0 g/cow/d Crina	+0.2	+1.7*	+1.6*	-0.01	+0.07	+0.02	+0.07*	+0.06	+0.07
2.0 g/cow/d Crina	+0.3	+2.0*	+1.8*	-0.03	+0.06*	+0.03	+0.08*	+0.007	+0.07
Schmidt et. al., 2004	+1.9*	+1.9*	+2.7*	+0.10	+0.11*	-0.04	+0.04	-0.04	0
Varga et al., 2004	NA[1]	+1.6	+1.6	+0.02	+0.06	+0.05	+0.07	NA	NA
LaCount, 1997	+1.0	+1.6	+2.6*	+0.15*	+0.13*	+0.11*	+0.10*	-0.02	+0.04
Average	**+0.4**	**+0.9**	**+1.4**	**+0.08**	**+0.07**	**+0.02**	**+0.03**	**+0.01**	**+0.04**

*P < 0.10. [1]Not available.

Table 5. Literature review: Other significant (P < 0.10) responses reported.

Trial	Other P < 0.10 Results
Yang et al., 2007	
Garlic	ROMD[1] +5.8%; RND[2] +6.5%
Junniper Berry	ROMD +7.1%; RND +5.7%
Benchaar et al., 2007	Ruminal pH +0.10; Total VFA -9.2 mM for CS[3]
Benchaar et al., 2006	TTADFD4 +2.9%; Ruminal pH +0.12;
Offer et al., 2005	NR[5]
Schmidt et al., 2004	NR
Varga et al., 2004	Continuous culture fermenter data
LaCount, 1997	NR

[1]Ruminal organic matter digestibility (truly) as % of intake. [2]Ruminal nitrogen digestibility (truly) as % of intake. [3]Corn silage based diet. [4]Total tract acid detergent fiber digestibility. [5]None reported.

Table 6. UW-Madison trial diet ingredient and nutrient composition (Tassoul and Shaver unpublished).

	Prefresh TMR	Lactation TMR
Ingredients, % DM		
Alfalfa silage	11.0	17.0
Corn silage	48.0	30.0
Mixed Alfalfa/Grass Hay	--	3.7
Wheat straw	11.0	--
Ground shelled corn	18.2	22.0
Soybean meal-48%	9.2	9.2
Distillers dried grains	--	9.2
Whole cottonseed-linted	--	5.6
Tallow	--	0.9
Minerals & Vitamins	2.6	2.4
Nutrients[1]		
DM, % as fed	46.1 ± 2.9	53.6 ± 3.0
	----------DM basis----------	
CP %	12.5 ± 0.7	17.1 ± 0.8
NDF%	38.1 ± 4.6	35.3 ± 1.9
Starch%	29.9 ± 4.6	24.7 ± 2.1
Fat%	3.5 ± 0.4	6.3 ± 0.6
TDN_{1x}%	68.9 ± 1.9	--
NEL_{3x}, Mcal/kg	--	1.71 ± 0.03

[1]TMR sampled weekly, composited by month, and analyzed using wet chemistry by Dairy One (Ithaca, NY).

Table 7. UW-Madison trial results (Tassoul and Shaver unpublished).

	Control	Crina	SEM	P<
Prepartum DMI, kg/d	13.8	13.1	0.4	NS1
Lactation DMI, kg/d	24.5	22.7	0.6	0.04
Milk Yield, kg/d	48.2	48.1	1.1	NS
4% FCM, kg/d	43.9	44.0	1.2	NS
Fat				
%	3.48	3.46	0.10	NS
kg/d	1.65	1.64	0.09	NS
True Protein				
%	3.10	2.95	0.05	0.03
kg/d	1.46	1.41	0.06	NS
MUN, mg%	12.9	13.4	0.3	NS
Milk/DMI	1.99	2.15	0.06	0.08
FCM/DMI	1.83	1.98	0.06	0.07
Lactation EB[2], Mcal/d	-1.1	-3.6	0.9	0.06
Body Condition Score				
Prepartum	3.9	3.8	0.1	NS
Lactation	3.4	3.3	0.1	NS
Body Weight, kg				
Prepartum	734.2	745.3	16.0	NS
Lactation	672.0	657.7	15.5	NS
Blood Data[3]				
NEFA, mEq/L	524.1	530.9	34.5	NS
BHBA, mg/dL	6.9	7.8	0.6	NS
Glucose, mg/dL	53.8	55.0	0.9	NS
Urea-N, mg/dL	11.9	12.0	0.3	NS

[1]Not significant (P > 0.10).

[2]Energy balance = $((DMI*NEL_{Diet}) - ((0.08*BW^{0.75})+(NEL_{Milk}*Milk)))$.

[3]Averaged across -21, -7, -1, 1, 8, 15, 22, and 29 d samples.

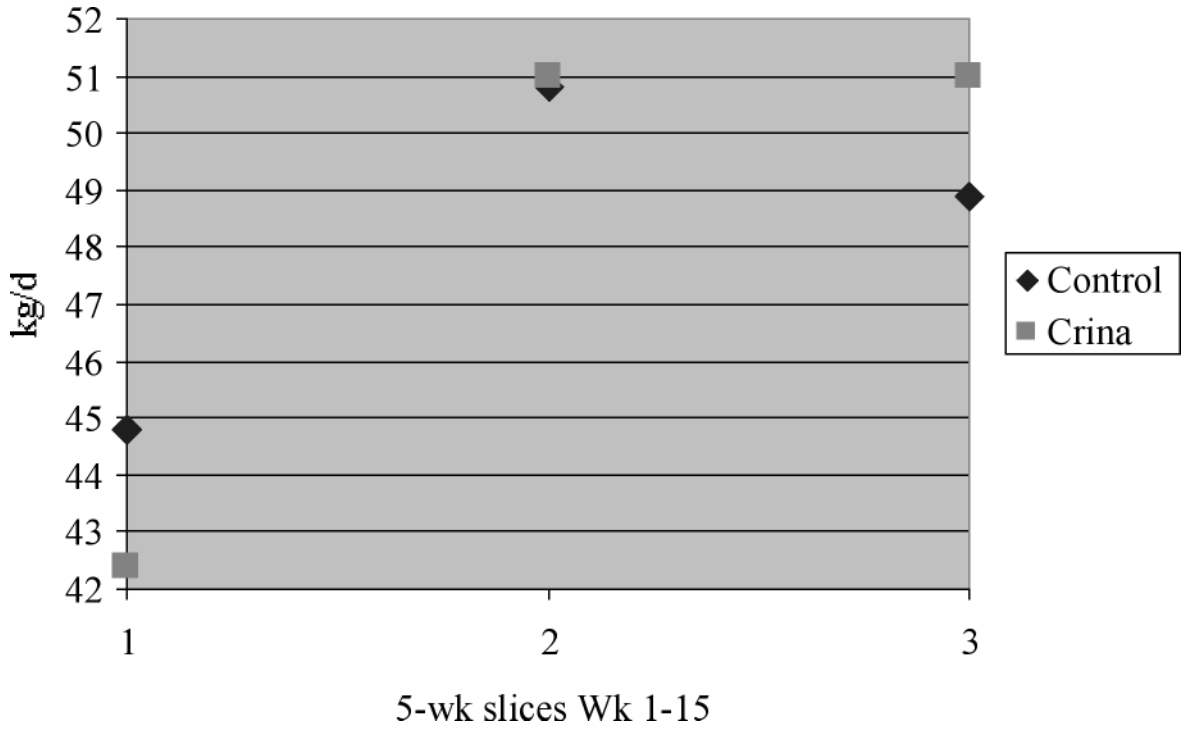

Figure 1. Milk yield (kg/d) summarized by 5-wk slices from wk 1-15 of lactation (P >0.10 differences and SEM = 1.3 kg/d for each slice).

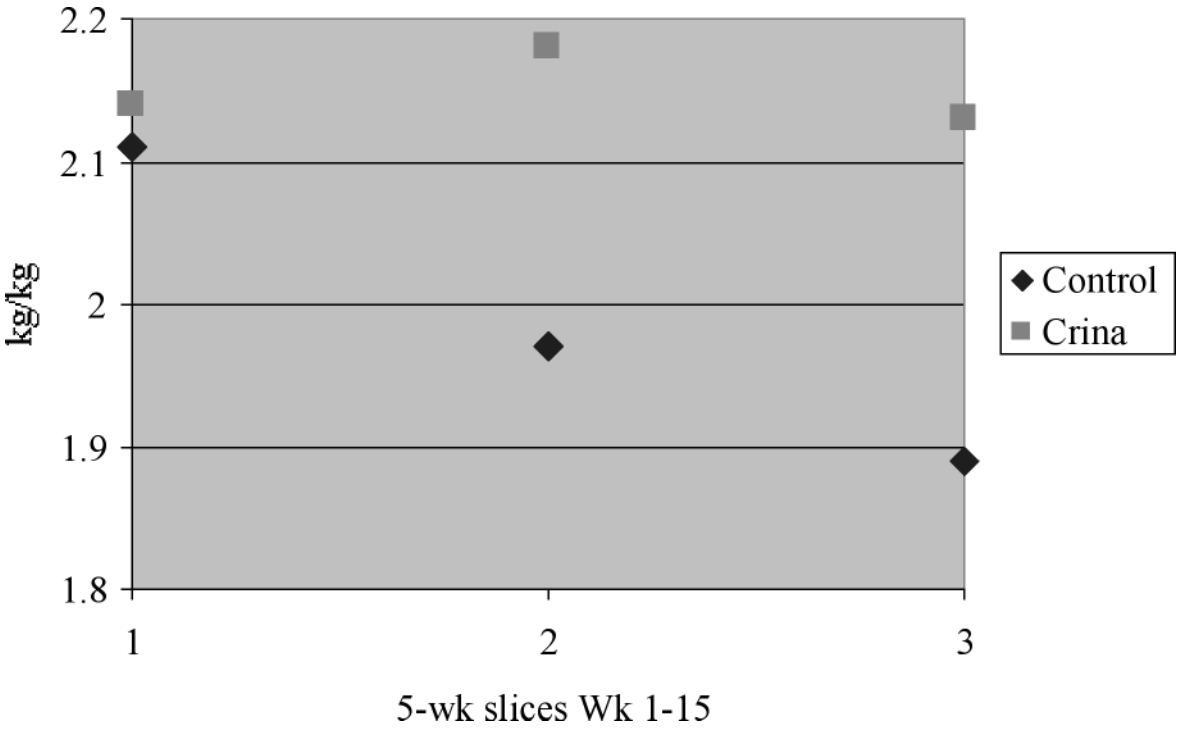

Figure 2. Feed efficiency (kg Milk/ kg DMI) summarized by 5-wk slices from wk 1-15 of lactation (Slice 1 - P > 0.10; Slice 2 - P < 0.04; Slice 3 - P < 0.02; SEM = 0.07 by slice).

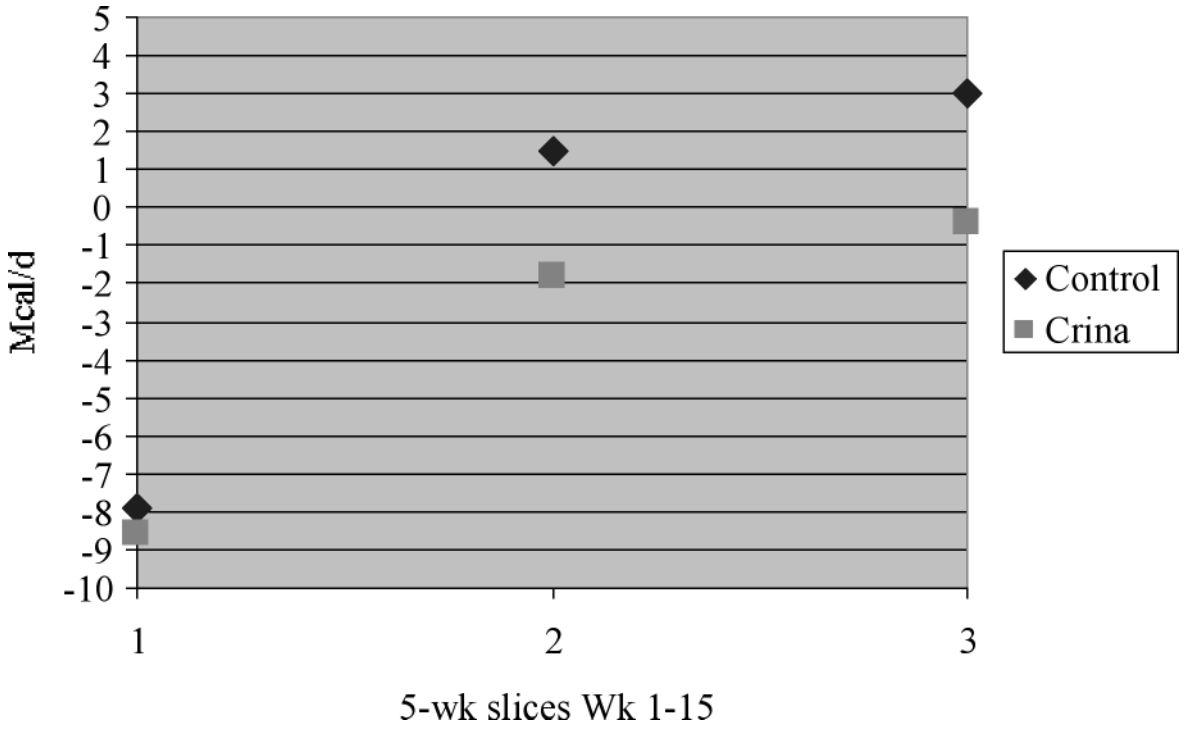

Figure 3. Energy balance (Mcal/d) summarized by 5-wk slices from wk 1-15 of lactation (Slice 1 - P > 0.10; Slice 2 - P < 0.04; Slice 3 - P < 0.03; SEM = 1.1Mcal/d by slice).

[1]Paper originally appeared in Proceedings of 2008 Mid-Atlantic Nutrition Conference, Timonium, MD.

Troubleshooting On-Farm Udder Health Programs: Back to Basics

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Diplomate – ABVP, Dairy Practice

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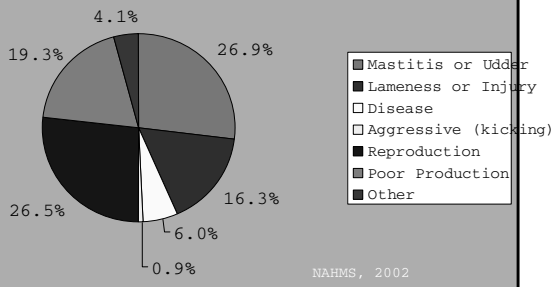
4 State Dairy Nutrition & Management Conference
June 12, 2008

Iowa State University College of Veterinary Medicine Food Supply Veterinary Services

Reasons for Culling



NAHMS, 2002

Iowa State University College of Veterinary Medicine Food Supply Veterinary Services

3

Economics of Mastitis

Table 1. Estimated annual losses caused by mas

Source of loss	Loss/cow	% of total
Reduced production	$116.10	64
Discarded milk	$24.44	14
Early Replacement	$13.60	8
Reduced Cow Sale Value	$9.94	5
Drugs	$9.68	5
Veterinary Services	$4.84	3
Labor	$2.42	1
Total	$181	

Iowa State University College of Veterinary Medicine Food Supply Veterinary Services

4

Economics of Mastitis

- Reproduction and Mastitis - $32 – 107 in reproductive losses due to mastitis.
  - Longer Days to 1st Service
  - Failure to conceive
  - Abortions.

5

Quality – Who's Involved?

- Dairy's Quality Team
  - Dairy Manager/Herdsman – Most Important
  - Veterinarian
  - Nutritionist
  - Fieldman
  - Others

6

Quality – Who's Involved?

- Dairy
  - Clean environment for the cows.
  - Maintaining a low somatic cell count.
  - Proper milking procedures.
  - Maintaining the milking, milk transport, and milk storage equipment.
  - Proper nutrition.

- Multi-Factorial Process!!!

7

Mastitis Triangle

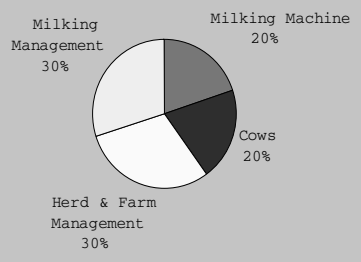
The Cow & Her Environment

Man

Equipment

8

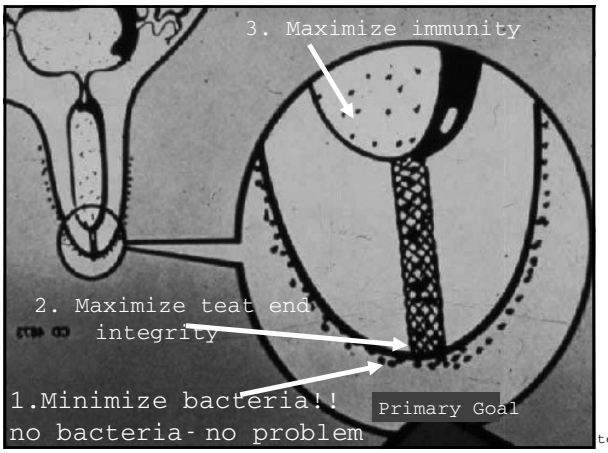
Contribution to Mastitis



9

Mastitis - Where does it come from?

1. The Cow & Her Environment



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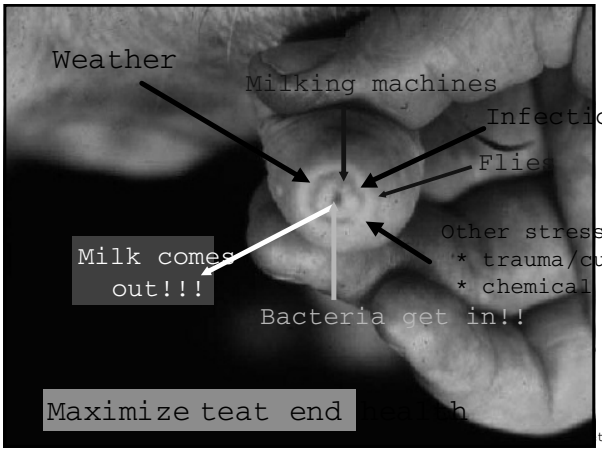

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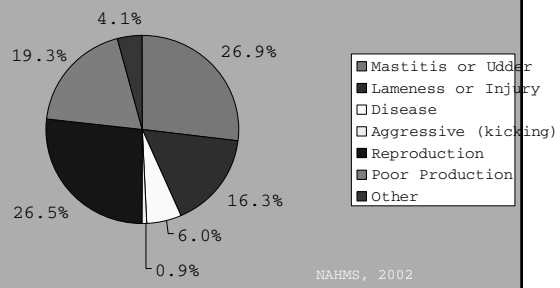

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16

How do milkers cause mastitis?

1. Poor teat sanitation
2. Liner slips
3. Overmilking

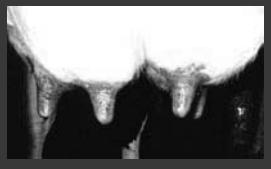
17

How do milkers cause mastitis?
1. Poor Teat Sanitation

- Attaching the milki unit to this teat increases the chanc of mastitis.
- The milking machine flushes this manure and bacteria into t milk.

18

How do milkers cause mastitis?
1. Poor Teat Sanitation



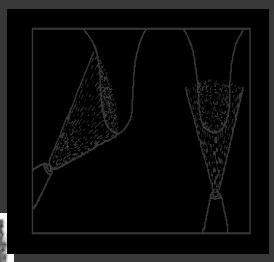
19

Post-dipping

- Proper teat dipping must cover the portion of the teat the inflation cover at least the bottom 75% of the teat.

20

Dipping vs. Spraying



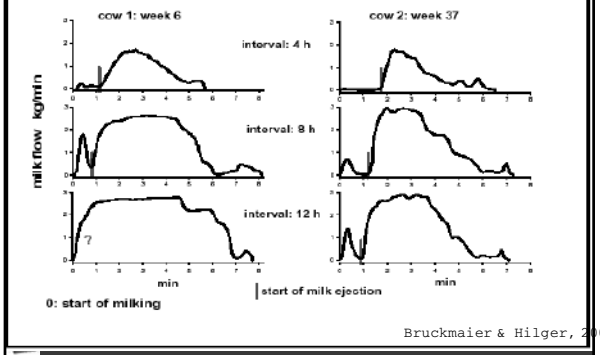
- Teat sprayers are often not used at t proper angle to cov the teat.
- Even when held directly below the teat, the barrel of teat is not adequat covered.

21

Milking Procedures

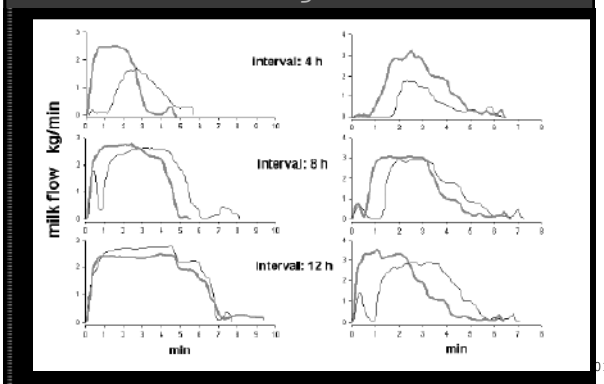
1. Pre-milking Observations
2. Forestripping/Check for mastitis.
3. Pre-dipping and clean the teats.
4. Attachment
5. Adjust Unit
6. Determine End of Milking
7. Unit Removal
8. Post-dipping

Evaluating Milk Letdown



Bruckmaier & Hilger, 2001

Evaluating Milk Letdown



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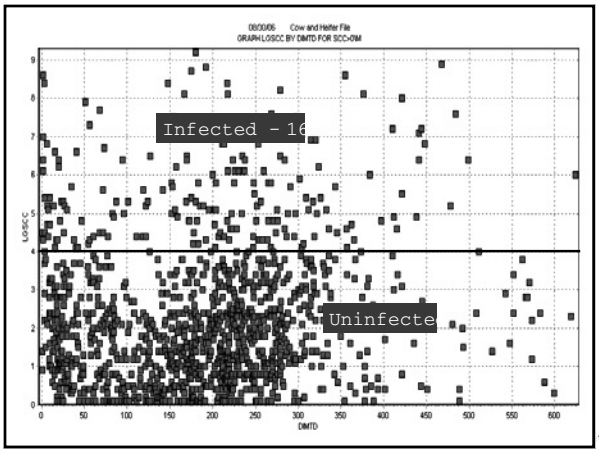
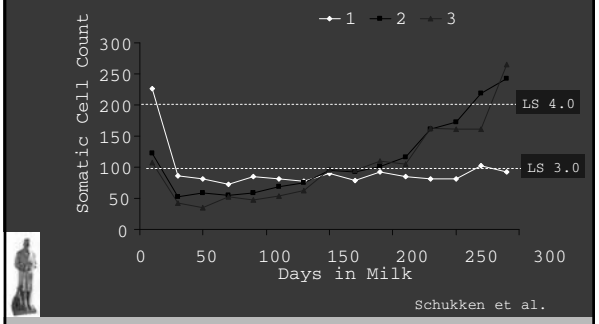


terinary Services

25

SCC in Healthy Cows

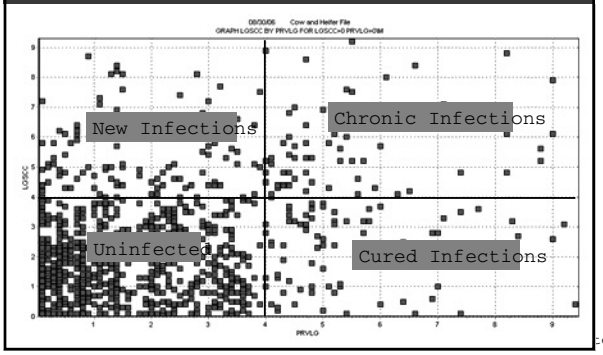
(upper limit 95% confidence interval)



Schukken et al.

26

Comparison of Consecutive Linear Scores for Somatic Cell



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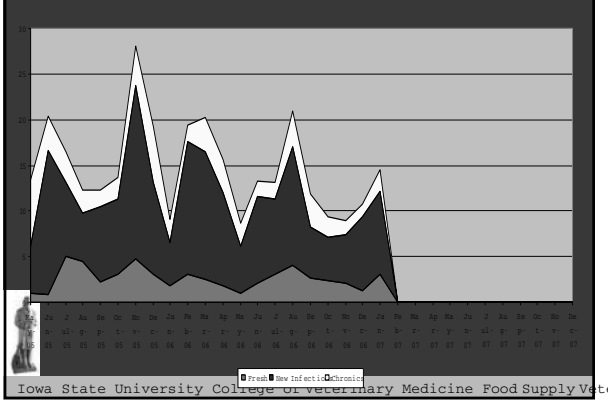
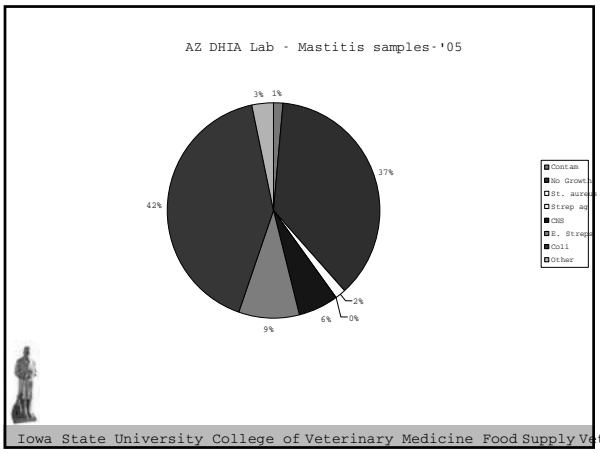
Prevalence Chart





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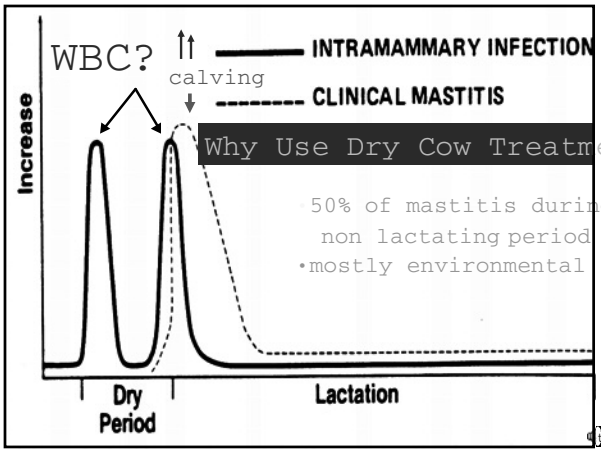
Dry Cow Treatment

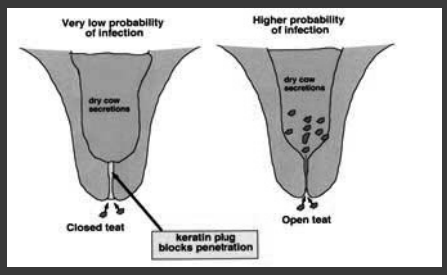


Why Use Dry Cow Treatment

- 50% of mastitis during non lactating period
- mostly environmental

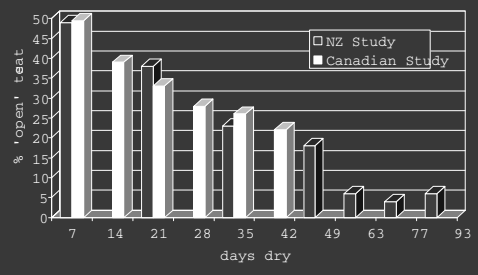
31

Natural Teat Sealing



32

'Open' teats observed using the same method in NZ and Canada



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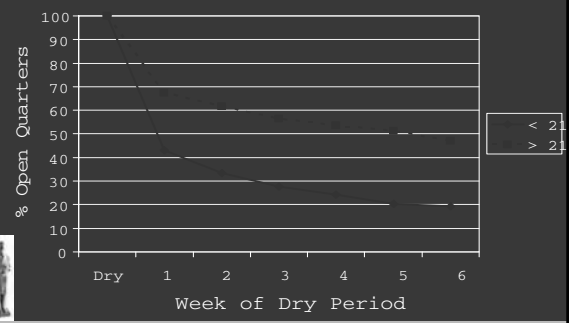
Results

Hazard Ratio = 0.56 P = 0.01



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Dry Cow Teat Barrier Prod

- Persistent barrier teat dip sealants (external barrier)
- Internal barrier sealants (teat end toothpaste)

ECONOMICALLY A NO-BRAINER!!
Only if done properly!

35

CAN REDUCE ENVIRONMENTAL INFECTIONS BY >70-80% IF DONE PROPERLY!!!

36

NUTRITION!!

- KETOSIS - Slows down the movement WBC's.
- Vit E/Selenium - Antioxidant effect protecting PMN's.
  - 0.3 ppm Se
  - 4000 IU Vit E in pre-fresh cows.
  - 1000 IU Vit E in lactating cows.

37

VACCINATIONS

- **Staph aureus:**
  - too late in adult cows
  - only if there is a herd problem (????)
  - Must start in heifers (6 mo. of age)
  - 2 shots, then every 6 months
  - some benefit, but mild prevention
- **Coliforms: E. coli, Klebsiella, etc**
  - -Yes! No Brainer! Core antigen vaccines!

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CORE ANTIGEN VACCINES

- Cross protects across gram negatives
- Reduces infections and toxic signs
- NOT JUST FOR MASTITIS!!!
  - uterus - gut - lungs - udder
- 3+ shot regime during dry & early lactation period
- 100 days protection post calving
- What about the rest of the year?
- Hypervaccination

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NMC

A global organization for mastitis control and milk quality

www.nmconline.org

Building on Milk Protein

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As milk prices decline from record high prices in the second half of 2007 by $2.00 per one hundred pounds (cwt), dairy managers will look for other sources to maintain income and profitability. The value of true milk protein is over three times the value of milk fat leading to higher milk income (Table 1). Increasing milk yield can maintain milk income. Another approach is to reduce feed costs through lower protein feed costs while maintaining milk production.

Milk protein opportunities

Understanding the relationship between milk fat test and true milk protein test can uncover milk component opportunities (Table 2). If your true milk protein test to milk fat test is below 0.75 or 75 percent, look for reasons why this ratio is too wide. This ratio should be examined by groups of cows, parity or lactation number, days in milk, and milk yield using DHI or PC DART data. If milk protein levels are low, consider the following benchmarks listed below.

- Check ration summaries to determine the levels of crude protein (16.5 to 17 percent), RDP (65% of the total crude protein), RUP (35 percent of total crude protein), and soluble protein (33 percent of the total crude protein) are limiting.
- Check starch (22 to 26 percent of ration dry matter) and sugar (4 to 6 percent of total dry matter) levels.
- Compare true milk protein test to milk fat test (Table 2). Values below 0.75 (true milk protein test to milk fat ratio) should be evaluated.
- Stiff or firm manure (manure scores over 3.5) could be an indication of a nitrogen shortage.

By improving nitrogen capture from feed to milk and tissue, protein efficiency can be increased to over 30 percent of dietary protein consumed.

Amino acid balancing

Computer based rumen models are available to estimate amino acid supplies for dairy cattle based on microbial yields and RUP (rumen undegraded protein) sources. Balancing rations for metabolizable protein and amino acids (lysine and methionine) can lead to the following advantages:

- An increase in milk yield (4 to 5 pounds), milk protein test (0.1 to 0.2 percent point), and/or milk fat (0.1 to 0.3 percent point).
- The level of crude protein in the ration dry matter may be lowered to 16.5 percent saving 20 to 40 cents a cow per day.
- An improvement in feed efficiency by 0.08 unit which can increase profit by 15 to 20 cents a cow day.
- Lower metabolic disorders such as fatty liver and conversion of ammonia to urea in the liver.
- An increase in fertility based on lower blood urea nitrogen (BUN).

If metabolizable protein (MP) levels are optimized, the level of lysine (6.6 percent of MP) and methionine (2.2 percent of MP) will meet amino acids needed for high producing cows. Methionine has several key roles including improve milk yield and components, a source of methyl donor (similar to choline) to improve fat mobilization from the liver, and reduce the level of ketone bodies. When feeding legumes (such as alfalfa, clover, and soybean meal), metabolizable methionine can be limiting when balancing amino acids. Corn products (such as corn silage, corn grain, and corn by-products) may require both metabolizable lysine and methionine.

A standard ration was balanced using a software program (Spartan II, Michigan State University) that did not have a rumen modeling software. The ration consisted of 20 pounds of corn silage, 10 pounds of alfalfa haylage, 9 pounds ground shelled corn, 4 pounds of 44 percent soybean meal, 2 pounds of heat treated soybean meal, 3 pounds of corn distillers grain, 0.50 pound of blood meal, 0.20 pound of urea, 3 pounds of fuzzy cottonseed, and 1 pound of soy hulls (all values on a 100% dry matter basis). The cow requirements were 1350 pounds of body weight, 100 pounds of milk, 3.5 percent milk fat, 3.3 percent total protein (3.1 percent true protein), 42 months of age (second lactation), and not pregnant. No minerals, vitamins, or additives were included as protein was the focus. Feed ingredients and amounts were selected to meet Spartan requirements using typical Illinois feeds and levels. The same ration and forage qualities were entered in NRC 2001 model, Cornell Net Carbohydrate Protein System model (version 4.10.13), and AminoCow model (Table 3).

The three models predicted similar levels of dry matter intake, NDF, NFC, and fat. Differences in MP reflect variation in model equations and differences in feed library values (existing library values were used for grain and protein supplements). All three rumen model programs indicated that excess protein was fed. Each program provided unique values (for example potential milk and amino acid requirements). Ration differences included excess rumen nitrogen and shortage of RUP. Dairy nutritionist and managers should use a rumen modeling program to fine-tune rations realizing each program will provide different values. Select a model program that is easy to run, economical to purchase and maintain, and monitor farm results when using the rumen model program. All three programs performed satisfactorily.

Economic protein sources

Protein prices have increased due to increased corn acreage and reduced soybean acreage in the U.S. Using Feed Val 3 (University of Wisconsin computer program), breakeven prices are listed in Table 4. Based feeds and prices were $6.00 a bushel for corn (energy), $300 and $400 a ton for 44% soybean meal (RUP and protein), 30 cents a pound of tallow (fat/oil), $10 per cwt for limestone (calcium), and $30 per cwt for dicalcium phosphate (phosphorous).

Interpreting MUN values

Herds will have different optimal MUN levels depending on feeding and milking relationships, feeding system (total mixed rations, component-fed, or pasture-based systems), and cow eating pattern and frequency. The value in herd and individual cow MUN tests is to monitor changes in MUN.

- Develop a MUN baseline that is "normal" for your herd (values may range from 7 to 16).
- When MUN values shift from the baseline by more than 2 to 3 points (normal variation), look for changes that cause this shift.
- Calculate weekly bulk tank averages to reduce variation from day to day. Use DHI, Dairy Comp, or PC DART data to evaluate groups of cows within the herd (differences due to parity, days in milk, and milk yield).
- DHI and milk plant MUN values will vary due to machine standards and sampling differences. DHI processing centers may provide MUN group averages by lactation number, days in milk, and milk production. Pennsylvania workers recommend a minimum of 8 to 10 cows per group are needed to calculate an "unbiased/true" group MUN value.
- Heat stress can contribute to an increase on MUN values by 2 to 3 units due to rumen and blood flow changes. MUN can be used to monitor the impact of heat abatement improvements on farms.
- If sub acute rumen acidosis (SARA) is occurring, microbial growth will be reduced and excess ammonia not captured.
- Mobilization of body tissue releasing amino acids in early lactation when cows are in negative energy balance using amino acids as a source of energy can increase MUN values.
- Cows with a MUN over 15.5 had a 37 percent reduction in odd of conception compared to cows below 15.5 ($P < 0.001$) in a Canadian field study.

Feeding factor impacting MUN values

Processed corn silage (no partial or whole kernels) can improve fermentable and available starch in the rumen lowering MUN. New crop corn silage will have lower levels of fermentable carbohydrate (less starch available) raising MUN. Michigan workers recommend three months of storage before feeding to optimize starch availability in the rumen. Cows consuming lush pasture or legume-grass silage that is wet and/or higher in crude protein can raise MUN values. Grinding or processing grain finer increases the rate of fermentation in the rumen and increasing ammonia capture by rumen microbes lowering MUN. Shifting to less degraded protein sources (heat-treated soybeans compared to raw soybeans for example) can lower MUN values.

Summary

- Capturing the milk protein potential in a herd can increase milk value 30 to 50 cents per cwt (one hundred pounds).
- Amino acid balancing using rumen model computer software can lower levels of crude protein while increasing milk volume and components.
- Select protein supplements based on amino acid needs and economics.
- If MUN (milk urea nitrogen) levels are under 7 and over 16 mg/dl, herd values may not be optimal.

Table 1. Value of milk components and yield.

Year	2003	2004	2007 (Dec)	2008(Mar)
	---------- ($) ----------			
Milk fat (lb)	1.21	2.05	1.43	1.36
Milk protein (lb)	2.24	2.60	4.71	4.33
Milk (cwt)	11.40	15.06	21.31	18.51

Table 2. Normal milk fat and milk protein relationship for various breeds of dairy cattle.

Breed	Milk fat	Milk True Protein	Ratio
	--------- (%) ----------		% protein / % fat)
Ayrshire	3.86	3.13	0.81
Brown Swiss	3.95	3.25	0.82
Guernsey	4.42	3.30	0.75
Holstein	3.66	2.99	0.82
Jersey	4.57	3.54	0.77

Table 3. Comparison of three rumen model program (CNCPS, NRC, and AminoCow) based on a balanced ration from a traditional program (Spartan II).

	Spartan II	CNCPS	NRC	AminoCow
Performance summary				
Dry matter intake				
Actual (lb)	52.7	52.7	52.8	52.7
Predicted (lb)	52.2	46.7	54.3	53.2
Milk yield potential				
Protein (lb)	100(CP)	99 (MP)	88 (MP)	na
Energy (lb)	100	93	87	na
Ration summary				
Crude protein				
(% DM)	18.7	18.7	18.6	18.7
RDP (% CP)	62	61	62	63
RUP (%CP)	37	39	38	37
Soluble protein (%CP)	26	33	na	na
NE lact (Mcal/lb DM)	0.77	0.79	0.72	0.77
ADF (%)	20.5	na	24.2	20.8
NDF (%)	34.5	33.8	36.6	34.5
NFC (%)	37.7	41.0	37.1	37.4
Fat/oil (%)	4.4	4.3	4.4	4.5
Rumen model protein summary				
Metabolizable protein				
MP supplied (lb/day)	na	6.25	6.13	5.74
MP bacteria (lb/day)	na	3.38	2.84	2.11
MP RUP (lb/day)	na	3.14	3.04	3.63
MP endogenous (lb/day)	na	na	0.25	na
Lysine (grams)	na	194	217	187
Methionine (grams)	na	55	61	52
Lysine/methionine ratio	na	3.53	3.56	3.59

Table 4. Break-even prices of various protein supplements.

	---------- $ / ton ----------	
Price of SBM (44%--base feed)	300	400
Price of SBM (48%)	310	425
Blood meal	647	1061
Brewers grain, dry	256	333
Canola meal (34% CP)	234	297
Corn gluten meal	489	739
Corn distillers grain	316	392
Fish meal	647	958
Pork meat and bone meal	667	924
Soybeans, heated (55% RUP)	424	580
Heat treated soybean meal	406	583

Applied Calf Research from Birth to Six Months

University of Minnesota Southern Research and Outreach Center (SROC), 2004-2007

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Introduction

The University of Minnesota SROC Calf and Heifer Research and Extension facility in Waseca contract raises over 800 dairy heifer calves annually for three commercial dairy operations. Calves are picked up twice weekly at 2 to 4 days of age and remain at SROC until 6-7 months of age. A partnership was established between the University of Minnesota and Ridley Inc. (including Hubbard Feeds, Inc. and FeedRite, Canada) in 2003 to focus on applied nutrition and management research. Milk Products joined the partner team and more recently APC, Inc. The SROC calf and heifer facilities were upgraded and new facilities were completed in April 2004. This allowed for sufficient number of calves to be raised to accommodate applied pre- and post weaning studies developed by the partner team (up to 400 calves/year) and also have calves to be able to conduct studies with other University or allied industry collaborators. Contracts with each of the three dairies were finalized prior to moving to the new facilities. A close working relationship has developed between the University of Minnesota and management at each of the three dairies which has helped to maintain the quality of heifers raised at SROC. Since 2004, completed nursery (56 day) and post weaning (up to 112 days) applied studies have involved over 3,000 heifer calves. This paper will provide a brief management overview of the facility and highlight the results of selected pre-and post weaning applied research programs. .

Calf and Facility Management

Nursery phase. Calves are picked up weekly by SROC staff from the respective dairies on Monday and Thursday and co-mingled in a well-bedded livestock trailer. During winter months, calf blankets are used at pick-up and remain on the calves at the discretion of SROC staff until they adjust to their new environment. In the nursery phase, calves are housed in one of two 200 ft x 30 ft curtain side-wall naturally ventilated calf barns. Each barn contains two 90 ft x 30 ft rooms with 40 individual pens (approx 30 sqft/calf) within each room. A 20 ft x 30 ft mixing and feed storage area is centrally located in each barn. The rooms are managed as an all-in, all-out system. All pen panels are removed and power washed between calf groups. All bedding material is removed and the remaining front gates and rear panel holders are also power washed. Chopped straw is used for bedding calf pens in the winter and sawdust in the summer months.

Calves will remain in their respective pens for about 56 days unless a specific protocol requires a longer feeding period. Upon arrival, calves are weighed, hip heights taken and two jugular blood samples drawn. One sample is used to check total serum proteins using a refractometer and a second sample for whole blood analyses by an outside laboratory to identify persistently infected BVD calves. Calves are administered an intranasal modified live IBR/PI3 and salmonella vaccine upon arrival. Calves between 75 and 110 lbs at 2 to 4 days of age are assigned to applied nursery studies, if appropriate, across resource location. Usually cross-bred calves are not used in the studies (about 3% of total calves). An individual recording sheet is prepared for every calf regardless if they are on trial or not. Daily records are kept for feed intake (milk and calf starter), fecal scores and health treatments. Period growth parameters and management such as vaccinations, dehorning, and tail docking (one herd only) are also noted. All data from individual cards are transferred to an Excel worksheet for management and study statistical analyses.

At approximately 2 and 6 weeks after arrival calves will be administered a bovine respiratory complex vaccine and a 2nd dose of the salmonella

vaccine. Dehorning and tail docking is completed about 30 days after arrival. The current standard feeding protocol is to offer a 20:20 all milk protein medicated milk replacer at 0.625 lbs/feeding twice daily diluted with water to 12.5% solids for 35 days and once daily from day 36 to weaning at 42 days. An 18% CP complete texturized calf starter (including an ionophore) is offered from day 1. Fresh water is offered daily. This standard feeding protocol is included in as many nursery studies as possible to build a control data base. Calves will remain in their respective pens until 2 weeks after weaning and then transfer to group pens of 6 heifers. Occasionally calves have remained in the nursery for up to 70 days. At least 20-25 calves are assigned for each treatment group for nursery studies. Prior to moving to group pens, all calves receive a 2nd intranasal modified live IBR/PI3 vaccine.

Postweaning group housing. Two postweaning barns are used to house heifers until they attain 6 months of age. A new 65 ft x 150 ft curtain side-wall naturally ventilated facility completed in 2004 is located north of the calf nursery barns. This contains 20 12ft x 25 ft pens and a scale with handling area. The front part of each pen is a scrape alley and the rear a manure pack. Heifers are fed through diagonal bars from a central feed alley. The front alley is scraped weekly and the manure pack cleaned out as often as deemed necessary. Pens are re-bedded once or twice weekly. A second postweaning barn is an existing 80 ft x 160 ft manure pack pole barn. The barn contains 20 15 ft x 30 ft pens each with 10ft concrete feed bunks. There is a central scale and heifer handling area. This barn is cleaned out twice annually but pens are re-bedded once or twice weekly. Both barns are used for studies alternating a complete study between each. Heifers are fed once daily and both barns are managed as a continuous flow system.

Calves will remain on their nursery calf starter for 7-10 days after moving to their respective group pens then switch to a grain mix with access to long hay. The amount of feed offered by pen is recorded and refusals are weighed as per study protocol. Body weights, body condition score and hip heights are monitored. There have been a number of grain mixes evaluated either offered free choice or limit-fed with or without access to long hay. A 16% whole corn and pellet grain mix fed at 6 lbs/heifer daily for 28 days and 5 lbs/day from 29 to 112 days with access to long hay has been established as basis to which to compare performance. Heifers are transferred to other contract growers at 6-7 months of age but often due to excess heifer numbers at SROC above capacity, an additional facilities are used for 2-3 weeks prior to their transfer. Similarly an existing inside calf room is used for overflow calves during the nursery phase. In between 4 and 5 months after arrival at SROC heifers are vaccinated against leptospirosis and clostridium species.

Calf profiles. One of the key areas for raising dairy heifers is to start with a high quality calf. The respective dairies are continually working to maintain calf quality. At least 3 feedings of colostrum are required before calves are picked-up. The goal is to evaluate the profiles of total serum proteins on all calves upon arrival. In addition, minimizing other potential health issues such as navel infections are a priority for the dairies. The incidence of navel infections or related problems is 1.8%. There have been occasional leg problems (0.6%; contracted tendons, swollen, injured etc.). Table 1 provides a heifer calf profile including total serum proteins and a summary of growth parameters at 6 months of-age across the 3 dairy farms. Overall calf losses at SROC are < 2%. A recent addition to the overall project is to be able to use DHIA records to follow the heifers back to their respective dairy herds and document calving age and first lactation performance.

1. Calf Nursery Research Studies. A target goal for calf performance in the nursery phase is to double the initial body weight by the end of the nursery phase and gain at least 4 inches of frame height in the same time period. These goals have been attained in a number of calf groups but there are some variations by season of the year. Calves fed the standard SROC program during the 56 day nursery phase during studies from 2004-2007 have averaged 194% of their initial 2-4 day old body weight (184-207%), almost 4 inches of frame gain (3-4.6 inches) and 1.50 lb daily gain (1.3 -1.7 lb). Studies have been designed to provide options for both liquid and calf starter programs in relationship to calf performance, health and potential changes in economic efficiencies. Performance summaries of nursery studies presented at national meetings have included Ziegler et al. (2005a); Ziegler et al. (2005b); Ziegler et al.(2006a); Ziegler et al. (2006 b); Braman et al. (2006), Chester-Jones et al. (2006b); Chester-Jones (2007), Hayes et al. (2007), and Ziegler et al. (2007a).

a. Liquid feeding programs: The premise of these programs have been to evaluate milk replacers (MR) containing varying protein levels, alternative proteins, energy sources and nutritional supplements. In addition, MR feeding management strategies have been assessed in some studies in conjunction with varying calf starters (CS).

Conventional vs Intensive MR programs. The initial MR study focused on conventional (C) vs. modified intensive (MI) or intensive (I) programs (Table 2). Calves on the intensive program were weaned at 49 days and remainder at 42 days. Gain advantages were apparent for the modified intensive and especially intensive programs vs. more conventional system. Calf health was not affected by MR programs. Daily feed costs/calf (April 2008 feed

prices) to 56 days averaged $1.57, $1.58, $2.18, $2.07, and $3.05 for calves fed non acidified C, acidified C, MI high solids (HS) , MI low solids (LS) and I, respectively. The Calves remained in their pre-weaning treatments and were moved to group pens where they were limit-fed a 16 (conventional) vs 18% CP grain mix (modified intensive and intensive) with access to long hay. There were no differences in post weaning performance from 9 to 25 weeks of age.

A complete analysis of raising costs would have to undertaken to determine a viable cost:benefit ratio for each of the MR programs based on first calving age and lactation performance. The latter information will be forthcoming from DHIA tracking of heifers once they have entered the respective milking herds.

Alternative protein and energy sources in MR. The cost of milk proteins have remained high for sometime and alternative proteins that do not compromise calf performance but result in lowering MR costs are worth pursuing. The standard SROC nursery feeding program (MR and calf starter) was compared to calves fed MR replacing 50% of the milk protein with hydrolyzed wheat gluten (WG) protein vs. 50% of the milk protein with soybean protein concentrate (SPC) vs. replacing 30% of the milk protein with WG vs. 50% of the milk protein with 25% WG and 25% SPC (Table 3). All calves were fed the 18% CP calf starter. The MR were balanced for amino acids. Calves fed an all milk protein 20:20 MR had better overall performance than calves fed MR containing alternative protein sources. However, calf performance for those fed the standard SROC program exceeded that of the control calves from other SROC studies. Calves fed the alternative protein MR gained as well as control MR calves in other SROC studies. Current work at SROC is looking at other alternative protein sources and additives focusing on improving calf health during the pre-weaning period.

Animal fats (lard) are commonly used for MR formulations as energy sources. Interest in alternative energy sources has focused on all-vegetable fat sources or a combination of animal and vegetable fat. A study was undertaken to look at calf performance when offered varying energy sources using a 24:20 all milk protein medicated MR fed as per standard SROC protocol with a 18% CP CS. Fat treatments were: Animal fat (AF); Vegetable blend of 80% palm oil and 20% coconut oil (VF); and, AF plus a blend of medium chain tri-glycerides containing 1% caproic, 69% caprylic, 1% capric and 29% lauric acids fed at 5 g/calf daily (AFVF). The study was conducted between January and March. Calves fed AF tended to have higher CS and total DMI than those fed AFVF but overall calf performance was not influenced by fat source. The average frame growth exceeded 4 inches and overall gain was within the range of other studies. Calf starter DMI, total DMI, daily gain and feed/gain for the 56 day study were 127.52, 174.85, 1.60, 1.96; 118.46, 165.87, 1.52, 1.95; 119.34, 166.92, 1.55, and 1.93 for calves fed AF, VF, and AFVF, respectively.

Additives in MR and feeding strategies. Research at SROC has also included nutritional management to help calf health, intestinal health and/or immune function during the nursery phase. An example involved incorporating mannan oligosaccharides (Bio-mos® , fed at 2 g/calf daily), fructo-oligosaccharides (inulin, fed at 5.67 g/calf daily) and a combination of Bio-mos® and inulin in non-medicated 20:20 MR. The additives did not affect pre- and immediate post weaning calf performance vs. non-medicated control MR. Other recently completed or on-going studies are investigating non-medicated additives incorporated with different MR feeding rates. In addition, the implications on calf performance of varying the number of milk feedings a day are being documented.

b. Calf starter programs. Offering a high quality CS and promoting optimal intake is integral to the success of all SROC nursery feeding programs. To evaluate CS options for calves, establishing some benchmarks for pre- and immediate post weaning intake and expectations for calf performance under consistent management are indicated. Table 5 summarizes CS intake by season of the year at SROC. Under the SROC program, calves are weaned by days on feed rather than CS intake. However, it is apparent that good CS intake could allow for earlier weaning and reduce extra costs of extending the liquid feeding period. A number of nursery studies have investigated various CS fed with the standard SROC MR program. .

Calf starter composition and physical form. In the initial SROC CS study, calves were fed the standard SROC MR program with texturized CS containing 6, 9 or 12% liquid molasses. Overall, when compared to calves fed 6% molasses, those fed the 12% molasses had 8.3% lower gains and utilized their feed 5.3 % less efficiently. Calves fed the 9% molasses had similar performances to those fed the 6% level. A common question is why do we not feed complete pellets vs texturized CS for consistency of product? This was investigated when calves were offered free choice 18% CP CS as a complete texturized (T), complete pellet (P) or P with chocolate, whey or sweet tart as intake enhancing supplements. Calves fed the complete T CS had the highest feed efficiency and gained 7.1% faster than calves fed the complete P. Intake enhancing supplements were not advantageous. Preliminary data suggests that corn processing and physical form does not improve calf performance when comparing CS based on steam flaked corn, pellet and oats; whole corn and pellet or roasted corn, pellet and oats.

2. Postweaning Studies. Transitional nutrition and management of calves when moving from individual to group housing is a challenge on many dairy operations. On-going SROC research is looking at ways of improving this adjustment period by management strategies in the nursery prior to moving or changes in feed formulations during the transition. Once adjusted to the group pens, postweaning studies have been implemented. Performance summaries of postweaning studies presented at national meetings have included Linn et al. (2005); Larson et al. (2006); Chester-Jones et al. (2006a); Chester-Jones et al. (2007); and Ziegler et al. (2007b). An initial study in 2004 found that continually feeding a grain mix at 6 lbs/heifer daily with access to long hay for 112 days, resulted in good growth but higher than expected body condition. Follow-up studies then included variable grain feeding rates. A summary of heifer performance on the SROC control limit-fed whole corn (WC) and pellet (P) 16% grain mix program across 4 studies is summarized in Table 5. Key points to note are average hay intake, average DM intake as a % of body weight and heifer performance parameters.

Protein sources (dried distillers grains and urea), grain mix protein levels (13,16,19% CP), rumen fermentation enhancer (FERMENTEN®), fiber levels, and limit vs full feeding grain mixes, have been investigated. Regardless of feeding regimen whether limit for full- feeding grain mixes with or without access to hay, heifer DM intake consistently represents close to 3% of body weight. Limit feeding to more precise target gains with improved feed efficiencies is a next logical step in the process.

Forage quality. The variability of hay quality offered to heifers is often related to market prices and current inventory on the farm. A SROC study investigated feeding hay of low (100 RFV) with or without a low moisture molasses block (CRYSTALYX®; 30% CP); medium (134 RFV) or high (154 RFV) quality hay fed with a 16% CP cracked corn and pellet grain mix for 112 days (6 lbs/day for days 1-14 and 4 lbs/day from days 15-112).Using a low moisture block supplement (B) with 100 RFV hay increased daily gain by 4% and feed efficiency by 3.3% compared to feeding 100 RFV without a block supplement. Average daily block consumption was 0.3 lbs/heifer. Using a 130 RFV hay compared to 100 RFV hay increased daily gain by 9% and feed efficiency by 4%. Using a 154 RFV hay compared to a 130 RFV hay increased daily gain by 1.4% and feed efficiency by 5.7% over the 112 day study. Heifer performances were acceptable and an economic comparison should be the criteria to select the hay of choice when limit feeding concentrates. Daily gain and feed/gain were 1.91, 4.73; 1.99, 4.62; 2.10, 4.59; 2.13 and 4.32 lbs for heifer fed 100 RFV, 100 RFV + B, 130 RFV, and 154 RFV hay, respectively.

Summary

An overview of SROC calf management, facility management and applied research programs have been presented. Options have been investigated to support an improvement in consistency of nutritional management for calf raising programs from 2 to 4 days up to 6 months of age. The information collected at SROC over the past 4 years also allows for future refinement of nutritional and management strategies to optimize the growth and health of dairy calves especially in the early pre-weaning phase.

Table 1. Profile of heifer calves contracted at SROC from 3 dairy farms from 2-4 days up to 6 months of age.

Item	Farm A	Farm B	Farm C
A. Upon arrival			
Number of heifers	885	1,593	978
Initial BW. lb	88.8	86.7	87.2
Initial serum protein, g/dl	5.4	5.4	5.2
Initial serum protein profiles			
< 4.0 g/dl, %	0.9	2.7	1.3
4.0-4.5 g/dl, %	8.2	12.2	13.7
4.6-5.0 g/dl, %	22.8	22.5	33.2
5.1-5.5 g/dl, %	24.8	20.5	23.4
5.6-6.0 g/dl, %	28.5	22.8	20.7
> 6.0 g/dl, %	14.8	19.3	7.7
B. 6 mth profile of 2,397 heifers			
Final BW, lb	476	462	451
Final Hip Height, in	45.5	44.9	45.1
Total ADG, lb	1.92	1.91	1.91

Table 2. Performance of heifer calves fed varying milk replacer and complete texturized starter programs (least squares means)[a]

	Milk Replacer (%CP, %Fat)				
Parameter	**20:20 C Non-Acidfied**	**20:20 C Acidified**	**28:16 MIHS**	**28:16 MILS**	**28:16 I**
Feed rate lbs/day MR[1]	1.25	1.25	1.5	1.5	2.25
Solids %	13.88%	13.88%	16.67%	12.50%	16.67%
CS CP %, as-fed	18%	18%	22%	22%	22%
No. calves	26	28	26	29	24
Init. BW, lb	90.9	91.08	89.74	87.05	88.86
Init. HH, in	31.80	32.00	31.78	31.73	31.81
SP, g/dl	5.00	5.11	4.90	4.89	4.98
Pre-weaning					
CS DM 42 d, lb	43.38^{b}	41.62^{b}	43.49^{b}	37.99^{b}	23.61^{c}
CS DM 49 d, lb	73.50^{b}	70.64^{b}	74.82^{b}	67.98^{b}	43.85^{c}
Milk DM, lb	47.76^{b}	47.45^{b}	57.51^{c}	55.40^{c}	94.89^{d}
ADG 1-42 d, lb	1.25^{b}	1.19^{b}	1.47^{c}	1.39^{c}	1.74^{d}
ADG 1-49 d, lb	1.34^{bc}	1.28^{b}	1.52^{d}	1.45^{cd}	1.78^{e}
Overall 56 days					
Final BW, lb	171.45^{b}	167.55^{b}	180.09^{c}	169.42^{b}	188.61^{d}
CS DM 56 d, lb	108.81^{b}	105.09^{b}	111.87^{b}	102.63^{b}	77.70^{c}
Total DM, lb	156.57^{b}	152.55^{b}	169.38^{cd}	158.03^{bc}	172.59^{d}
ADG, lb	1.43^{b}	1.36^{b}	1.61^{c}	1.47^{b}	1.78^{d}
Total gain, lb	80.54^{b}	76.47^{b}	90.35^{c}	82.37^{b}	99.75^{c}
Gain/feed, lb	0.51^{b}	0.50^{b}	0.53^{b}	0.52^{b}	0.58^{c}
Final HH, in	35.87^{b}	35.83^{b}	35.91^{b}	35.71^{b}	36.65^{c}
HH gain, in	4.07	3.83	4.13	3.98	4.84
Total BW gain, %	189	184	201	195	212
Treatment costs/calf, $	1.54	1.15	1.41	2.33	1.11

[a]Adapted from Ziegler et al. (2005b).

[bcd]Means in the same row with different superscripts differ (P <0.05).

[1]All C, MIHS and MILS calves fed the MR in 2 equal feedings twice daily for 35 days and ½ the amount x1 daily from day 36-42. Intensive calves were fed MR in 2 equal feedings twice daily for 42 days and ½ the amount x1 daily from day 43-49.

Table 3. Performance of calves fed milk replacers with alternative protein sources[1]

Parameter	Standard SROC	50% WG	50% SPC	30% WG	25% SPC + 25% WG
Init BW[2], lbs	89.7	89.5	89.1	90.6	90.6
Init. HH, in	31.6	32.1	31.9	32.0	31.8
Pre-weaning					
BW 42 d, lb	154.1[a]	146.2[b]	145.5[b]	146.6[b]	143.5[b]
MR, DM lb	48.2	47.8	48.0	48.1	47.8
CS DM, lb	57.2[a]	49.3[b]	52.6[ab]	48.9[b]	48.5[b]
ADG	1.54[a]	1.35[b]	1.32[b]	1.35[b]	1.28[b]
Feed/gain, lb	1.64[a]	1.74[ab]	1.89[b]	1.77[ab]	1.89[b]
Postweaning					
BW 56 d, lb	186.3[a]	177.5[b]	176.4[b]	176.0[b]	173.3[b]
CS DM, lb	68.7[a]	64.0[ab]	66.7[ab]	62.1[b]	62.4[b]
ADG	2.32[a]	2.23[ab]	2.18[ab]	2.09[b]	2.14[ab]
Overall 56 d					
Total DM	174.3[a]	161.3[b]	167.8[ab]	158.6[b]	158.9[b]
ADG	1.72[a]	1.57[b]	1.54[b]	1.52[b]	1.50[b]
Feed/gain, lb	1.80[a]	1.85[ac]	1.98[b]	1.88[ac]	1.93[bc]
Final HH, in	36.2	35.8	35.7	35.7	35.6
HH gain, in	4.6	3.7	3.8	3.7	3.8
Total BW gain, %	208	198	198	194	191
Treatment costs/calf	1.27	1.88	2.15	2.62	2.55

[a,b]Means within a row without common superscripts are different at $P < 0.05$.
[1]Adapted from Hayes et al. (2007).
[2]Initial BW included in the model as a covariate.

Table 4. Average pre – (1-42 days) and post weaning (43-56 days) calf starter (CS) intake by 14 day periods and season of the year across recent SROC studies 2004-2006[ab]

Time of Year	No. Calves	20:20 MR lbs/day	CS CP%	Day 1-14	Day 15-28	Day 29-42	Day 1-42	Day 43-56
Dec-Feb	40	1.50	20	2.6	14.8	34.2	51.6	67.2
March-May	72	1.25	18	2.0	11.2	29.0	42.2	63.7
March-May	111	1.25	18	1.9	12.1	29.9	43.9	63.5
May-July	124	1.25	18	1.2	8.8	24.6	34.6	55.9
July-Sept	100	1.25[c]	18	0.8	9.4	27.2	37.4	58.3
Oct-Dec	125	1.25	18	1.8	15.8	33.4	51.0	64.5

[a]Adapted from Chester-Jones (2007)
[b]Intake averaged across all milk replacer (MR) and calf starter treatments to obtain benchmarks for SROC dairy heifers.
[c]Non-medicated Milk replacer

Table 5. Examples of postweaning heifer performance from 9 to 25 weeks of age when limit fed a 16% CP whole (WC) corn and pellet (P) grain mix with access to hay (acceptable range 120-140 RFV).

Parameter	A	B	C	D
Mth study started	July 2004	December 2005	January 2007	July 2007
WCP, lb as-fed/d	112 d 6 lbs	56 d 6 lbs 56 d 5 lbs	28 d 6 lbs 84 d 5 lbs	28 d 6 lbs 84 d 5 lbs
No. Pens of 6 heifers	4	4	5	4
Init. BW, lb	187.7	208.0	194.3	187.8
Init. Hip Height, in	36.98	36.9	36.8	36.7
Init. BCS	2.97	2.96	3.03	2.90
Period 1-112 d				
BW 112 d, lb	462.0	464.6	459.7	423.8
Daily gain, lb	2.45	2.29	2.37	2.11
WCP/d, lb DM	5.4	4.85	4.75	4.7
Hay/d, lb DM	3.9	5.27	4.83	4.6
Feed/gain, lb	3.80	4.42	4.04	4.41
DMI, % of BW	2.86	3.00	3.30	3.10
Final HH, in	45.12	45.01	45.0	44.4
HH gain, in	8.14	8.11	8.2	7.7
BW gain:hght ratio	33.7	31.6	32.4	30.7
Final BCS	3.96	3.73	3.88	3.80
BCS gain	0.99	0.77	0.85	0.90

[a]Adapted from Chester-Jones (2007)
[b]Intake averaged across all milk replacer (MR) and calf starter treatments to obtain benchmarks for SROC dairy heifers.
[c]Non-medicated Milk replacer

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Opportunities for Glycerol Use in Dairy Diets

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Introduction

Glycerol, also referred to as glycerin or glycerine, is a product of the processing of fats for the chemical industry and for biodiesel production. Its main component is glycerol (propane-1,2,3-triol or 1,2,3-propanetriol), with varying amounts of water and other impurities. While pure glycerol has high value as a starting material for a number of industrial applications, crude or unrefined glycerol that arises as a byproduct of biodiesel production has a much lower value. Given the unprecedented recent increase in prices for corn and other cereals, crude glycerol has been considered as an economically attractive feed ingredient for dairy cattle. However, prices for crude glycerol have now increased to the point where it does not appear attractive even when compared with corn over $6 per bushel. Moreover, crude glycerol has a number of limitations that must be borne in mind by nutritionists and dairy producers. Given that economic evaluations of the potential role of glycerin for dairy cattle may change as conditions change, this review will summarize findings from research conducted on use of glycerol in dairy cattle diets, including information on its metabolism, potential problems, and practical issues in its use in rations.

Glycerol Production

Glycerol is obtained as a by-product from the industrial processing of fats and oils and in the manufacture of "biodiesel" fuels. Large industrial operations that "split" or hydrolyze fats for production of pure fatty acids may also chemically refine and purify glycerol to food grade that can be used in human food, cosmetic, and drug applications. Such purified glycerol is too expensive to be considered as a dairy feed. However, many biodiesel manufacturers lack the size or scope to efficiently refine the crude glycerol, which results in the byproduct being a drain on the profitability of biodiesel production. The low value is a result of the impurities present in crude glycerol. Hence, its low value makes it potentially competitive as an animal feedstock.

Production of biodiesel in the USA has increased by a factor of 1,000 over the period of 1999 through the end of 2007, resulting in co-production of 50 million gallons of crude glycerol annually (Dasari, 2007). Supply of glycerol in the United States and worldwide is projected to grow over the next decade as long as government policies and incentives favor increased processing of plant oils for production of biodiesel fuels and as worldwide production of fats and oils continues to increase. However, the recent run-ups in oilseed prices have greatly diminished the profitability of biodiesel production (Toh and Koh, 2008). Glycerol prices were relatively low throughout 2006 and into 2007, but have climbed recently along with prices of all feeds. Whether glycerol becomes economically attractive again depends on many considerations in the prices of raw commodities, fuels, supply, and demand. In the long term, the incentive certainly exists for manufacturers to invest in capabilities to further refine and purify crude glycerol to higher value products (Toh and Koh, 2008), which will decrease supply to the animal feed market and increase its cost.

Metabolism of Glycerol

Glycerol is a potential glucose precursor via the pathways of gluconeogenesis if it is absorbed into the portal blood via the rumen or small intestine and then taken up by the liver. However, glycerol also is easily fermented in the rumen by bacteria, thus increasing VFA supply but only contributing to glucose production for the proportion of the VFA that is propionate. This is similar to the situation for propylene glycol, which contributes to total glucogenic substrate supply both by being absorbed as propylene glycol and via its fermentation to propionate in the rumen (Neilsen and Ingvartsen, 2004).

Because of its gluconeogenic properties, most early research in which glycerol was given orally (by either feeding or bolus doses) to dairy cows concerned potential benefits of glycerol as a treatment or preventative for ketosis (Johnson, 1953; Fisher et al., 1971; Fisher et al., 1973; Sauer et al., 1973). Glycerol disappears rapidly from the rumen, but the relative amount of absorption as glycerol vs. fermentation has been difficult to determine. Reports suggests that a portion of the glycerol entering the rumen can be absorbed directly (Remond et al., 1993). In studies where 15 to 25% glycerol was added most disappeared within 6 h (Bergner et al., 1995). A German study (Kijora et al., 1998) demonstrated that

twice-daily infusion of 200 g of glycerol into the rumen of steers increased plasma glycerol compared with non-infused steers (0.06 mM vs 0.19 mM). Disappearance of glycerol from the rumen was rapid after its administration, but no glycerol was detected in duodenal digesta. More than 85% of glycerol disappeared within 2 h of administration in the glycerol-adapted steers (Kijora et al., 1998). Maximal rates of glycerol disappearance determined using in vitro fermentors was 0.52 to 0.62 g/h, compared with rumen disappearance rates ranging between 1.2 to 2.4 g/h when 240 g of glycerol were dosed into the rumen (Remond et al., 1993).

More recent information indicates that net absorption of glycerol in cows is limited, even when large doses are administered. Kristensen and Raun (2007) measured glycerol absorption and liver metabolism of glycerol in cows given 925 g/d of 85% glycerol once daily through a ruminal cannula. Only about 10% of the glycerol administered was recovered as glycerol in the portal vein, but nearly all of that absorbed was taken up by the liver and most likely converted to glucose. The remainder of glycerol that was not recovered in the portal vein presumably was fermented in the rumen.

Ruminal fermentation of glycerol could contribute to its role as a glucogenic substrate to the extent that it is converted to propionate. However, data on the ruminal fate of glycerol are conflicting. Some early reports of glycerol fermentation indicated that it was fermented to large proportions of propionate (Johns et al., 1953; Garton et al., 1961), while other studies reported increased acetic and propionic acids (Wright, 1969) or increased propionic and butyric acids (Czerkawski and Breckenridge, 1972). Using rumen fluid inoculum from cows previously adapted to glycerol feeding resulted in greater production of propionate and butyrate at the expense of acetate when glycerol was added to in vitro fermentations (Remond et al., 1993). Bergner et al. (1995) showed that 14C- labeled glycerol was mostly converted to propionate. Kijora et al. (1998) found that intraruminal administration of glycerol decreased ruminal pH (from 6.3 to 5.4) and decreased the acetate to propionate ratio (from 3.5 to 2.1).

Linke et al. (2004) administered 1 kg of crude glycerine (80% purity) by feeding or oral administration via drench or stomach tube. Their results (Table 1) showed that glycerol decreased molar percentages of acetate and increased molar percentages of propionate and butyrate at 4 h after either feeding or oral administration although butyrate increased to a greater degree than did propionate. Kristensen and Raun (2007) also found that glycerol administration into the rumen decreased the molar percentage of acetate and increased butyrate, but did not affect the molar percentage of propionate. Trabue et al. (2007) compared ruminal fermentation characteristics when either propylene glycol or glycerol was provided as the single substrate to in vitro fermentations. They found that propylene glycol addition resulted in much larger increases in propionate concentration over time than did addition of glycerol. Furthermore, addition of glycerol also increased concentrations of butyrate, valerate, and caproate compared to the control or addition of propylene glycol. Schröder and Südekum (1999) noted increased concentrations of butyrate when diets were supplemented with glycerol. DeFrain et al. (2004) found greater proportions of butyrate in ruminal fluid from cows administered glycerol as a drench. Together, these data indicate that providing glycerol into the rumen via feeding or oral bolus would contribute to ruminal fermentation as a microbial energy source; however, it appears that glycerol fermentation likely will not provide as much propionate for glucose production as would propylene glycol.

Table 1. Ruminal fermentation characteristics at 4 h postadministration for cows administered 1 kg of glycerine (80% glycerol). From Linke et al. (2004).

	Treatment				
VFA	Control	Fed	Drench	Tube	P value
Acetate, mol %	53.3	44.9	44.6	43.0	0.05
Propionate, mol %	26.4	28.7	30.4	30.4	0.05
Butyrate, mol %	14.1	20.0	20.3	21.5	0.05

Glycerol in the diet also might affect other aspects of ruminal fermentation. Kijora et al. (1998) found that incorporation of ^{15}N-labeled urea into microbial protein was decreased when 200 g of glycerol was administered into the rumen twice daily. Roger et al. (1992) examined the impact of glycerol addition to in vitro microbial cultures on growth, adhesion, and cellulolytic activity of two major cellulolytic bacterial species (*Ruminococcus flavefaciens and Fibrobacter succinogenes*). They found that low concentrations (0.1 to 1% of volume) did not affect any of the aspects studied; however, addition of glycerol at 5% of volume had strong negative effects on growth and cellulolytic activity of these organisms. Ruminal liquid volume of lactating dairy cows typically ranges from 50 to 60 L, which indicates that glycerol inclusion at low rates (~250 g or less at one time) is unlikely to result in negative effects; however, greater amounts (~1.25 kg at one time) could result in some negative effects on ruminal cellulolytic activity (Overton, 2007). Recent research at Purdue University showed that glycerol at up to 15% of the dietary substrate maintained DM fermentation rates, whereas more than 5% molasses depressed DM digestibility (Donkin and Doane, 2007).

Nutritional Value of Glycerol

In assessing the nutritional value of glycerol, the purity must be taken into account. Pure glycerol would be almost entirely available as an energy source. As mentioned earlier, however, pure sources of glycerol are unlikely to be used in dairy cattle feeding because of their high cost. Crude glycerol from the biodiesel industry may range from >70% to more than 90% glycerol (Dasari, 2007). The water content of glycerol used in various scientific studies has ranged from a low of 1% (for purified glycerol sources) to as much as 26.8%. German researchers determined that the net energy (NEL) value of glycerol (1.03 to 1.05 megacalories per pound dry matter) in sheep, steers, and dairy cows was equal to or greater than that of corn grain (Schroder and Sukekum, 1999). Similar conclusions have been reached for glycerol use in poultry (Dozier et al., 2008) and swine (Lammers et al., 2008) diets. Net energy values were approximately 13% lower in high-starch diets (about 0.90 megacalories per pound) than in lower-starch diets, which was attributable to decreased cell wall (NDF) digestibility caused by addition of glycerol to the higher-starch diets. Therefore, the economic value of energy from glycerol can be compared directly with that of corn grain after correcting for the glycerol content (analogous to the "dry matter" content of the glycerol) of the material. This contention is supported by recent research at Purdue (Donkin et al., 2007; Donkin and Doane, 2007).

It must be remembered that glycerol, unlike corn, supplies essentially no protein and few nutritionally important minerals, which would need to be compensated if glycerol was used as an energy source. The South Dakota study reported that glycerol contained 11.5% "salt", but other sources have reported low sodium contents. Potassium content in the German research ranged from 2.2 to 2.3% of the dry matter and phosphorus from 1.05 to 2.36%. Contributions to mineral intake by glycerol might be a factor in dry matter intake and need to be accounted for in ration formulation. A recent evaluation of crude glycerol from soy biodiesel production indicated a glycerol content of 76.2% and as much as 7.98% fat, 0.05% protein, and 2.73% ash. The latter was composed of 11 ppm calcium, 6.8 ppm magnesium, 53 ppm phosphorus, and 1.2% sodium (Thompson and He, 2006).

An important consideration for crude glycerol use is the impurities that may be present, including methanol, spent catalysts, and salts after neutralization. For example, a low-purity source of glycerol tested by German researchers contained 26.7% methanol on a dry matter basis (Schröder and Südekum, 1999) and the glycerol used in the South Dakota study contained 1.3% methanol (DeFrain et al). While methanol may be detoxified to some degree in the rumen, methanol consumption from larger amounts of less pure glycerol sources may be excessive. Methanol would be even more detrimental for preruminant calves and other nonruminants. Mmethanol content of crude glycerol should be less than 0.5%. A recent regulatory letter issued by FDA indicates that methanol levels higher than 150 ppm (interpreted as in the total diet) could be considered unsafe in animal feeds.

Use of Glycerol in Diets for Dairy Cows during the Transition Period

Glycerol has been proposed as a preventative for metabolic problems in transition cows. Goff and Horst (2001) drenched up to 3 L in ketosis treatment and prevention. Administration of 1, 2 or 3 L of glycerine (80% glycerol) by esophageal pump increased plasma glucose by 16, 20 and 25%, respectively, over pretreatment values. DeFrain et al. (2004) evaluated glycerol supplementation in the diet of transition cows. Glycerol (0, 0.43, or 0.86 kg/d) was topdressed on the TMR and fed to transition cows (n = 10 per treatment) from 14 d prepartum to 21 d postpartum. Glycerol did not affect prepartum concentrations of glucose, insulin, NEFA or BHBA; however, postpartum concentrations of plasma glucose tended to be higher for the cows fed the control diet compared to those fed glycerol (65.8 vs. 63.0 and 60.1 mg/dL). Cows fed either 0.43 or 0.86 kg/d of glycerol had decreased prepartum DMI compared with the control cows, but postpartum DMI was not affected by treatment. Energy-corrected milk yield tended to be decreased in cows fed glycerol compared with the control. Feeding 500 ml of glycerol, or approximately 3.1% dietary DM, from 3 wk before calving through 70 days in milk increased milk yield and milk protein content in milk (Bodarski et al., 2005).

Cornell University researchers studied the use of glycerol either as a dietary supplement or as a short-term postcalving drench (Ogborn et al., 2004; Ogborn, 2006). In the dietary study, 48 Holstein cows entering second or greater lactation were assigned to two prepartum treatments beginning at 21 d before calving and subsequently to four postpartum treatments after calving. Prepartum treatments consisted of a control or dietary addition of crude glycerine (80.6% glycerol) at 5% of diet DM. Postpartum treatments consisted of a control, dietary addition of glycerine (3.3% of diet DM), oral glycerine drench (500 ml; 625 g) once daily for the first 5 d postcalving, or a combination of diet addition and oral drench of glycerine. Postpartum dietary addition of glycerine continued through 21 d postcalving; thereafter, all cows were fed the same diet. Cows fed glycerol during the prepartum period consumed on average 0.59 kg/d of glycerol (0.74 kg/d of crude glycerine). In contrast to the DeFrain

et al. (2004) study, prepartum glycerol feeding increased prepartum DMI (14.8 vs. 13.2 kg/d); however, this increase in prepartum DMI did not translate into any effects on postpartum DMI or milk yield and composition. Furthermore, prepartum dietary glycerol did not affect plasma metabolites (glucose, NEFA, BHBA) and liver composition (triglycerides and glycogen) during either the prepartum or postpartum periods.

Cows fed glycerol during the postpartum period consumed on average 0.50 kg/d of glycerol (0.63 kg/d of crude glycerine). Glycerol feeding tended to decrease postpartum DMI by about 1 kg/d and drenching glycerol markedly decreased postpartum DMI by about 1.5 kg/d. Feeding glycerol postpartum did not affect milk yield or composition, BW and BCS change, or plasma metabolites and liver composition during the postpartum period. Drenching glycerol did not affect milk yield or milk composition but did result in greater BW and BCS loss during early lactation. Overall concentrations of plasma metabolites and liver composition were not affected by drenching glycerol. Short-term responses of plasma metabolites on d 5 postcalving indicated that glycerol drench tended to increase plasma glucose and decrease plasma NEFA concentrations during the first 6 h after administration (Ogborn, 2006). This glucogenic effect of glycerol is weaker than that typically expected when propylene glycol is drenched (Pickett et al., 2003; Neilsen and Ingvartsen, 2004).

Chung et al. (2007) topdressed 250 g/d of a blended "dry" glycerin source (65% glycerol) from calving through 21 d postpartum. Postpartum DMI and metabolic responses during the first 21 d postcalving were not affected by treatment. Milk yield and composition was largely not affected by treatment, although there was a trend for increased milk yield of cows fed glycerin by wk 6 of lactation, suggesting some residual effect of the non-significant alterations in metabolism during the transition period.

Use of Glycerol in Diets for Dairy Cows in Established Lactation

Fewer studies have examined glycerol supplementation as an energy source in diets for dairy cows. Glycerol at 3.6% of the diet fed to mid-lactation cows did not affect DM intake, milk production, or milk composition but increased rumen propionate and butyrate at the expense of acetate (Khalili et al., 1997).

Donkin et al. (2007) evaluated pure glycerol (99.5% glycerol) as an ingredient in dairy rations by replacing corn grain with a combination of glycerol and corn gluten feed (6.25:1). They fed Holstein cows (n = 60) diets containing 0, 5, 10, and 15% glycerol on a DM basis. Some results from this experiment are shown in Table 2. Dietary glycerol at up to 15% of total diet DM did not affect overall DMI or milk yield, although the authors reported that cows fed the 15% glycerol diet had decreased DMI for the first 7 d of the experiment. Glycerol did not affect milk fat or protein content, but decreased milk urea N content, suggesting that the glycerol was more fermentable in the rumen than ground shelled corn. Cows fed glycerol had larger increases in BW during the experiment.

Table 2. Effects of feeding glycerol in diets for lactating cows (Donkin et al., 2007; Donkin and Doane, 2007; as summarized by Overton, 2007).

	Dietary glycerol (% of DM)					
Variable	0	5	10	15	SEM	*P*
DMI, lb/d	52.8	53.9	54.1	53.0	1.1	0.82
Milk, lb/d	81.4	81.2	82.1	80.1	1.3	0.71
Milk fat, %	3.70	3.52	3.58	3.58	0.11	0.69
Milk protein, %	2.79	2.84	2.86	2.89	0.06	0.62
Milk urea N (MUN), mg/dl	12.5[a]	10.9b	10.7[b]	10.2[b]	0.4	0.05
BW change, lb	69.3[a]	89.3[ab]	109.1[b]	113.3[b]	10.1	0.05

[ab]Means within a row with different superscripts differ, $P < 0.05$

Taken together these experiments indicate that glycerol may be added to diets for lactating cows to a level of at least 10% of dry matter without deleterious effects and in some cases beneficial effects on milk production and composition.

Glycerol in Diets for Calves and Growing Cattle

We recently examined whether glycerol could be used as a partial replacement for lactose in milk replacers (Drackley et al., 2008). Holstein calves (6 male, 6 female) born at the University of Illinois dairy unit were assigned alternately to each of two treatments (24 calves total): control milk replacer or milk replacer supplemented with 15% glycerol. The experimental base milk replacer contained greater protein, fat, minerals, and vitamins so that when glycerol was added the composition would be the same as control, except that glycerol replaced some lactose. Calves were housed in individual hutches bedded with straw and had water freely available; no starter was offered until d 36. Calves were fed milk replacers twice daily from d 3 of life. Milk replacers contained 28% protein (all from whey proteins), 2.6% lysine, and 15% fat. Control milk replacer contained 40% lactose; glycerol milk replacer contained 25% lactose. Both replacers were reconsituted to 15% solids. Glycerol (liquid) was added to reconstituted base milk replacer at each feeding. During wk 1 milk replacers were fed at a rate of 1.5% of BW daily as powder and from wk 2 through 6 at 2% of BW daily. Starter was offered beginning on d 36. Milk replacer

offered was reduced by half on d 43 and calves were weaned at d 49. Measurements of BW and stature were made weekly through d 56. Calf BW through d 35 did not differ significantly between treatments (1.50 vs. 1.41 kg/d for controls and glycerol, respectively). Stature measurements (withers height, body length, heart girth) and measures of health (fecal scores, medical treatments) also did not differ between treatments. Our results indicate that glycerol could be an acceptable replacement for at least 37.5% of the total lactose in milk replacer if economically favorable. At this point glycerol cannot be incorporated into spray-dried protein-fat mixtures or in dry milk replacers. Liquid glycerol could be added into on-farm mixes of liquid milk replacer such as are often used for feeding veal calves.

In growing cattle, Schröder and Südekum (1999) fed 10% glycerol to dairy steers, effectively replacing over one-half of the starch in the diet, without negatively affecting intake, ruminal digestibility, rumen microbial synthesis or total tract nutrient digestibility in steers. Feeding glycerol increased water content of rumen digesta, and has been reported to stimulate water intake in other species.

Glycerol in Manufactured Feeds

Large farms may be able to handle glycerol as a bulk liquid and incorporate it into total mixed rations. However, glycerol may work well in pelleted concentrates as well. An interesting set of evaluations of glycerol addition to pelleted feeds was made by German researchers (Schröder and Südekum, 1999). Glycerol was added in increasing amounts to a concentrate containing wheat, soybean meal, rapeseed meal, beet pulp, wheat bran, corn, and vitamin-mineral premix. The mixture then was pelleted and stored under different conditions for different amounts of time. As little as 5% glycerol added to the mixture was effective in preserving higher-moisture pellets as indicated by suppression of fungal growth. Other measures of pellet quality and integrity were unchanged or improved by glycerol addition. Pelleting mixures with less-pure glycerol resulted in little methanol detected in the pellets, probably because the heat generated in the pelleting process caused the methanol to volatilize. Consequently, the prospects for addition of glycerol to pelleted feed mixtures for dairy cattle seem promising.

Conclusions

Based on the body of research conducted in recent years, it is evident that glycerol could be used at up to 15% of the dietary DM without negative effects on cow performance. Glycerol could be an effective replacement for corn grain on an energy basis, with approximately the same efficiency of use as corn grain. Economics will dictate whether that replacement is feasible.

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