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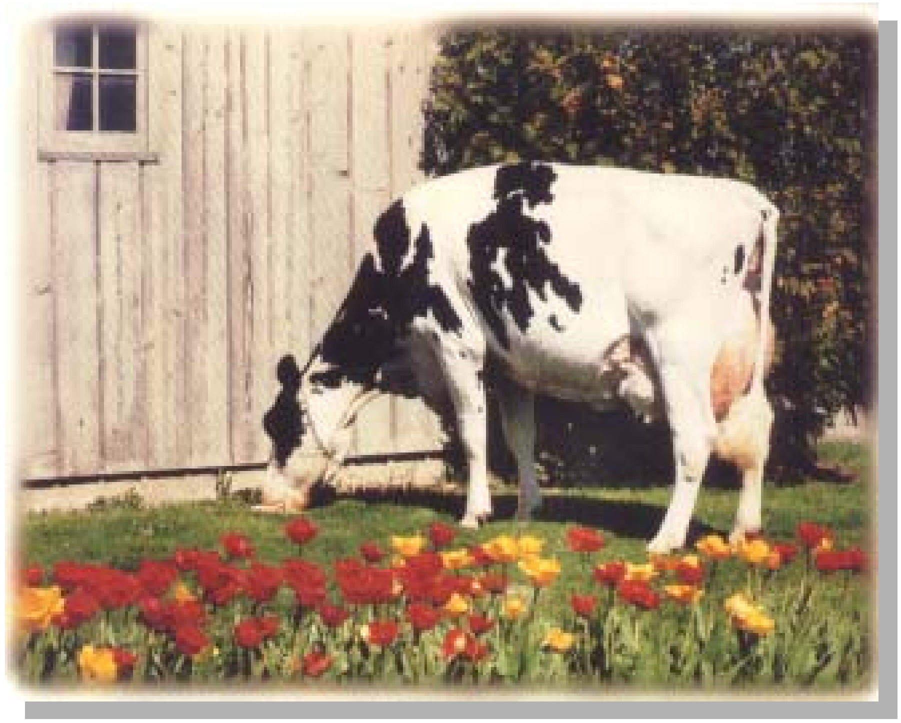

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The Conference Planning Committee extends appreciation to Ms. Cheryl Hall for her assistance in organizing the Conference and acknowledges Ms. Michelle Milligan for assistance with preparation of the *Proceedings*.

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Role of Sugars and Starch in Ruminal Fermentation

W.H. Hoover and T.K. Miller-Webster[1]
Division of Animal and Veterinary Science
West Virginia University

The major nutrients needed by rumen microbes are proteins and carbohydrates. Both nutrients are required to maximize microbial growth, but each serves a different role in the process. Proteins, in the proper amount and proper balance among ammonia, peptides, and amino acids, have a major impact on the efficiency of microbial growth. Efficiency is the pounds of microbial protein produced per unit of carbohydrate fermented and is subject to considerable variation. With appropriate available feed protein, about one-third pound of microbial protein can be produced for each pound of carbohydrate fermented in the rumen. Once the dietary protein has been properly balanced for maximum efficiency, the total quantity of microbial protein produced in pounds per day will be dependent on the amount or pounds of carbohydrate fermented in the rumen. It is in attempting to maximize the quantity of carbohydrate fermented that we cause most of the metabolic problems associated with rumen function.

Feed carbohydrates include sugars, starches, hemicellulose, and cellulose. Sugars and starches are much more extensively fermented in the rumen than are hemicellulose and cellulose. In attempting to maximize total carbohydrate fermented, the common approach is to reduce the fibrous carbohydrates in the ration and increase sugars and starches. If overdone, this can lead to rumen dysfunction and decrease microbial growth, as shown in Figure 1, and result in metabolic distress for the cow.

This paper will address the fermentation of sugars and starches, their effects on microbial growth, and how they can have both negative and positive effects on production.

Sugars

Levels in feeds and rations

The sugar content of most of the common feeds fed to lactating cows can range from less than 1 to over 20% of dry matter **(DM)**. Table 1 shows the soluble, total reducing sugar content of several feeds. These values were determined by extracting the ground feed for one hour in 39°C water and determining the total reducing sugar content of the extract. As a consequence of the low levels of sugars in the ingredients in a typical diet for lactating cows, the total sugar content will often be only 1.5 to 3.0% of DM. There is interest in knowing if additional sugar would have a positive effect on ruminal function. A beneficial effect could be the result of several factors, such as a rapid increase in microbial growth due to the higher level of rapidly available energy, more efficient utilization of the nitrogen in diets high in soluble nitrogen or non-protein-

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nitrogen, or the effects of altered volatile fatty acid **(VFA)** ratios on milk production or milk composition.

In addition to molasses and whey products as the main sources of sugar that can be added to dairy rations, there are a number of other by-products that contain relatively high levels of sugar. A concern that applies to all sources is obtaining a product with a consistent sugar content or in simply being aware of the actual sugar levels in various products. Table 2 gives values for sugars in a variety of products.

Effects on rumen function

With the exception of pentoses, all sugars studied by Cullen et al. (1986) caused a reduction in fermentation pH and resulted in the production of high quantities of lactic acid (Table 3). The key element with regard to negative effects of sugar fermentation on rumen function appears to be the reduction in pH. When Khalili and Huhtanen (1991) fed 2.2 lb of sucrose (16% of DM) to male Friesian cattle, pH was decreased and lactic acid production increased nearly three fold, while the same amount of sucrose fed with buffers that maintained pH caused no increase in lactic acid production. Sucrose supplementation in this study decreased the activities of both cellulolytic and hemicellulolytic enzymes when pH was allowed to decrease but not when pH was maintained (Huhtanen and Khalili, 1992). Similar results have been reported with regard to depressions in fiber digestion that occur when rapidly fermentable carbohydrates are fed, i.e., if the pH can be maintained, fiber digestion will not be greatly affected (Hoover, 1986).

Effects of sugars on VFA ratios vary considerably. Additions of sugars at low levels, less than 15% of DM, do not appear to greatly change VFA ratios (Table 4). In contrast, however, increased proportions of propionate and butyrate frequently are associated with feeding high levels of sugars (Table 5). Not only is level of sugar important, but source or type of sugar also appears to affect VFA and ruminal pH. Giduck and Fontenot (1987) directly compared equal additions of three sugars plus starch to an all-hay diet on ruminal function in sheep. These results are shown in Table 6. Glucose and lactose depressed ruminal pH to a greater extent than did sucrose or starch. Both glucose and sucrose decreased the molar percentage of acetate and increased propionate and butyrate, while lactose and starch had little effect on molar proportions.

A major aspect of the current interest in adding sugars to ruminant diets is related to the effects on nitrogen metabolism and microbial growth. A reduction in ruminal ammonia concentration has been noted in nearly all studies in which sugars have been added to the diet. In the study by Giduck and Fontenot (1987), ruminal ammonia concentrations were significantly reduced by all carbohydrate additions, with lactose being the most effective followed by starch, sucrose, and glucose. Chamberlain et al. (1985) found xylose most effective in reducing ruminal ammonia in goats fed grass silage, followed by glucose, sucrose, and starch. The reductions in ruminal ammonia suggest a more efficient utilization of the rapidly available nitrogen components of the diet and a concomitant increase in microbial growth and metabolism. Improved microbial growth can result from an increase in microbial efficiency (quantity of microbes grown per pound of carbohydrate fermented in the rumen) or by simply providing a greater amount of fermentable carbohydrate. It appears that improved microbial growth due to added sugars is primarily associated with the added available energy. No increase in microbial efficiency has been observed due to increased dietary sugars (Figure 2). If sugars improve microbial growth by causing a better synchronization between rapidly available nitrogen and carbohydrate, there should be an optimum ratio of available sugar to soluble protein. At this time, data on microbial growth responses to increases in the sugar to soluble protein ratios are very limited. The data in Table 7 indicate that microbial growth may be improved when the total sugar to soluble protein ratio exceeds 2:1.

The improved microbial growth may not entirely be due to an increase in available energy. Increases in liquid or solids turnover rates, which can increase microbial yield, have been noted due to addition of molasses (Susmel et al., 1995), dextrose (Piwonka et al., 1994), and whey (Stock et al., 1986).

Intake and production responses

Studies with lactating cattle have been conducted involving a number of sugar to starch ratios fed with a variety of forage sources and levels. In diets with cottonseed hulls **(CSH)** as the only forage, substitution of various liquid supplements for corn grain was investigated by Wing et al. (1988). Compared to the control diet, addition of 6% citrus molasses (4.3% sugar), 3% Masonex (54% sugar), or 3% Flambeau (45% sugar) all increased DM intake. Although milk production was marginally increased, it was less per unit of DM intake than production on the control diet. Only cane molasses significantly increased production without increasing DM intake (Table 8). In a study by Morales et al. (1989), levels and types of forages were studied with and without substitution of molasses for corn grain. This permitted evaluation of combinations of starch-to-sugar ratios, total starch plus sugar, and levels of soluble protein. These data are summarized in Table 9. Regardless of sugar-to-starch ratio, intake and production were higher when the diet contained 30% CSH and 34 to 35% total sugar plus starch than with 35% alfalfa silage and a similar total sugar plus starch. Substitution of molasses for corn in the CSH and alfalfa diets did not affect intake or production, even though the 35% alfalfa silage diet contained nearly twice as much soluble protein. Diets containing 65% alfalfa silage provided only 19 to 20% total sugar and starch and both intake and production were less than in the diets with 30 to 35% forage and 34 to 35% starch. In this study, as with the results of Wing et al. (1988), production responses appeared to be more related to DM intake than to level of sugar, starch, or to the sugar-to-soluble protein ratio.

Different ratios and sources of sugar, starch, and soluble nitrogen were studied by Casper and Schingoethe (1989). In diets varying from 29 to 40% soluble protein, corn was found superior to either barley or dried whey for milk production (Table 10). Dry matter intake for diets with corn or corn-whey combinations were higher than those containing barley. In a more recent study, no effects on production or intake were noted when whey or a molasses-whey-fat blend replaced part of the corn in diets of lactating cows (Table 11). While whey and lactose are palatable and do not usually decrease intake, both have been associated with decreased milk production (Schingoethe, 1976). In studies at West Virginia University, lactose was found to significantly increase intake and milk true protein content, but did not affect production.

Starch

Starches are the main storage polysaccharide in grains and the stems and leaves of legumes and tropical grasses. Like cellulose, starches are made up of glucose units, but there is a major difference in how the glucose units are linked together, in that starches have alpha linkages and cellulose has beta linkages. The former are digestible by enzymes secreted by animals as well as those of the ruminal microbes, while beta linkages can only be hydrolyzed by the microbes.

Fermentation of starch by microbes can result in lactic acid production, but the total quantity of lactic, as well as the proportion of D(-) and L(+), were found by Cullen et al. (1986) to differ markedly among sources (Table 3). The total lactate from starch fermentation was less than that produced from simple hexose fermentation, as was the proportion of D(-) lactate, which is the more potent of the isomers in causing lactic acidosis.

Effects on microbial growth

Diets for lactating cows have two major sources of carbohydrates that provide energy for microbial growth, the fibrous or structural carbohydrates **(SC)** and the sugars and starches, or nonstructural carbohydrates **(NSC)**. For high producers, the percentages of SC and NSC in the ration are similar at around 30 to 32% of DM. The fibrous portion is less ruminally available in dairy cattle fed high grain diets, ranging from as little as 11% (McCarthy, Jr. et al., 1989) to somewhat over 50% (Aldrich et al. 1993). On the other hand, starch digestion, although variable due to source, is usually 65 to 80% (Hoover and Miller-Webster, 1997). Since sugars are normally less than 10% of the total NSC, starch becomes the major source of carbohydrates for microbial growth. Effects of level of dietary starch on microbial growth was studied by Stokes et al. (1991). Results are shown in Table 12. These data show increased microbial growth with increased level of starch in the diet. The increased growth of microbes was accompanied by an increase in DM and fiber digestion. As with sugars, increased available carbohydrate was not associated with an increase in microbial efficiency. Available starch is not only a function of starch content in the diet but also is dependent on the extent of ruminal digestion of starch, which varies with source and processing (Table 13). High levels of NSC do not cause major negative effects on ruminal function, such as reduced fiber digestion, unless the pH of the fermentation decreases. This is seen in the Stokes et al. (1991) data in Table 12. In this study, pH was held at 6.4, and increasing starch level was not associated with decreases in digestion of DM or NDF. Similar results were reported by Hoover et al. (1984) and Shriver et al. (1986), where NDF digestion was not affected until the pH fell below 6.2. Excessive rate starch digestion and the concomitant decrease in ruminal pH can affect lactation performance as well as ruminal function. This may have been the cause of the decreased milk production in the study by McCarthy, Jr. et al. (1989), as shown in Table 14. Recommendations for concentrations of both NDF and NSC for dairy cattle have been compiled from a number of sources (Table 15).

Summary and Conclusions

By virtue of their higher digestibility and often higher dietary concentration compared to fibrous carbohydrates, sugar and starch together provide the major source of carbohydrate for the growth of rumen microbes in diets for high producing dairy cows in most parts of the US. Usually starches make up 90% of the total starch plus sugar. With the intent of increasing the utilization of rapidly soluble protein or NPN by rumen microbes, and thus increasing microbial growth, several studies have been conducted in which part of the dietary starch was replaced by sugars. The addition of sugar to give a sugar-to-soluble protein ratio between 2 and 3:1 on a percentage of DM basis resulted in an average increase in microbial protein production of 25% when compared to a ratio of less than 1:1. In lactation studies involving addition of sugars from molasses, whey, sucrose, dextrose, or lactose, responses in terms of increased DM intake and milk production have been inconsistent. In the studies reviewed, milk production did not exceed 75 lb/day and in most studies was less than 70 lb/day. Under these conditions, increased microbial growth was probably not as critical to production as in a cow producing in excess of 80 lb/day. Based on the studies reviewed, sugars from a variety of sources can be successfully used to partially replace starch in the ration, but production will likely not exceed that of cows on a diet containing an equivalent amount of available starch.

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Table 1. Typical total water-soluble reducing sugar content of feeds.[1]

Feed	Sugars (% of DM)
Alfalfa hay	3.0 - 6.0
Legume silage	1.7 - 5.0
Corn silage, mature	0.7 - 3.0
Clover pasture	11.6 - 13.1
Orchardgrass pasture	12.6 - 20.1[2]
Corn grain	0.3 - 1.5
Hominy	1.0 - 6.0
Barley grain	1.0 - 3.0
Corn gluten meal	1.0 - 2.0
Soybean meal	1.0 - 2.0

[1]Miller-Webster and Hoover, 1998
[2]Includes fructans

Table 2. Composition of various products containing sugars.

	Composition, As Fed Basis		
Product	DM	Protein	Sugar
	------------------------%	------------------------	
Molasses, cane[1]	75	4.3	61
Molasses, beet[1]	78	6.6	63
Molasses, citrus[1]	68	8.2	57
Almond hulls[3]	78	3 - 6	17 - 33
Whey, condensed[2]	64	8.7	48
Whey, dried[2]	93	12.2	72
Whey, delactosed[2]	88-90	16 - 26	37 - 60
Carrot, dehydrated[3]	83	6	24
Citrus pulp[3]	83	6	25

[1]Schingoethe, 1991
[2]Schingoethe, 1976
[3]Miller-Webster and Hoover, 1998

Table 3. Lactate and pH from 12-hour in-vitro Fermentations.[1]

Source	Final pH	Lactate, mM L(+)	Lactate, mM D(-)
Glucose	4.38	114	36
Sucrose	4.41	103	37
Fructose	4.45	93	52
Galactose	4.45	117	34
Ribose	6.59	0	0
Xylose	6.40	18	0
Beet pulp	5.52	40	2
Corn	5.14	22	8
High moisture corn	5.40	0	0
Steam flaked barley	4.59	102	25
Wheat	4.93	79	31

[1]Cullen et al., 1986

Table 4. Effects of additions of low levels of sugars on volatile fatty acid (VFA) ratios.

Sugar Added	% of DM or OM[1]	VFA, molar % Acetic	VFA, molar % Propionic	VFA, molar % Butyric	Reference
Lactose	0	79	28	17	Hoover and Miller-Webster,
	3.5	77	31	15	1997
Glucose	0	70	17	10	Piwonka et al.,
	5.6	69	18	10	1994
Glucose	0	72	18	12	Wu et al., 1994
	5.3	77	25	15	
Glucose	0	68	18	8	Rooke et al., 1987
	14.5	69	18	9	
	12	67	19	10	
Sucrose	0	64	18	15	Khalili and
	13.3	59	17	20	Huhtanen, 1991
	13.3	62	19	16	
Molasses	0	61	23	13	Maiga et al., 1995
	8.3	61	23	13	
Whey	5.4	61	22	13	

[1]DM = dry matter and OM = organic matter

Table 5. Effects of additions of high levels of molasses or whey on proportions of volatile fatty acids (VFA).

Additive	Amt. Added, % of DM	VFA, molar % Acetic	Propionic	Butyric	Reference
Molasses	0	65	15	16	Huhtanen, 1988
	18	62	18	18	
	20	62	18	14	
Whey	0	58	26	12	Casper and Schingoethe, 1989
	30	59	23	14	
	30	59	23	15	
Whey	0	59	14	8	Susmel et al., 1995
	23	55	15	12	
	46	59	21	12	
Whey	0	43	32	17	Windschitl and Schingoethe, 1984
	38	44	23	24	
Molasses	0	67	16	14	Moloney et al., 1994
	55	58	17	23	

Table 6. Ratios of volatile fatty acids (VFA) from ruminal fermentation of various carbohydrates.

Carbohydrate	VFA, molar % Acetic	Propionic	Butyric	pH	References
Glucose	58	27	14	5.87	Giduck and Fontenot, 1987
Sucrose	54	25	20	6.40	
Lactose	63	23	13	5.44	
Starch	65	18	15	6.70	
Hemicellulose	60	38	3	--	Marounek et al., 1985
Pectin	88	9	3	--	
Starch	65	30	6	--	

Table 7. Percentage change in microbial growth at sugar to soluble protein ratios greater than 1:1.

Sugar Source	Sugar to Soluble Protein Ratios >1:1 to 2:1	2:1 to 3:1	Reference
	------------% change[1]	------------	
Lactose	106	--	Hoover and Miller-
Lactose	106	--	Webster, 1997
Molasses	104	106	Huhtanen, 1988
Whey	97,104,108,120	122,125	Stock et al., 1986
Glucose	--	116	Piwonka et al., 1994
Glucose	--	125,131,146	Khalili & Huhtanen, 1991
Glucose	--	126	Wu et al., 1994
Mean Response	106	125	

[1]Responses are relative to ratios of 1:1 or less in the same study.

Table 8. Effects of liquid feed additives on intake and production.[1,2]

Additive	Added (% of DM)	DM intake (lb/day)	Sol CP (% of CP)	Starch (% of DM)	Sugar (% of DM)	Milk (lb/day)
Control	--	51[a]	16	38	1.0	50[a]
CMDS[3]	6	58[b]	18	34	1.2	53[a]
Molasses	6	51[a]	18	34	4.2	55[b]
Masonex[4]	3	58[b]	16	36	2.6	54[a]
Flambeau[5]	3	60[b]	16	36	2.3	52[a]

[1]Wing et al., 1988
[2]Main forage source in diets was cottonseed hulls
[3]Citrus molasses distillers solubles, 4.3% sugar
[4]Hemicellulose extract, 54% sugar (Masonite Corp., Laurel, MS)
[5]Spent sulfite liquor, 45% sugar (Flambeau Paper Corp., Park Falls, WI)
[a,b]Values in the same column with different superscripts differ ($P < .06$)

Table 9. Effects of molasses combined with forages on intake and production.[1]

Forage[2] Source	% in Diet	Molasses (% of DM)	DM intake (lb/day)	Sol CP (% of CP)	Starch (% of DM)	Sugar (% of DM)	Milk (lb/day)
CSH	30	0	53[a]	14	34	1.3	57[a]
		8	55[a]	17	27	7.9	59[a]
HCS	35	0	51[b]	28	37	1.7	58[b]
		8	49[b]	31	30	7.8	54[b]
HCS	65	0	45[c]	38	19	1.6	51[c]
		8	48[c]	41	12	7.3	52[c]
CSH & HCS	49	0	54[a]	28	26	1.5	59[a]
		8	50[a]	31	19	7.5	56[a]

[1]Morales et al., 1989
[2]CSH = cottonseed hulls and HCS = alfalfa haylage
[a,b,c]Values in the same column with different superscripts differ (P < .05).

Table 10 Effects of energy sources on intake and production.[1]

Protein Source	Energy Source	DMI intake (lb/day)	Sol CP (% of CP)	Starch (% of DM)	Sugar (% of DM)	Milk, (lb/day)
SBM[2]	Corn	44[a]	29	38	3	72[a]
	Barley	42[b]	30	35	3	70[b]
	Corn, Whey	46[a]	33	28	14	71[b]
Urea	Corn	46[a]	36	40	3	72[a]
	Barley	41[b]	40	36	3	69[b]
	Corn, Whey	45[a]	39	30	14	67[b]

[1]Casper and Schingoethe, 1989
[2]SBM = soybean meal
[a,b]Values in the same column with different superscripts differ, ($P < .01$).

Table 11. Effects of dried whey or a dried whey-molasses-fat blend on intake and production.[1]

Diet	Additive (% of DM)	DM intake (lb/day)	Sol CP (% of CP)	Starch (% of DM)	Sugar (% of DM)	Milk (lb/day)
Control	0	53	23	32	1.8	74
QLF 4-19[2]	8.3	54	25	28	5.2	74
Dried Whey	5.4	54	25	29	5.8	75

[1]Maiga et al., 1995
[2]Molasses, whey, and tallow blend (Quality Liquid Feeds, Inc., Dodgeville, WI)

Table 12. Effects of dietary nonstructural carbohydrate (NSC) content on microbial metabolism in continuous cultures of rumen contents.[1,2]

	NSC, % of DM		
Item	25	37	54
Digestion			
Dry matter	55	51	68
NDF	33	39	48
NSC	81	82	85
Microbial			
N, g/day	1.02	1.13	1.63
Efficiency[3]	18	21	23

[1]Stokes et al., 1991
[2]Fermentation pH was constant at 6.4
[3]Grams microbial N/kg digested dry matter

Table 13. Extent of starch digestion in the rumen of lactating cattle.

Feed	% Digested
Lykos and Varga (1995) in situ, lactating cows[1]	
Corn, coarsely cracked	45
Corn, cracked	53
Corn, fine ground	66
Corn, steam flaked	75
McDaniel and Miller (1995) in situ, lactating cows[2]	
Corn silage	76
Barley, ground	74
Corn, ground	61
Hominy	64
Midds	72
Distillers dried grains	77
Theurer et al. (1995) in vivo, lactating cows[1]	
Sorghum, dry rolled	54
Sorghum, steam flaked	76

[1]Values are for starches only
[2]Values are for enzymatically determined total nonstructural carbohydrates (starches and sugars)

Table 14. Effects of starch source on ruminal carbohydrate digestion.[1]

Item	Starch Source: Ground Corn	Starch Source: Steam Rolled Barley
Starch digested, lb/day	11.44	14.3
NDF digested, lb/day	5.17	2.82
Total carbohydrate, digested, lb/day	16.61	17.12
Microbial protein, lb/day	3.81	4.07
Rumen pH	5.84	5.67
Milk, lb/day	78.2	71.5

[1]McCarthy, Jr. et al. (1989)

Table 15. Recommendations for Percentages of NDF and NFC in Diets for Dairy Cattle.

Status	Recommended NDF[1]	Recommended NFC[2]
Early dry	60 - 65	20 - 25
Close-up dry	32 - 36	35 - 40
Lactating, lb/day of milk		
< 31	48	28 - 30
31 - 46	40	32 - 34
47 - 64	35	34 - 36
65 - 80	31	36 - 38
>80	28	38 - 40

[1]Based on Grummer and Minor (1996), Mertens (1985), and Van Saun and Sniffen (1993).
[2]Calculated values for nonfiber carbohydrates (NFC). Based on Batajoo and Shaver (1993), Eastridge et al. (1988), Grummer and Minor (1996), and Stokes et al. (1991).

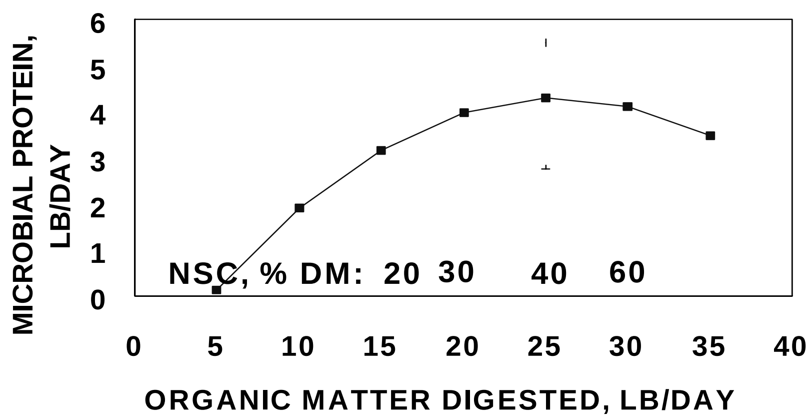

Figure 1. Microbial protein response to ruminal organic matter digestion (Clark et. al., 1992).

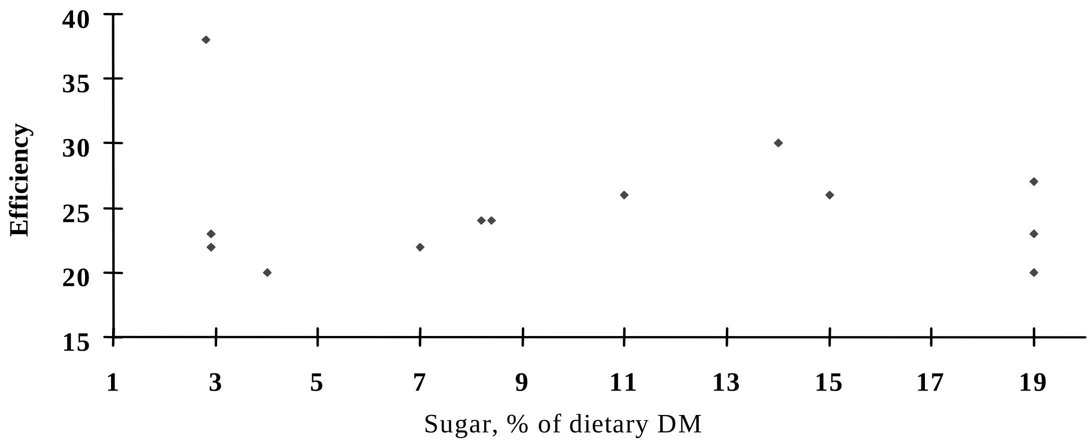

Figure 2. Effects of diet sugar content on microbial efficiency (g microbial N/kg organic matter digested).

Measuring Nonfiber Carbohydrates in Feedstuffs

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Several reviews of carbohdyrate feeding have been presented at this conference over the last few years, including Dr. Hoover's in the current proceedings. Clearly, acid production needs to be balanced with acid neutralization (Allen, 1997; Allen and Beede, 1996). Forage particle size and degradation rate of nonfiber carbohdyrates (**NFC**), sometimes called nonstructural carbohydrates (**NSC**), are important factors needed to balance the input of salivary buffers with the production of acid from fermentation. However, many dairy rations are formulated to meet or exceed a recommended amount of fiber, preferably forage neutral detergent fiber (**NDF**), and to not exceed a recommended limit for NSC. Reducing forage NDF from the NRC guidelines of 21% of DM down to about 15% of DM reduces total chewing time, but chewing efficiency (chews/intake of forage NDF) increases as a compensatory mechanism (Firkins, 1997). Therefore, the determination of this NSC concentration in the diet is very important for properly balancing dairy rations to prevent production or metabolic problems that are associated with reduced ruminal pH. Laboratory analyses for NSC should reduce acidosis problems and reduce the safety factors needed to account for variability among NDF and NSC concentrations and among particle sizes of feeds as well as other factors involved, including animal differences and bunk management. The purpose of this paper is to discuss problems and considerations for the measurement of NFC or NSC.

Terms for Carbohydrate Fractions

For this paper, NFC will always be used to designate the calculated ("difference") assay: NFC = organic matter – NDF – CP – fat; NSC will always represent the enzymatic digestion of feed followed by an analysis for reducing sugars (including glucose but also other monosaccharides or oligosaccharides) or for sugars by gas chromatography. Because most labs measure reducing sugars, the result is not necessarily all starch, especially with certain feeds. Therefore, NSC (reducing sugar assay), starch (sugars by gas chromatography), and sugars will be referred to in this paper.

Measurement Concerns

Nonfiber Carbohydrates

Common recommendations are to formulate rations for 40% NFC and 30% NSC. Pectins, organic acids (from fermented feeds), and other non-starch carbohydrates are dissolved in neutral detergent solution (Hall et al., 1997; Van Soest, 1994). Several authors have documented that NFC should

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be higher than NSC because of problems in the calculation of NFC. Underestimation of total fiber concentration would cause an overestimation of NFC by difference. In Table 1, NFC was 10 percentage units or more greater than NSC because of pectin, organic acids, and probably other non-starch compounds solubilized by neutral detergent solution. Pectin is found in legumes or soyhulls (in diets in Table 1) and especially in beet and citrus pulps (Hall et al., 1997). Because of the rapid degradability of pectin (Van Soest et al., 1991), NFC actually may be more appropriate than NSC for beet and citrus pulps. Fat concentration is often estimated as fatty acids divided by .90. Forage can have as low as half of the ether extract as fatty acids (waxes, chlorophylls, and other compounds make up the rest). However, using fatty acids instead of ether extract (underestimation of total lipid) would make only about a one percentage unit overestimation of NFC in typical dairy rations. In a compilation of published literature, Oldick et al. (The Ohio State Univ., Columbus; unpublished data) evaluated the relationship between NFC and NSC (Figure 1). Based on 73 treatment means, the relationship (± standard errors of regression coefficients) was:

$$NSC = 15.0 (\pm 3.0) + .492 (\pm 0.08) * NFC; \quad r^2 = 0.35$$

There was a strong bias for NFC to underpredict NSC at low concentrations and to overestimate it at high concentrations; because these were treatment means (generally n = 4 to 6), the relatively low r^2 may be due largely to variability in feed concentrations of pectins and other non-starch NFC and to variation in techniques among various researchers rather than to repeatability in lab procedure used by respective authors. Mertens, (1992) reported an extensive table in which NFC was always higher or similar to NSC. However, at low levels of NSC in Figure 1, presumably less grain would be in diets and proportionately more non-starch NFC should be present. Thus, the lower NFC than NSC would not be expected.

Underestimation of NFC can occur because NDF is often overestimated for several reasons. First, mineral contamination of NDF can result in an overestimation of NDF and an underestimation of NFC. Second, protein contamination can similarly overestimate NDF. Recall that organic matter and CP already are accounted for by ash and protein in the NFC equations, and contamination of NDF double-counts these components. Our experience is that mineral contamination of NDF generally is 1 to 2 percentage units. Crude protein concentration in NDF (NDFCP) generally is 2 to 4 percentage units of feed DM (Harmison et al., 1997), although De Peters et al. (1997) reported that NDFCP can be much higher for brewers grains (4.7 to 9.2 percentage units) and distillers grains (12.8 to 16.8 percentage units). All NDF samples should be corrected for protein and mineral contamination for diets high in insoluble ash and for certain byproducts that are abnormally high in NDFCP. No correction should occur otherwise because general feeding recommendations of 35 to 40% NFC were made based on uncorrected NDF for typical diets. If these corrections are made, then be aware that corrected NFC would be higher than original NFC for the same diets. Third, starch contamination of NDF is a large problem. Although Van Soest et al. (1991) reported significant improvements in the methodology of measuring NDF in starch-containing feeds, many labs still cite reports that used older methodology. Heat-stable amylase is much better than the amylase that was available at the time the older methodology was reported. Presoaking starchy samples with urea greatly improves filtration and reduces NDF. However, care must be taken to ensure that all urea is removed prior to analysis of NDFCP. If laboratory managers monitor amylase activity by periodically evaluating its ability to dissolve purified starch, then rapid filtration of starchy feed samples probably is a fairly good indicator of starch contamination of NDF. However, they should still monitor expiration dates and activities of amylase because our experience has been that activities can be too low once in awhile. If the lab does NSC assays, starch contamination of NDF could be monitored easily. Fourth, greater than 5% total fat interferes with the detergent's ability to solubilize nonfiber fractions (Van Soest et al., 1991). Prerinsing samples with boiling ethanol dissolves and filters enough of the fat to prevent this problem (Harmison et al., 1997; Van Soest et al., 1991).

Nonstructural Carbohydrates

Starch was about 5 percentage units lower than NSC in Table 1. The obvious reason is that other sugars besides glucose were present. However, total sugars were quantified by a gas chromotography procedure (and were minor). Therefore, other potential problems appear to exist for these NSC or starch procedures. One obvious potential problem is that the amylase enzyme preparation contains significant glucose contamination, but this was corrected (subtracted) from all samples in Table 1. In one study (Sarwar et al., 1992), we had overestimated NSC and discovered why later. The original procedure that we used did not include the enzyme preparation in the standard curve. Besides background correction for glucose in the enzyme solution, the presence of enzyme can also reduce the <u>slope</u> of the standard curve because of "matrix" effects. Standards need to be treated exactly like the samples. Additionally, when glucose is bound to another glucose to form maltose, a water molecule is released. If glucose has a molecular weight of 180 and water has a molecular weight of 18, then maltose (two glucoses) actually has a molecular weight of 342 (180 + 180 - 18). As more glucoses are formed in a starch polymer, the molecular weight per glucose approaches 90% of free glucose, so many labs correct the free glucose standard curve by assuming a molecular weight of 180 x .90 grams per mole of glucose in starch. However, using pure corn starch as a sample to correct for this problem resulted in a 4.9% overestimation (104.9% recovery) rather than the expected 90% recovery relative to free glucose in the data used in Table 1 and Figures 2 and 3. This discrepancy apparently is because our reducing sugar assay commonly uses a chemical that can react strongly with incompletely hydrolyzed starch dextrins (Sarwar et al., 1992). A 5% reduction in NSC reported in Table 1 would only reduce NSC by about 1.6 percentage units. More research is needed to explain and corroborate this discrepancy.

Inherent Variation in Procedures

The treatment means in Table 1 leave the impression that NFC, NSC, and starch are highly related and that rations could be balanced for 40, 30, and 25% NFC, NSC, and starch, respectively. However, within this fairly narrow range of values from individual diets, NFC was not well related to NSC or starch (Figure 2). Concentrations of NSC and starch were somewhat better related (Figure 3). Because the slope is <1, as NSC increased, starch concentration was progressively less than NSC, perhaps because of increasing incompletely hydrolyzed starch oligosaccharides that were measured by the reducing sugar assay but not by the gas chromatography method. All of these results are preliminary because they are from individual diets (not treatment means) from only one study, but they show that potential errors can result from using only one or a few samples from feed analysis. Until more work is done, safety factors will be needed and results should be compared among labs before making feeding recommendations.

Conclusions

More accurate starch degradability coefficients in the rumen and better verification of analytical procedures are needed in future studies. To date, some serious questions remain to be answered for in vitro and in situ degradation of starch; for instance, are the passage rates of ground and high moisture corn the same? However, the assays discussed above and in vitro and in situ techniques still should be useful in ranking feeds and in trouble-shooting. These should be much better than waiting to see corn particles in feces and trying to quantify such a subjective observation. These procedures are all markedly better than nitrogen-free extract, which should not be used (see Van Soest, 1994). Hopefully, in the future, tabular and quick yet accurate assays for ruminally degradable carbohydrate will be available. Until then, determination of NFC and NSC will be much better than assumed values, especially if care is taken to correct for problems identified in this paper. Even then, some safety factor or a ruminal pH diagnostic (Allen and Beede, 1996) still may be warranted.

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Table 1. Calculation of NFC, NSC, and starch in diets containing corn processed in different ways[1].

	Laboratory Assay[2]		
Corn	NFC	NSC	Starch
	--------------(% of DM)---------------------		
Coarse roll	41.8	31.3	27.0
Medium roll	42.4	31.9	26.6
Fine roll	43.5	33.4	27.8
Steam roll	43.1	32.3	27.2
Coarse/steam roll combination	41.9	30.4	25.5
Overall mean	42.6	31.9	26.8
Overall CV[3], %	6.0	8.9	8.9

[1]Callison et al., The Ohio State Univ., Columbus (unpublished data); n of 5 per treatment. Alfalfa silage, soyhulls, and corn grain were 50.0, 7.9, and 34.4% of the DM, respectively, for all diets.

[2]Nonfiber carbohydrates (NFC) = organic matter – CP - (NDF – NDFCP) – (fatty acids/0.9); NDFCP = NDF corrected for CP contamination; nonstructural carbohydrates (NSC) = enzymatic assay followed by analysis of reducing sugars; starch = as hydrolyzed for NSC except that free sugars were quantified by gas-liquid chromatography.

[3]CV = coefficient of variation

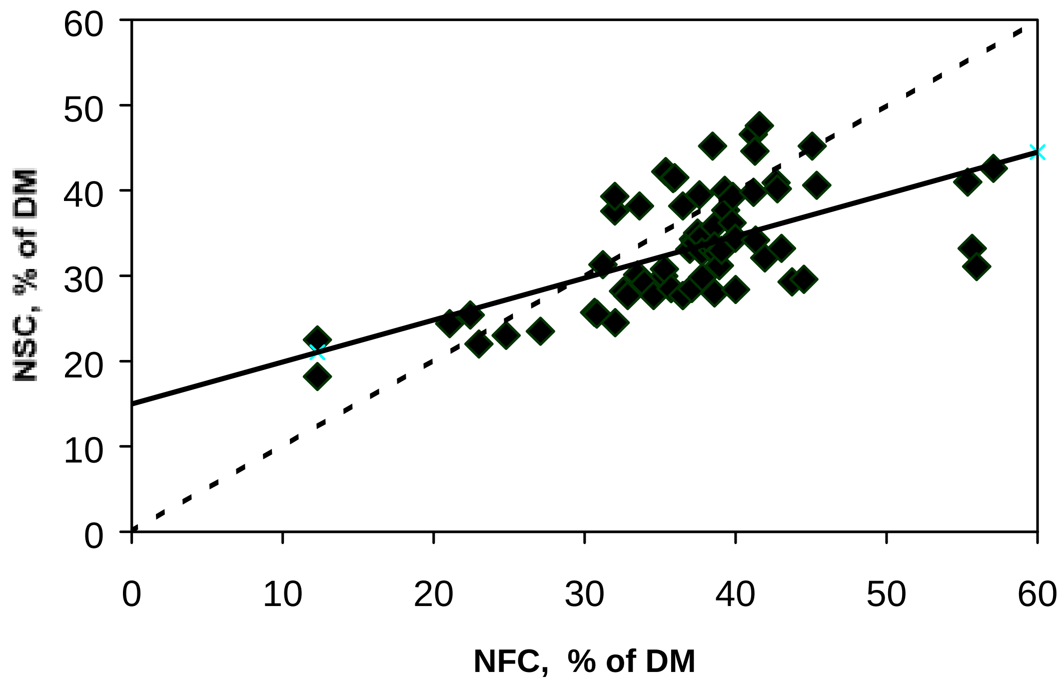

Figure 1. The relationship of nonfiber carbohydrates (NFC, by difference method) to nonstructural carbohydrates (NSC, enzymatic assay) in 73 diets reported in published literature (Oldick et al., 1998, The Ohio State Univ., Columbus; unpublished data). The dashed line is the unity line, y = x. The solid line represents the equation, NSC = 15.0 (± 3.0) + 0.492 (± 0.08) * NFC; r^2 = .35.

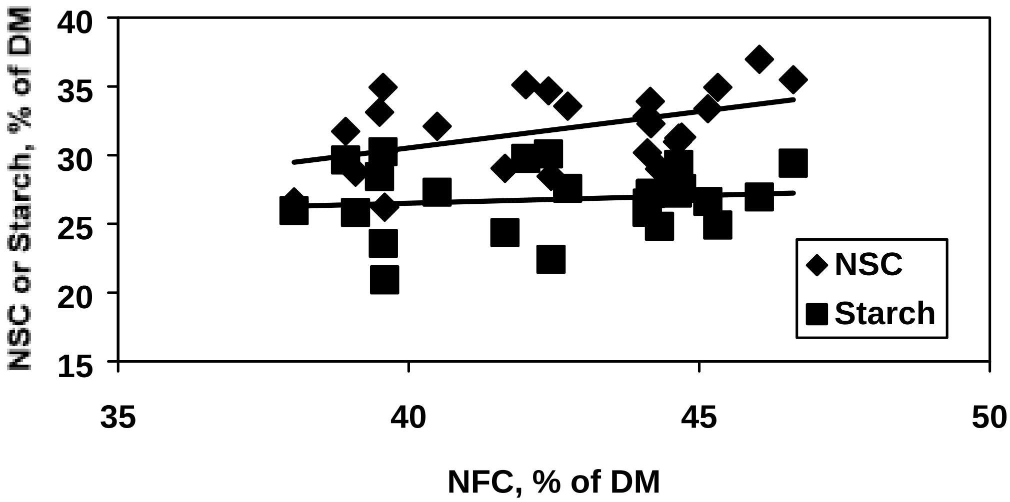

Figure 2. The relationships between nonstructural carbohydrates (NSC, enzymatic hydrolysis followed by a reducing sugar assay) or starch (enzymatic assay followed by sugar analysis using gas-liquid chromatography) and nonfiber carbohydrates (NFC, by difference) in individual diets (Callison et al., 1998, The Ohio State Univ., Columbus; unpublished data). The line for NSC represents the equation 9.45 (± 8.67) + 0.527 (± 0.203 * NFC; r^2 = .23. The line for starch represents the equation 22.1 (± 8.3) + 0.111 (± 0.194) * NFC; r^2 = .01.

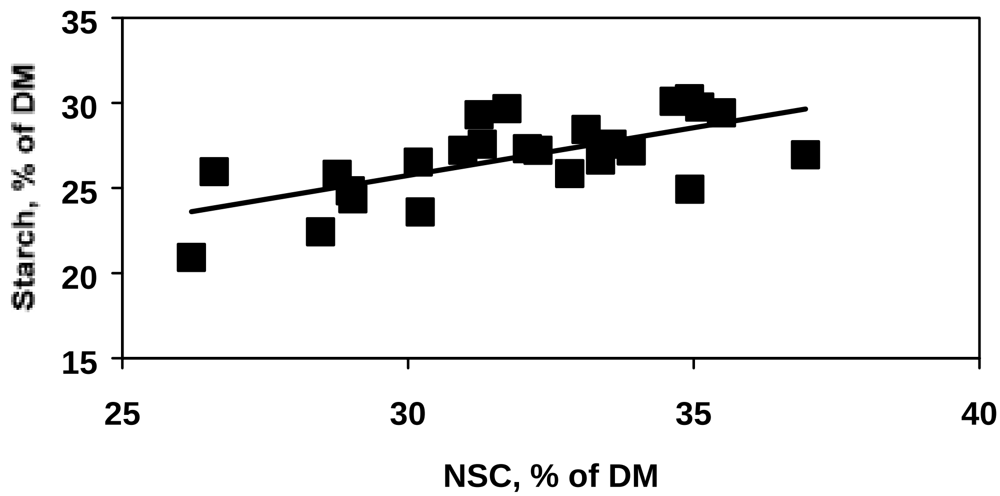

Figure 3. The relationships between nonstructural carbohydrates (NSC, enzymatic hydrolysis followed by a reducing sugar assay) and starch (enzymatic assay followed by sugar analysis using gas-liquid chromatography) in individual diets (Callison et al., 1998, The Ohio State Univ., Columbus; unpublished data). The line represents the equation 8.86 (± 4.21) + 0.563 (± 0.132)*NSC; r^2 = .44.

Feeding Highly Digestible Diets to Lactating Cows

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Diets for lactating dairy cattle are composed of forages, concentrates, and various coproduct feeds from the grain and oilseed processing industries. The chemical composition of these feeds and amount of physical processing, such as grinding for forages or roasting for grains and oilseeds, will have a tremendous impact on dietary organic matter **(OM)** digestibility and animal performance. Feeding highly digestible diets to dairy cattle requires the following feeding approaches (or any combination of these factors):

1. Low forage, high nonfiber carbohydrate **(NFC)** concentrations,

2. Physical processing of forage or grains to increase OM digestibility,

3. Nonforage sources of highly digestible fiber,

4. Improved digestibility of forage fiber, either by chemical treatment (as with alkali) or genetic selection (as with brown midrib hybrids), and (or)

5. Supplemental lipid.

Feeding highly digestible diets presents the nutritionist and dairy producer with several important opportunities and challenges. Often, highly digestible diets are low in forage content and particle length. At the same time, greater concentrations of grains (especially if processed) result in rapid production of fermentation end products and the potential for low ruminal pH. Consequently, we need to balance the physically effective neutral detergent fiber **(peNDF)** content of the diet that promotes ruminal buffering with dietary fermentability and production of organic acids. Ruminal pH and function cannot be compromised when highly digestible diets are fed; otherwise, any positive impact on performance of greater energy supply to the cow will be largely negated.

The influence of grain type, processing, and amount in the diet has been reviewed in previous papers presented at the Tri-State Dairy Nutrition Conference (Allen, 1994; Grant, 1995). Supplemental lipids as a means to increase the digestibility of the diet has also been reviewed (Grummer, 1991). This paper will focus primarily on use of nonforage sources of digestible NDF and improving forage NDF digestibility.

Physically Effective NDF and Organic Matter Digestibility

The amount of dietary OM fermented in the rumen impacts the fiber requirement of dairy cattle. Dairy cows require a minimum concentration of fiber in the diet, but this minimum has been poorly defined. Fiber should be of proper quality

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and particle size to ensure maximum dry matter intake **(DMI)**, normal ruminal fermentation and milk fat synthesis, proper muscle tone in the digestive tract, and ruminal pH greater than 6.0 (Grant, 1997). Of primary importance to nutritionists is peNDF which is the fraction of NDF that stimulates chewing activity, particularly rumination. Chewing results in saliva secretion which contains bicarbonate and phosphate buffers to neutralize the organic acids produced from OM digestion in the rumen. Diets which contain substantial amounts of NFC result in rapid fermentation and production of acids in the rumen. Feeding fibrous coproduct feeds in place of NFC can effectively reduce the acid load placed on the rumen environment per unit of fermentation time. The balance between the production of fermentation acids (as affected by rumen OM digestibility) and buffer secretion (as influenced by peNDF and chewing) primarily determines ruminal pH (Allen, 1997).

Low ruminal pH is associated with reduced DMI, fiber digestion, and microbial yield, and compromised milk and milk solids production. The digestibility of OM in the rumen varies greatly among feed sources and diets. This variation in digestibility influences the amount of fermentation acids produced, and consequently, the amount of peNDF required to adequately buffer the ruminal contents.

If we agree that management of the acid load placed on the rumen is the primary objective when feeding highly digestible diets, then we must focus first on the carbohydrate fraction of the diet because carbohydrates comprise over 65% of the DM in dairy cow diets and potentially have a large range in ruminal digestibility for different diets (Allen, 1997). Although dietary NFC is often used to predict ruminal fermentability, it has limitations. Specifically, the ruminal digestion of both NFC and fiber is quite variable (Allen, 1997). The bottom line is that, when feeding highly digestible diets, the interaction of ruminally fermentable carbohydrates and peNDF must be understood and accommodated when formulating diets for high-producing dairy cows. This point is important when feeding high NFC diets, so that adequate chewing and buffering is maintained; it is equally important when fibrous coproduct feeds dilute NFC to reduce the acid load on the rumen.

Highly Digestible Diets Containing Fibrous Coproduct Feeds

Replacement of NFC with fibrous coproducts

When feeding substantial amounts of concentrates, especially when processed to increase ruminal digestibility, the composition of the concentrate mixture should be adjusted to include greater percentages of highly digestible coproducts, such as soybean hulls, corn gluten feed, or beet pulp. Inclusion of these fibrous feeds aid in minimizing ruminal acidosis and related herd health problems by reducing the fermentation rate per unit of time in the rumen.

Soybean hulls are high in NDF (Table 1), but the fiber is so highly digestible that the hulls are essentially equivalent to corn grain in energy value when fed to dairy or beef cattle. In fact, when soybean hulls are incubated in Dacron bags in situ, the average ruminal fiber digestibility at 30 hours is 96%. The typical composition of several common coproducts is given in Table 1. The coproducts vary widely in crude protein **(CP)** content, ranging from 4% for cottonseed hulls to 25% for brewers grains. The NDF and lignin concentrations vary from 90 and 24%, respectively, for cottonseed hulls to 54 and 2% for beet pulp. The coproducts with the least lignification, such as soybean hulls, beet pulp, and corn gluten feed, have the greatest fractional rates of ruminal NDF digestion.

The typical NDF digestion rate for many forages is approximately 4 to 5 %/h, so the NDF in many fibrous coproducts is very rapidly digested. In contrast, the rate of starch digestion in the rumen ranges between 10 and 35%/h, and the rate for sugars falls between 100 to 200 %/h (Hoover and Webster, 1997). Consequently, dilution of NFC with NDF from coproduct feeds results in slower rates of fermentation, reduced acid load in the rumen, and the ability to feed a highly digestible diet with minimal risk of ruminal acidosis.

Dairy cattle, as ruminants, evolved as utilizers of forage and other roughage sources. However, in the US high levels of grain feeding has often been the most economical means to increase digestible energy intake. Overconsumption of starchy grains, although highly digestible, can result in ruminal acidosis and a negative associative effect of starch on fiber digestion, likely mediated by low ruminal pH. Ruminal acidosis is associated with feed intake fluctuations, off-feed problems, milk fat depression, laminitis, poor body condition, and reduced milk yield.

Anderson et al. (1988) fed beef steers diets containing stalklage (control), and either 50% corn grain or 50% soybean hulls in place of stalklage. At this level, steers consuming the corn diet showed a rapid decline in ruminal pH to below 5.65, followed by a rapid return to prefeeding levels (Figure 1). Steers fed the 50% soybean hull diet exhibited a more gradual decline in pH to 6.2, then a slow decline to 6.0 by 12 hours postfeeding. The decrease in ruminal pH from 6.2 to 6.0 for this diet was due to soybean hull fermentation because cell solubles would not account for the prolonged, lower pH. It would be ideal if ruminal pH did not decrease substantially with hull supplementation, but because the hulls are as digestible corn grain, a similar amount of volatile fatty acids must ultimately be produced. However, because soybean hulls contain high NDF and low lignin concentrations, they result in a ruminal volatile fatty acid profile more closely resembling that of forages than mixed diets comprised of forages and grains with comparable energy content (Birkelo and Thomson, 1993).

Similar research has not been conducted with dairy cattle, although one would expect a similar effect on ruminal pH by adding soybean hulls or other fibrous coproducts to the diet in place of NFC. Nakamura and Owen (1989) fed diets to lactating dairy cows in which the pelleted concentrate contained 100% corn, 50% corn:50% soybean hulls, or 100% soybean hulls, plus 5 to 10% soybean meal, minerals, and vitamins. All diets contained equal CP (16% of DM) and were fed as total mixed rations. The results of the experiment are shown in Table 2.

Addition of soybean hulls did not improve milk yield. However, they did minimize the depression of milk fat percentage often associated with feeding pelleted grain mixes. Consequently, production of 3.5% fat-corrected milk was maintained at normal levels. This study clearly indicates that substitution of fibrous coproducts for NFC minimizes the milk fat reducing effect of pelleted grain diets and that soybean hulls in particular have an energy value similar to corn grain when fed to lactating dairy cows. More recently, Cunningham et al. (1993) found that intake and flow of NDF to the duodenum was 42 to 43% greater for cows fed soybean hulls in place of corn grain in the concentrate mix at levels similar to the study by Nakamura and Owen (1989). Flow of total and essential amino acids to the duodenum was not altered when soybean hulls replaced either 25 or 50% of the forage or concentrate DM. Generally, it appears that replacement of up to 50% of the corn grain with soybean hulls is optimal for the lactating dairy cow.

Replacing forage fiber with coproducts

When replacing forage fiber with significant amounts of fibrous coproducts, adequate peNDF in the total ration must be maintained for effective buffering of ruminal contents. A complete consideration of fiber nutrition for dairy cows includes:

1. NDF = 26 to 29% of DM (minimum), with feeding management playing a substantial role in determining the safe lower limit, and

2. peNDF = approximately 20% of dietary DM, which correlates with ruminal pH above 6.2 and milk fat percentage greater than 3.5% for Holstein cows (Mertens, 1997).

Adequate fiber of proper particle length assures normal chewing activity and ruminal function. Dietary NDF from forage can be reduced to 60% or less, well below the National Research Council (1989) recommendations of 75% and still provide sufficient peNDF for fat-corrected milk production that is similar or superior to high-forage diets. In fact, the NDF from forage has been reduced to as little as 39.6% of DM, resulting in a highly digestible diet, with no significant effect on NDF intake or fat-corrected milk production.

The maximal, or optimal, amount of fibrous coproduct feeds that can safely replace dietary forage for a complete lactation is not known with certainty. Studies designed to determine the effectiveness of these feeds when replacing forage fiber have utilized midlactation cows. Early lactation cows may not tolerate large amounts of these highly digestible and small particle size coproducts compared with later lactation cows because of a greater tendency toward lameness, abomasal displacement, and other metabolic disorders. Some coproducts, such as wet corn gluten feed, have high ruminal digestibility but their small particle size results in little stimulation of chewing. Consequently, their peNDF is low. But, effective NDF measured by fat-corrected milk response is high, implying that the role of this coproduct is more related to dilution of NFC than to stimulation of rumination (Allen and Grant, 1998).

Figure 2 illustrates a potential decision support aid, based on limited data in the literature. If an economically sound decision has been made to replace forage with soybean hulls, for instance, then stage of lactation and dietary forage content should be considered. The source, amount, and physical form of the forage affects the use of fibrous coproducts (Weidner and Grant, 1994). Because no definitive data exist for feeding fibrous coproducts prior to 30 days in milk, Figure 2 indicates that these feeds can safely be fed beginning after this transitional period. Keep in mind that Figure 2 is conservative and will likely be modified as more research is conducted. However, it does provide dairy producers and nutritionists with information when making decisions about whether and how to feed fibrous coproducts. Recent research being conducted at the University of Nebraska indicates that a similar decision approach will work for corn gluten feed (R.J. Grant, unpublished).

A final consideration when feeding highly digestible fiber sources with small particle size is their potential to pass rapidly from the rumen. Rapid passage will reduce digestibility and result in lowered performance of cows fed the coproducts. Weidner and Grant (1994) tested diets containing 25% soybean hulls, 18% alfalfa silage, and 18% corn silage. Fiber digestion was improved and milk production increased by 6 lb/day when 10% of the alfalfa silage was replaced with coarsely chopped alfalfa hay to increase particle size and ruminal mat consistency. The positive production response was attributed to an improved ruminal environment characterized by a larger, more dense rumen mat, increased rumination, and a decrease in the rate of passage of soybean hulls from the rumen. Similarly, Allen and Grant (1998) were able to slow the passage of wet corn gluten feed (20% of ration DM) from the rumen from 6.4 %/h to 4.2 %/h by adding coarsely chopped alfalfa hay to a silage-based diet with smaller forage particle size. It appears that manipulating rate of fiber passage from the rumen offers a definite advantage when feeding highly digestible diets based on large amounts of fibrous coproduct feeds.

Improving Fiber Digestibility of Forages

There has been considerable research on increasing the OM, and specifically the NDF, digestibility of forages for use in lactation diets. Chemical means to upgrade the digestibility of forages have focused on alkaline treatments designed to break the lignin-carbohydrate bonds that limit cell wall digestion. Although these treatments are very effective in improving the NDF digestibility of forages, they are not routinely used in the US and will not be discussed here. Some companies, though, have been able to exploit niche markets in various parts of the country by marketing alkali-treated cottonseed hulls, wheat straw, and other products that dramatically increase the NDF digestibility of the total ration.

Recently, interest has resurfaced on the use of brown midrib (BMR) hybrids of corn and sorghum for lactating dairy cows. Brown midrib is the name of several genes that reduce the lignin content of forages. Because lignin is indigestible and reduces hemicellulose and cellulose digestibility, the BMR gene influences NDF digestibility. Recent research at Michigan State University on BMR corn silage and University of Nebraska on BMR sorghum silage both showed that DMI and milk production can be significantly improved versus the normal genotype (Allen, 1997; Grant et al., 1995). The use of BMR forages in dairy rations has been reviewed recently (Allen, 1997). Because BMR corn silage is more digestible than normal corn hybrids, traditional ADF and NDF values will not reflect the higher energy content. Also, greater amounts of fiber may need to be fed because of the higher NDF digestibility of BMR silages to maintain ruminal function.

The potential of these BMR hybrids would most likely be greatest for the early lactation dairy cow where ruminal fill would be limiting DMI. Feeding a diet based on highly digestible forage sources during this time period would allow greater intake of digestible energy and greater performance. The key would be to simultaneously ensure adequate peNDF to maintain a healthy ruminal environment. Currently, the peNDF of BMR corn silage is unknown, but the peNDF of BMR sorghum compared with normal sorghum is similar.

Summary

Feeding highly digestible diets to lactating dairy cows can improve performance. But, production of fermentation acids must be balanced with ruminal buffering. Consequently, the diet must not only be digestible, but it must stimulate adequate chewing activity as well. Fiber digestibility can be improved by chemical and genetic means, and grain type and processing can profoundly affect concentrate digestibility. Increasingly, the use of fibrous coproducts is becoming a common method of increasing the fiber digestibility of the diet. These coproduct feeds dilute the NFC fraction, thereby reducing the acid load on the rumen. To successfully feed highly digestible diets based on coproducts of small particle size, the interaction of the dietary forage fiber with the nonforage fiber must be considered. Specifically, good evidence exists that demonstrates a slower ruminal passage rate of fibrous coproducts when longer particle size forages are added to the diet. The slower passage rate is associated with greater NDF digestibility and performance.

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Table 1. Chemical composition and fiber digestion of some common fibrous coproducts[1]

Item	Soy hulls	Brewers grains	Beet pulp	Cottonseed hulls	Corn gluten feed
% of DM:					
CP	11.3	25.4	9.7	4.1	20.8
NDF	70.3	46.0	54.0	90.0	48.3
Lignin	2.0	6.0	2.0	24.0	3.4
NDF digestion rate, /h	0.070	0.043	0.116	0.035	0.068
NDF digestion lag, h	0.4	0.5	0.8	2.7	4.5

[1]Data from Allen and Grant (1998), Belyea (1991), Shain et al. (1993), and Torrent et al. (1994)

Table 2. Performance of dairy cows fed diets containing soybean hulls in place of corn in a pelleted grain mix.

Item	100% corn	50% corn-50% hulls	100% soybean hulls
DM intake, % of body weight	4.32	4.36	4.38
Milk, lb/day	65.7[a]	63.7[ab]	60.2[b]
3.5% fat-corrected milk, lb/day	61.3	61.9	60.0
Milk fat, %	3.13[a]	3.33[ab]	3.49[b]
Milk protein, %	3.08[a]	3.00[ab]	2.84[b]

[ab]Means within a row with unlike superscripts differ ($P < 0.05$).

Forages for Dairy Cattle: Economical Alternatives to Alfalfa, Grass, and Corn

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Dairy cattle by nature are designed to utilize forage resources to produce milk. Not all forages are created equally, however, in their ability to allow economical production of milk. Under optimal conditions, alfalfa, corn silage, and perennial grasses have proven most effective in fitting into economical dairy rations. There are circumstances, however, in which other forages can fit well in rations.

Many, but not all, of the alternatives to traditional harvested forages tend to be annual crops. Annual forage crops fit well into emergency remedy programs after winterkill of perennial species, during periods of prolonged drought, or when flooding delays or destroys spring plantings. Annual crops can also play an important planned role in areas where land resources are not suited for the more traditional alfalfa, corn, or perennial grass. Increasing use of pastures for dairy cows also will likely increase the use of alternative forages. Figure I illustrates the typical pattern of perennial pasture production during the grazing season. Annual forage crops offer increased flexibility in the pasture program by filling in production gaps and extending the grazing season (Figure 2).

Perennial alternative forages, though less widely used than annuals, have their niche as well. Returning interest in grazing and concerns about the environment will likely increase the use of alternative perennial forages. Perennial forages may fit on soils not suited for alfalfa or where annual tillage is not desired.

Cow Performance

The dairy cow is a highly dynamic system that is sensitive to its nutritional environment with requirements for energy, absorbable α-amino nitrogen, and fiber to maintain a healthy rumen (Cherney, 1997). There is a growing body of literature to suggest that diets balanced to meet nutrient requirements, including fiber, will result in similar levels of milk production.

Mertens (1996) demonstrated that a number of different types of forages could be used to obtain optimal milk production, even though the forages varied widely in chemical composition (Table 1), when diets were balanced to contain similar neutral detergent fiber **(NDF)** and energy. Weiss et al. (1996) evaluated the lactation performance of cows fed diets containing alfalfa/corn silage, triticale, or a mixture of 71% sorghum, 18% forage soybeans, and 11% forage peas on a dry matter **(DM)** basis. Milk production (64.5 lb/day) and milk composition (3.3% fat and 3.2% protein) were not influenced by source of forage in the diet. Weiss et al. (1996) concluded that these alternative forages were acceptable alternatives to the

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conventional alfalfa/corn silage system, but dairy cows required an additional 2.4 and 8.4 lb of concentrate DM, respectively, for triticale and the sorghum mixture.

In another trial, Messman et al. (1992) reported no differences in milk production for cows fed diets based on pea with triticale, pearl millet, or alfalfa/corn silage. Cows fed pea with triticale, however, produced milk with a higher level of fat than cows fed the alfalfa/corn silage diet (4.59 vs. 3.35%) and cows fed alfalfa/corn silage gained more body weight than those on the pearl millet or pea with triticale diets. Messman et al. (1992) suggested that differences in energy partitioning might have been due in part to differences in ruminal fermentation. In support of this theory, Jaster et al. (1985) reported that heifers fed warm season forages (pearl millet and sorghum silages) had lower molar percentages of propionate, butyrate, and valerate compared with cool season forages (oatlage, barley/pea, pea, and oat/pea). This is an area that needs further investigation.

So What Are the Alternatives?

There are many alternative forages to select from. Selection should be based on management goals and resources. Animal requirements and yield economics need to be considered as well.

Small grains

Small grains can provide high quality forage and good yields provided nitrogen fertilizer needs of the plant are met (Table 2) and are among the most used alternative forages. Small grains may be used in pure stands as part of a double-cropping system or to provide early spring forage. They are also often overseeded or sod-sown in perennial grass or legume pastures to provide high quality forage later into the season when costly energy and protein supplementation would otherwise be necessary (Rao and Horn, 1995).

Small grains should be harvested at boot stage (head beginning to emerge) for milking dairy cattle (Undersander, 1996). Harvesting small grains after the boot stage, like most perennial grasses, results in a rapid decrease in forage quality (Cherney and Marten, 1982; Figure 3). If the decrease in quality results in more concentrate needing to be fed to meet dairy cow requirements, this will result in decreased economic value per acre of forage crop. Cherney and Cherney (1993) reported that intensively managed grass (cut at boot stage) would have double the value per acre over less intensively managed grass (cut at heading). Oats is a very common small grain in the northeastern and northcentral regions of the United States and is often ensiled. Wheat, rye, and triticale are also often used. When harvested at boot stage and properly fertilized with nitrogen, crude protein **(CP)** can range from 15 to 18%, and energy levels can be comparable with corn silage.

The use of small grain forages is not without potential hazards. Some small grains, particularly wheat pasture, may be prone to cause tetany in recently calved cows (Rao and Horn, 1995). Wheat pastures may be high in potassium, nitrogen, organic acids, and soluble carbohydrates while relatively low in calcium, conditions ripe for causing tetany in susceptible animals. Wheat can contain a high proportion of its nitrogen as non-protein nitrogen, and with heavily fertilized barley, there is an increased risk of nitrate poisoning. Animals grazing lush small grain pastures may also be prone to bloat. The risk of these hazards can be greatly reduced with proper management, such as not putting hungry animals out on pasture and providing some dry hay for the animals.

Small grains, sudangrass, sorghums, millets, small grains, and corn are often implicated in nitrate poisoning. Nitrate accumulates in plant tissues because of luxuriant uptake of soil nitrogen when plant metabolism is slow or stopped. The alternative crops mentioned are often heavily fertilized and are more subject to drought and frost injury than many of traditional perennial grasses and legumes (Mayland and Cheeke, 1995). Ensiling will decrease the nitrates in these forages. The effect of suspected high nitrate forages can be mitigated by feeding low nitrate forages or diluting the high nitrates by feeding concentrates.

Small grains are increasingly planted with field peas. The primary benefit of the peas is to improve quality, primarily CP. Increases in yield are variable, ranging from 0 to 0.5 tons/acre (Undersander, 1996). Oats, triticale, and barley are the small grains most often planted with peas. Small grain-pea mixtures allow a wider harvest window than small grains planted alone, allowing the producer more management flexibility.

Small grains and small grain pea mixtures are increasingly used as “nurse” or companion crops in the establishment of perennial legumes and legumes. While it is tempting and sometimes necessary to be able to harvest forage from a first year seeded field; the use of “nurse” crops may be risky. The “nurse” crop may actually compete with the perennial crop for moisture and other nutrients, resulting in poorer establishment of the perennial species.

Summer annuals

Members of the gamineous genera such as sorghum and pennisetum are valuable in the development of year-round, high quality forage systems (Fribourg, 1995). During the summer, most cool season forages become dormant, and most perennial warm season grasses do not produce high quality forage. The warm season annuals are a good fit during the late spring and summer to provide high quality abundant forage. Sorghums and millets can offer advantages over corn because of their drought tolerance. There are some sorghum hybrids that can produce more DM per acre than corn. In areas or times when drought is not a problem, however, corn silage is considered superior to sorghum because of the higher energy content of corn silage (Fribourg, 1995). Corn will generally out yield these annuals when temperatures are cool. Grain content of these silages is very important and should constitute at least 25% of the DM harvested for silage. As such, these materials can be ensiled at later physiological maturities than would be recommended for small grains. Silage made from bird resistant varieties is generally inferior in quality (tannins) compared to the non-bird resistant varieties (Fribourg, 1995).

Prussic acid, also known as hydrocyanic acid, is extremely poisonous, with concentrations greater than 0.1% of DM being considered highly dangerous (Rhykerd and Johnson, 1983). Species in the genus sorghum, sudangrass, forage sorghums, and sorghum-sudangrass crosses, often planted for summer pasture and used green chop, silage, or hay, all contain prussic acid in the vegetative portion. Prussic acid is not produced in the millets. The amount varies with species, maturity, plant part, environmental conditions, and the use of fertilizers and herbicides (Table 3).

Haying or ensiling these forages generally eliminates the prussic acid problem. However, do not enter a silo during the first 2 to 3 weeks after making sorghum or sudangrass silage, as traces of escaping cyanide gas may still be present. Prussic acid risk for pastured animals can be greatly minimized with proper management, including not grazing young plants (less than two feet) or grazing frost damaged forage that has begun to regrow.

The usefulness of forages in dairy cattle diets in often limited by the quantity and quality of lignin in the forage (Cherney and Cherney, 1991). The brown midrib **(BMR)** gene observed in corn, sorghum, and pearl millet (Cherney et al., 1991) results in lower lignin content than in normal counterparts. Numerous studies have investigated the influence of the BMR trait on animal performance, intake, and digestibility (Cherney et al., 1991). Most studies indicate that digestibility of BMR genotypes is higher than that of normal counterparts. Voluntary feed intake is probably improved by the BMR trait because of its higher NDF digestibility (Allen et al., 1997). This has not always translated into higher milk production, but the trend is for improved animal performance (Cherney and Cherney, 1991). Unfortunately, the BMR trait appears to be linked to both stover and grain yield (Cherney et al., 1991). The BMR trait offers great potential for improving quality of forage annuals, once the problems with yield have been overcome.

Brassicas

Brassicas are annual crops with high digestibility (75 to 90%) and high CP content (18 to 25%), provided nitrogen fertilization is adequate. Because of high digestibility and insufficient fiber to maintain proper rumen function, forage brassicas should probably be considered “concentrates” rather than “forages” (Hall, 1993). Unlike many other forage crops, DM digestibility does not decrease markedly with advancing maturity (Hall, 1993). They have yield potentials of 1.3 to 3.3 ton/acre depending on days to harvest and species (Kunelius and Sanderson, 1990), reach this potential after only 90 to 100 days, and can be used as an assurance against summer drought or to extend the grazing season into November and December. They are used to a lesser extent as green chop or silage. Intensive management is necessary to prevent stem production, which markedly decreases palatability.

Forage brassicas are seldom used for dairy cattle, however, because they can cause an off flavor in milk. Some species can be managed to reduce off flavors in milk, although caution must be used. Kale, fodder beets, and stubble turnips such as “Tyfon” have low contents of mustard oil, so they may be fed to dairy cows. Recommendations for reducing off flavors are not to feed more than 5 to 11 lb DM/cow/day, depending on the brassica used, and not to bring animal straight in from pasture to milking.

If brassicas are not managed and fed properly, animal health disorders can occur. These disorders include bloat, atypical pneumonia, nitrate poisoning, hemolytic anemia (mainly with kale), hypothyroidism, and polioencephalomalacia (Hall, 1993). Proper management to avoid these disorders includes the following recommendations:

- Introduce grazing animals to brassica pastures slowly. Avoid abrupt changes from dry summer pastures to lush brassicas and do not turn hungry animals out onto brassica pastures.

- Supplement animals with dry hay or no-till brassicas into an existing sod.

Soybean

Soybeans are grown almost entirely as an oil-seed crop but are regaining popularity as an annual forage legume. While not as productive as some perennial forage legumes, it does have some advantages under some conditions. It fits well as an alternative forage in situations where alfalfa or clover are in short supply due to winter-kill or drought condition and when an early-killing frost terminates soybean growth prior to normal grain maturity (Oplinger et al., 1992). Yield and quality of soybean forage can be very good (Table 4). Other advantages are that equipment, seed, and technology required for soybeans are widely available, soybeans can be grown as a grain or forage (depending on needs), soybeans can provide nitrogen for subsequent crops, and soybeans can easily be integrated into a double-cropping system (Oplinger et al., 1992).

Soybeans should be harvested at the R7 stage (one pod on the main stem that has reached its mature color). This means that soybeans will not ensile well because of high oil content. It is recommended that soybeans be mixed with grass or corn at chopping to improve ensiling characteristics. If harvested after seeds are formed, soybean forage should comprise not more than 30 to 40% of the DM intake of the animal because of its high oil content.

Perennial Alternatives

There are a number of perennial forage alternatives that are used. Chicory (Cichorium intybus L.) is a perennial herb of the family Asteraceae that shows potential for use in grazing and is growing in popularity. Chicory produces leafy growth that can be higher in nutritive value than alfalfa if properly managed (Hall and Jung, 1994). Yield will vary according to management but can be in excess of 3 ton/acre. Correct grazing management is necessary to maximize stand life (5 to 7 years) and maintain forage quality. Chicory has a relatively deep taproot, which makes it drought tolerant. It requires nitrogen fertilization for maximum yield.

Cup-plant (Silphium perfoliatum L.) is a perennial tall-growing member of Asteraceae, which includes sunflower. This plant has yet to be selected heavily as a forage crop, but recent studies (Albrecht and Goldstein, 1998) suggest that this plant has potential of replacing corn silage on soils prone to flooding and alfalfa on marginal lands. Forage yields of 5 ton DM/acre have been reported, accompanied by forage quality comparable to alfalfa (Table 5). A major advantage of cup plant over corn, in addition to its ability to grow in wet soils, is its long lifespan of up to 20 years. Cup-plant does require a year to establish before the first crop is ready for harvest and does require nitrogen fertilization. A major disadvantage at the present time is seed cost, which would limit its usefulness as an alternative crop at this time.

Summary and Conclusion

There are numerous economical alternative forages that work well for feeding dairy cattle. Not all have been mentioned here, and it is likely that others will become popular in the future. Regardless of alternative forage selected, quality and yield are very important for use in dairy cow rations. Without sufficient quality, DM intake may be limited, resulting in lowered production. Increasing the concentrate level in the diet can usually compensate for lower quality, but this rarely is the most economical or best environmental scenario for a producer. An alternative forage cannot be considered economical unless agronomic yield is sufficient to cover costs associated with its planting and harvesting. Species must be selected based on site-specific conditions including animals to be fed, costs of grain to replace forage, environmental concerns, management goals, and land resources (availability, soil, and fertility conditions). The following steps should be considered when using alternative forages in dairy rations (Chase, 1998):

- Select forages best suited to your soil and fertility conditions. Work closely with your field crop advisor on this.
- Test forages to determine actual nutrient composition. Large variations exist within forage types. If your lab does not routinely analyze this type of forage, analysis based on wet chemistry may be more accurate than near infrared reflectance (NIR).
- Balance rations using NDF. Forage NDF in the total ration of 0.85 to 0.95% of body weight is a good starting point.
- Watch out for prussic acid, nitrate poisoning, and other anti-quality factors, and take precautions to minimize the risk.
- Timely harvest, as with any forage, is critical to ensure optimum quality.

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Table 1. Production responses of dairy cows fed rations containing similar neutral detergent fiber (NDF) levels from different forage sources (Mertens, 1996).

	Sorghum -Sudan silage	Orchardgrass silage	Alfalfa silage	Wheat silage	Corn silage
<u>Forage Composition</u>					
Dry matter (DM), %	40.2	44.8	57.9	51.7	42.1
Crude protein (CP), %	12.8	15.5	17.2	10.2	8.3
NDF, %	54.8	48.4	45.2	54.4	41.6
<u>Ration Composition</u>					
DM, %	55.0	57.4	64.9	64.2	67.6
CP, %	18.5	17.7	17.7	19.0	19.1
NDF, %	31.0	31.1	31.4	30.3	30.5
Forage, %	44.2	51.5	57.2	43.6	63.6
<u>Production Responses</u>					
DM Intake, lb/day	48.5	51.4	52.0	50.0	48.5
DM Intake, % of bw	3.8	3.8	4.0	3.6	3.6
Milk production , lb/day	71.3	74.1	73.9	73.7	76.1
Milk fat, %	3.6	3.8	3.6	3.4	3.5
Milk protein, %	3.1	3.1	3.0	3.0	3.1

Table 2. Harvest yield and quality of small grain forage crops (Undersander, 1996).

Crop	Harvest Date	DM Yield (ton/acre)	RFV[1]	Crude Protein (% of DM)
Winter rye	mid May	3 - 3.5	85 -90	12 - 13
Winter wheat	late May	3 - 3.5	85 -90	11 - 12
Winter triticale	early June	3 - 3.5	85 - 90	11 - 12
Barley	mid June	2.5 - 3	100 - 110	12 - 13
Barley & peas	mid June	2.5 - 3	115 - 120	15 - 16
Oats	late June	2.5 - 3	100 - 110	12 - 13
Oat & peas	late June	2.5 - 3	115 - 120	15 - 16
Wheat (spring)	early July	2.5 - 3	100 - 110	11 - 12
Triticale (spring)	mid July	2.5 - 3	100 - 110	13 - 14
Sp. triticale & pea	mid July	2.5 - 3	115 - 120	15 - 16
Oats	October	1 - 2	140 - 150	10 - 11
Barley	October	1 - 2	110 - 130	10 - 11
Triticale	October	0.5 - 1	130 - 140	13 - 14
Wheat	October	0.5 - 1	150 - 160	12 - 13
Mix (winter wheat and oats)	Oct & May	3 - 5	100 - 120	10 - 13

[1]RFV = Relative feed value, 100 equals fiber content of full bloom alfalfa.

Table 3. Factors affecting prussic acid content in forages.

Factor	Comment
Species	Content in sudangrass about 40% of other species. Some sorghum-sudangrass hybrids selected for low content.
Anatomy	Leaf blades normally higher in content than stem or leaf sheaths. Heads contain low levels and seeds contain no prussic acid. Upper, younger leaves, higher in content than lower, older leaves. Leaves on tillers and branches have highest content.
Maturity	Highest levels before the boot stage.
Drought	Most common cause of prussic acid poisoning.
Freezing	Frost kills only the top, allowing new shoots, high in content, to emerge from unkilled parts. Forage should not be used until plants are 2 ft in height.
Fertilizer	If high N rates are applied to soils deficient in P and K, prussic acid levels can increase.
Herbicides	2, 4-D may increase prussic acid content in plants, with the effect lasting for several weeks.

Table 4. Yield and quality of soybean forage as affected by harvest maturity and variety, Arlington, WI (Oplinger et al., 1992).[1]

Factor	Dry matter yield (ton/acre)	NDF (% of DM)	CP (% of DM)	EE (% of DM)
Maturity[2]				
R1	1.1	38.7	20.1	--
R3	1.7	43.1	18.1	--
R5	2.5	45.7	18.2	0.9
R7	3.3	40.7	19.2	10.5
LSD	0.1	0.6	0.5	0.6
Variety[3]				
Corsoy	3.0	40.5	20.5	11.8
Pella	3.3	39.5	19.0	12.6
Williams	3.6	42.2	18.2	7.1
LSD	0.3	0.1	0.9	0.7

[1]NDF = neutral detergent fiber, CP = crude protein, EE = ether extract, and LSD = least significant difference.
[2]R1 = one open flower on main stem; R3 = one pod 3/16 inch long at one of the four top nodes; R5 = a seed 1/8 inch long in a pod at one of the top four nodes; and R7 = one pod on the main stem that has reached its mature color.
[3]Data only for R7 harvest maturity.

Table 5. Yield and quality of three cup-plant accessions grown on a muck soil in southern Wisconsin (Albrecht and Goldstein, 1998).

	DM yield (ton/acre)	DM (%)	CP (% of DM)	NDF (% of DM)	ADF (% of DM)
Harvest 1					
Russia	3.64	15.6	15.8	38.0	28.4
Illinois	3.80	14.4	17.6	38.8	29.4
Minnesota	3.84	14.4	18.2	38.7	29.1
Harvest 2					
Russia	0.62	12.8	23.0	30.3	21.0
Illinois	1.15	12.6	23.3	26.6	18.7
Minnesota	0.99	12.5	23.3	27.1	17.8

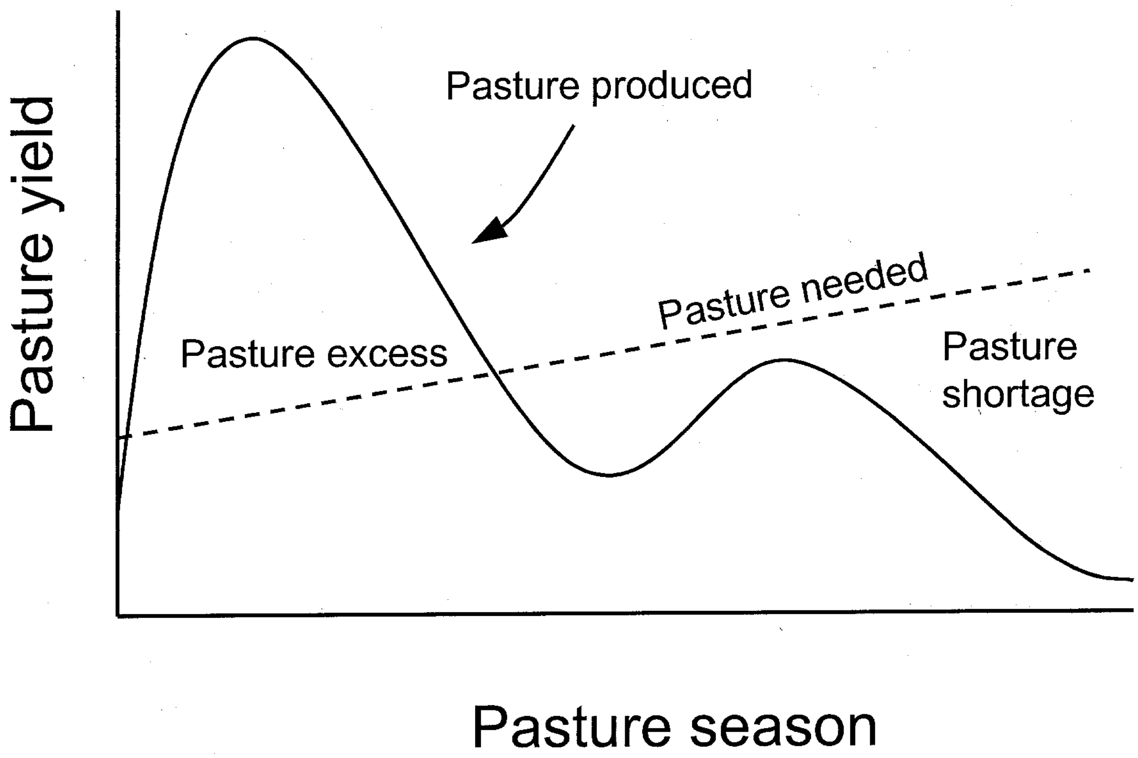

Figure 1. Average seasonal production of perennial pasture (Blaser et al., 1973).

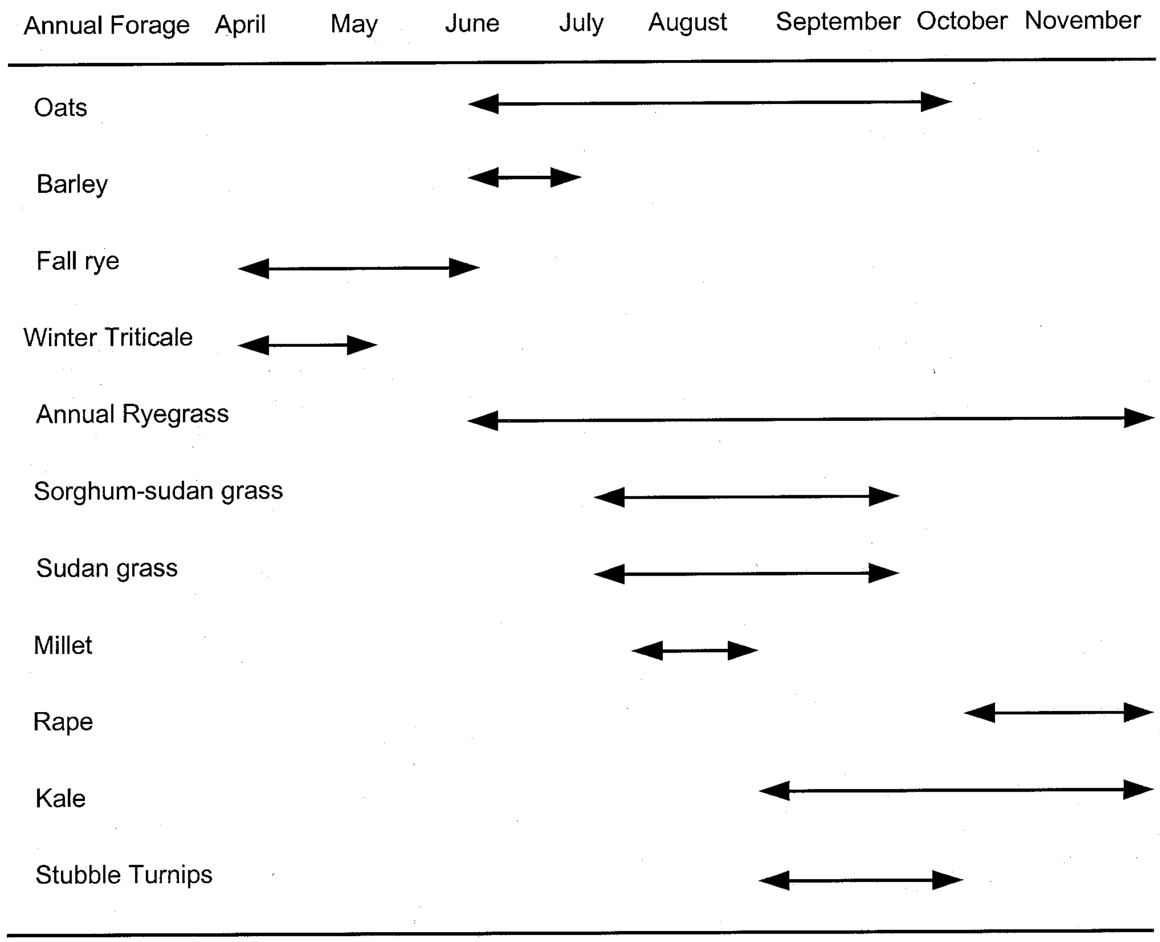

Figure 2. Annual forages to fill the pasture season (Robinson and Clare, 1988).

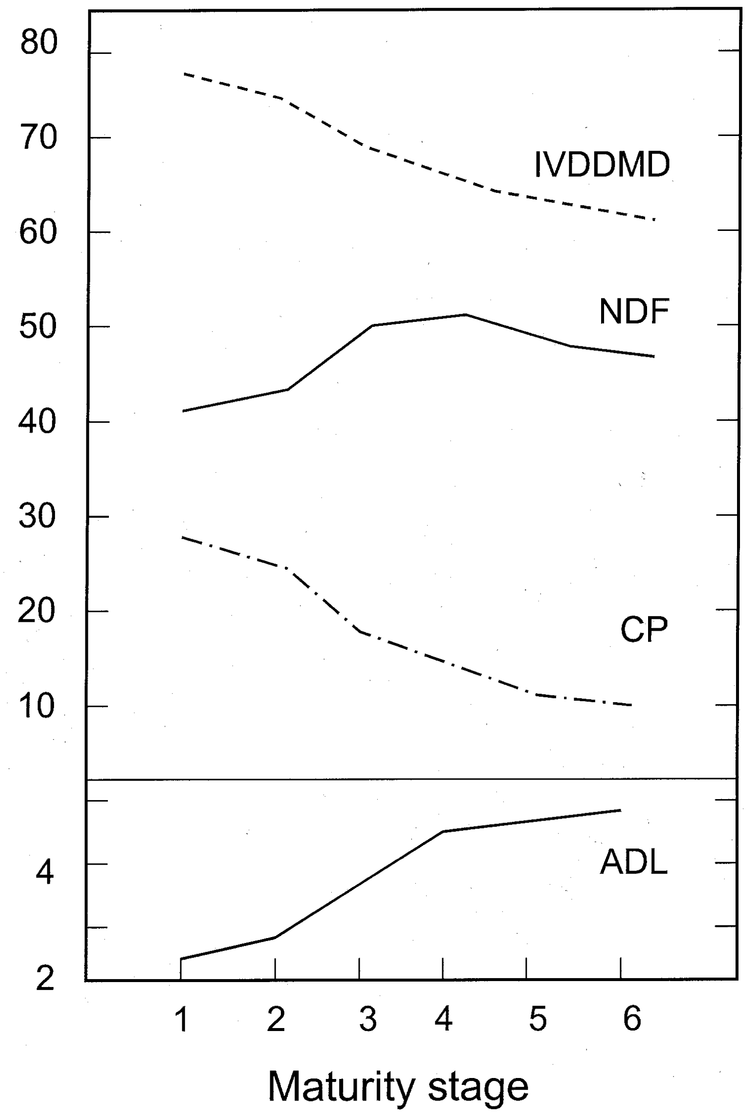

Figure 3. In vitro digestible dry matter (IVDDM), neutral detergent fiber (NDF), crude protein (CP), and acid detergent lignin (ADL) concentration changes with maturation of forage of small grain crop species. Maturiy stage 1 = flag leaf, 2 = inflorescence emerging, 3 = 7 days, 4 = 14 days, 5 = 21 days, and 6 = 28 days after stage 2 (Cherney and Marten, 1982).

Grain Supplementation to Grazing Herds

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Several studies suggest that well managed pasture based dairy systems could reduce input costs and increase net returns on small to medium sized farms in the United States by as much as $150 per cow when compared to conventional confinement dairy systems (Parker et al, 1992; Rust et al, 1995; Tranel and Frank, 1991). The primary advantage of grazing systems over confinement systems appears to be a reduction in costs of forage production. Increased profitability due to reductions in input costs will quickly be lost if milk production per cow is reduced. For grazing systems to perform financially as well as confinement based systems, milk production must be maintained at high levels.

Farmers who are successful at maintaining high milk yield with grazing systems generally are successful in three areas of nutrition and pasture management (Figure 1). The first and most important component of their grazing system is a pasture management strategy that maximizes the amount and quality of forage that cows harvest from pasture. Key management factors include: selection of forage species that are adapted for the soils and climate of the farm, optimal soil fertility to maintain forage growth through the grazing season, management of forage growth by manipulating stocking density, selective mechanical harvesting, and strategic use of grain and forage supplements.

The second management issue is provision of supplemental energy to optimize milk production. High quality pastures will not provide adequate energy to cows of high genetic merit (Table 1). If supplemental energy is not provided to high producing cows, milk yield, body condition, and reproductive performance will reduced (Kellaway and Porta, 1993). The amount of grain needed to optimize performance will differ as circumstances change between farms and at different times of the year. Successful grain feeding entails a strategy where adequate supplemental energy is fed to complement, not replace, the supply and quality of pasture. Excessive grain feeding is avoided because it will reduce pasture utilization. A common challenge faced by farmers who feed supplemental grain is maintaining pasture intake. It has been clearly demonstrated that even low levels of grain feeding to pastured cattle will reduce forage consumption if forage supply is not limiting. It becomes critical to recognize that stocking density and mechanical harvest of excess pasture forage will likely have to be adjusted when grain supplements are fed to grazing dairy cows.

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The third important area of management for grazing dairy cattle is when and how much supplemental protein, especially ruminally undegradable protein to feed. Protein supplements tend to be the most expensive component of the pasture feeding program, and therefore, overfeeding of protein will affect net returns. It is also important to recognize that the optimal amount of supplemental protein to feed will vary depending on the amount of energy provided by the diet. Supplemental protein will be of little benefit to cows that are consuming low to moderate levels of energy, but cows with high genetic potential for milk yield that are consuming adequate energy will likely produce more milk if the pasture supplements contain supplemental protein.

Managing Pastures to Optimize Forage Yield and Quality

Pasture stands should persist for several years and consistently yield high quality forage throughout the grazing season. In confinement systems, pure stands of alfalfa or rye grass are considered to be among the highest of all forage crops in yield of digestible energy per acre. In the midwest, however, pure stands of neither is adapted well to intensive grazing systems.

Cool season grasses and legumes tend to be the highest producing species of pasture forages in the upper midwest of the United States. Cool season grasses yield 60% of their total yearly production in May and June. Cool season grasses also green up earlier in the spring than legumes, allowing for as much as two weeks earlier start to the grazing season than with pure legume pastures.

Alfalfa is more deeply rooted than grasses or other legumes and maintains pasture production through mid to late summer better than other legumes or cool season grasses. Annual grasses such as oats, winter wheat, and winter rye can also be used as pasture forages in the midwest. They will yield approximately half as much as the perennial legumes and grasses, however, and do not yield well during the warmer, dry months of summer.

Regardless of forage species or mixture of forage species selected, forage production will be greater than can be utilized in May and June and insufficient in late summer and early fall. With dairy cattle, it becomes critical to design grazing systems around forage availability. Well managed improved pastures can be stocked at about 1 to 1.5 lactating cows per acre. Approximately 30% of the total summer production forage will have to be mechanically harvested to maintain forage quality and yield. In years with normal rainfall, most of the excess forage can be harvested at the late vegetative stage of maturity in late May or early June. It may also be necessary to harvest a second cutting of forage in July. Stocking rates of pastures that consist of native grass species or warm season grasses may be as low as .5 to .75 lactating cows per acre. It also may be necessary to supplement these pastures with higher levels of grain to maintain optimal milk yield.

Planting alfalfa in a mixture with grasses can reduce the risk of bloat and help decrease winter kill problems (Howarth, 1988). There is also evidence that when a legume and a grass are planted as a mixture, total yields will be greater than either of the two species grown in monoculture (Sheaffer et al., 1990). Legume-grass mixtures also ensure against failure of the entire stand under adverse weather conditions.

Depies (1994) compared forage yields, quality, and persistence of two pasture types in a three year study. They found that pastures consisting of alfalfa grown in monocultures were not as suitable as alfalfa/red clover/brome/orchard grass mixtures for grazing dairy cattle in a three year experiment (Table 2). Alfalfa did not persist well in either pasture system because of winter kill in this study. The grasses and red clover in the mixed pastures did survive, however, and yield of forage dry matter in the mixed species pastures increased by approximately 15% in both the second and third year of the trial. Several cattle grazing the pure alfalfa pastures were also treated for bloat during the grazing season, while none of the cows grazing the mixture of grasses and legumes bloated.

Forage quality of pure grass stands or grass-legume mixtures is usually lower than the quality of pure legumes. Depies (1994) found that although pasture composed of a mixture of grasses/legumes was lower in ruminal digestibility than a pure alfalfa pasture, there was little difference in milk yield due to pasture. In this study, cattle in a confinement feeding system produced similar yields of 3.5% FCM/acre as compared to the legume-grass pasture system in the first year (Table 3). In the second and third years of the study, the legume-grass pastures systems produced more milk/acre than the confinement feeding system. The legume-grass pastures were better suited for grazing than the pure alfalfa pastures because of greater yields, better forage persistence, and higher milk production per acre. A mixture of legumes and grasses in this study yielded more forage DM, was more persistent, and appeared to be more suitable for grazing than alfalfa pastures.

Meeting Energy Requirements of Grazing Cattle

High producing cows receiving excellent pasture but no grain will show typical signs of energy deficiency in early lactation: low peak daily milk yield, excessive loss of body condition, poor persistence after peak, silent heats, and low conception rates (Kellaway and Porta, 1993). With pure legume pastures, a high producing cow would be expected to consume only enough digestible energy to support about 50 to 60 lb/day of milk. Under field conditions, however, cattle on high quality pasture fed no supplement have produced as much as 75 to 80 lb/day. Most of the time these cattle lose weight rapidly and show poor persistency in mid lactation. Many nutritionists express concern that it is difficult to maintain body condition and lactation persistency with grazing dairy cattle. Poor lactation performance is often attributed to the inability of cattle to consume adequate amounts of fresh forage. One concern is that the high moisture content of fresh pasture may limit rumen capacity. In order for cows to consume 25 lb of DM from pasture, cows need to consume approximately 200 lb of fresh material. Another problem may be that forage intake is limited by either sward density, sward height, or grazing pressure. Our research (Depies, 1994) indicates that grazing dairy cattle are not likely limited by rumen fill of fresh material, but it is likely that grazing pressure could be a factor in limiting intake of grazing cattle (Table 4). Grazing cattle appear to be able to consume as much forage DM from pasture as alfalfa silage. In this experiment, cows on alfalfa pasture consumed on average as much as 250 lb/day of wet forage. In order to attain forage DM intakes that were comparable to the confinement system, grazing cattle had to have ample supply of pasture and be allowed to leave at least 35% of the available sward as residue. When we tried to reduce residual pasture, forage intake and milk production declined.

Ohio State work (Table 5) suggests that the production response to supplemental grain on legume based pastures is similar (1.1 lb milk per pound of supplemented grain DM) to the response to grain on orchard grass pastures (.85 lb milk per pound of supplemented grain). This work suggests that for both pastures, forage consumption decreased and total DM intake increased as more grain was added to the diet. Total DM intake of cows receiving the highest supplement rates on pastures were similar to the total DM intake of cows fed the alfalfa silage based diet. The substitution effect of grain on pasture consumption appears to be similar to that observed when grain is added to high quality hay or silage based diets. Other studies have reported little or no substitution effect of grain for forage (Jones-Endsley et al., 1997). This may be an indication that pasture consumption was limiting.

Several experiments have attempted to quantify the milk response to supplemental grain for grazing cows (Arriaga-Jordan and Holmes, 1986a, 1986b; Hodge and Rogers, 1984; Hodge et al, 1984; Jennings and Holmes, 1984; Kibon and Holmes, 1987; Moate et al., 1984; Muller, 1993; Stakelum, 1986; Taparia and Davey, 1970). In general the response in milk yield to each additional pound of grain has been between .50 and .67 lb/day of 4% FCM. Each pound of grain added to the diet of grazing cows will increase total DM intake by about .4 to .6 lb/day and decrease forage consumption by .6 to .4 lb/day. These are typical responses when pasture supply is not limiting. When pasture supply or pasture intake is low, forage intake is often unaffected by grain feeding, and milk production may or may not be affected by grain feeding (Kellaway and Porta, 1993).

The substitution effect of grain for forage can be an important management tool for pasture based systems. Increasing the level of supplemental grain will increase total intake of digestible energy, which in turn will help meet the energy output of milk and reduce loss of body condition. Grain feeding also can be an effective tool for managing pasture inventories. In late summer or early fall, increasing the rate of grain feeding could slow pasture consumption enough to eliminate the need for supplemental forage while at the same time increasing total energy intake to help replenish body condition.

Supplemental grain also improves body condition score in cattle on pasture. Australian researchers (Kellaway and Porta, 1993) suggest that the greatest economic benefit to grain supplementation is the improvement in body condition. Body condition is correlated to reproduction efficiency. Supplemental grain to cows in late lactation also helps to replenish fat reserves that are critical if cows are to produce well in the next lactation.

Protein Supplements

High quality immature forages are relatively high in CP, but low in protein that “bypasses” ruminal degradation (Table 1). As legumes make up a larger portion of the forage species in the pasture, undegraded intake protein content of the pasture decreases. From NRC (1989) guidelines, it can be calculated that cattle grazing high quality immature forages and supplemented with corn-soybean concentrates may not consume adequate bypass protein. Fox et al. (1991) evaluated the impacts of supplemental energy verses protein on growth of Holstein heifers. In this study, heifers grazed high quality pastures that supplied CP well in excess of NRC feeding guidelines. Their work suggests that average daily gain of both lightweight and heavy heifers increased by .2 lb/day when .9 lb of soybean meal supplement was fed in place of cracked corn. Daily gains of heifers fed the soybean meal supplement were not different from heifers fed a fish meal supplement. This study suggests that growing heifers consuming lush high CP pastures can respond to supplemental protein. The amount of bypass protein needed, however, appears to be met with a limited amount of protein supplement. Milk production responses to bypass protein have not always supported the hypothesis that fresh forage diets are limiting in bypass protein. Hongerholt et al. (1993) evaluated milk yield response to bypass protein in high producing Holstein cows grazing immature orchard grass pastures. In this trial, cattle were fed grain at a rate of 1 lb per 5 lb of milk yield. Diets fed the control cows were calculated to be deficient in bypass protein, relative to energy intake. Mature cows fed a grain supplement containing more bypass protein than control diets produced more milk. Milk production responses to bypass protein has not been observed in other grazing studies (Jones-Endsley et al., 1997; Penno et al, 1995; Welch et al, 1990). It would appear that in these trials, energy, not bypass protein, may have limited milk yield. Energy can be limitied by inadequate intake of pasture or by insufficient grain supplementation. In experiments where the base diet has been limiting in energy relative to bypass protein, milk production responses to protein supplements typically range from .5 to 1 lb of milk per pound of supplement fed. These responses would be consistent with what would be expected if animals were catabolizing the supplement for energy. When energy supply is adequate, milk production responses to protein supplements would be expected to be in the range of at least 7 to 8 lb of milk per pound of supplemental protein fed. Under field conditions, it is extremely important to focus supplement strategies first on supplying energy and secondly on protein.

Summary

The use of intensively managed pastures offers many dairy producers an opportunity to increase profitability with a modest capital input. Well managed pastures will produce forages that are comparable or better than can be produced with mechanical harvesting systems. Inputs to and net returns from intensive rotational grazing dairy systems appear to compare favorably to more traditional confinement-stored forage feeding systems.

High producing cattle that are grazed on high quality pastures will respond to supplemental energy and bypass protein. The response to concentrates and bypass proteins, however, will vary depending on the quantity and quality of pasture. More research is needed to define circumstances when marginal returns to supplemental feeding of grazing cows is economically viable.

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Table 1. Nutrient recommendations for dairy cows and average composition of intensively managed pastures in the upper midwest.

	Production level		Pasture type		
Nutrient	Early Lactation	70 lb/day	Grass	Grass-legume	Legume
NE_L, Mcal/lb	.78	.74	.65 - .70	.66 - .72	.68 - .74
CP, % of DM	19	16	18 - 22	21 - 23	23 - 25
Bypass CP, % of DM	7.2	5.7	4.4 - 6.3	4.2 - 5.7	4.6 - 5.0
NDF, % of DM (Minimum)	28	28	50	44	38
NFC, % of DM[1]	36 - 40	36 - 40	15 - 20	15 - 20	20 - 25

[1]NFC = Nonfiber carbohydrate

Table 2 Forage dry matter yields for alfalfa and legume-grass mixed pasture at the University of Wisconsin Arlington Research Station (Depies, 1994).

Year	Alfalfa pasture	Mixed pasture
	-- Tons DM/acre--	
1991		
Forage consumed by grazing	2.5 ± .2[1]	2.5 ± .2
Forage mechanically harvested	.9 ± .04	1.2 ± .05
Total yield for season[2]	3.4 ± .2	3.7 ± .2
1992		
Forage consumed by grazing	1.8 ± .1	3.5 ± .2
Forage mechanically harvested	.4 ± .07	.52 ± .01
Total yield for season	2.2 ± .12	4.0 ± .18
1993		
Forage consumed by grazing[3]	0	3.9 ± .15
Forage mechanically harvested	3.1 ± 3	.67 ± .02
Total yield for season	3.1 ± .3	4.6 ± .2

[1] Standard deviation of the means of the 3 pastures for each treatment.
[2] Based on herbage samples harvested at a 5 cm stubble height.
[3] Alfalfa pastures were not grazed in 1993.

Table 3. Milk produced per acre by cows receiving all forage from alfalfa silage in a confinement feeding system or from grazing alfalfa or legume-grass pastures (Depies, 1994).

Year	Alfalfa silage	Alfalfa pasture	Grass-legume pasture
	Forage System		
1991			
Milk produced per acre forage consumed, Tons/acre[1]	7.4	6.1	6.8
Milk/acre forage less grain NE_L, Tons/acre[2]	1.0	1.9	2.4
1992			
Milk produced per acre forage consumed, Tons/acre	6.2	3.8	7.8
Milk/acre forage less grain NE_L, Tons/acre	2.5	.55	3.9
1993			
Milk produced per acre forage consumed, Tons/acre	7.6	0	9.2
Milk/acre forage less grain NE_L, Tons/acre	1.2	0	2.8

[1]Milk90 is a spreadsheet used to calculate milk/acre using forage yield and quality (Undersander et al., 1993).

[2]Grain NE_L estimated to be .80 Mcal/lb and the NE_L value of milk was .32 Mcal/lb.

Table 4. Intake and milk production by cows receiving all forage from alfalfa silage, alfalfa pasture, or legume-grass mixed pasture. (Depies, 1994).

	Treatment			
Year/item	Alfalfa silage	Alfalfa pasture	Grass-legume pasture	
	lb/day			SE[1]
1991				
Grain DM offered	24	21	21	
Grain DM consumed[a]	23	18	17	.7
Forage DM offered[c]	31	36	33	
Forage DM intake	22	22	22	2.4
Total DM intake[b]	45	43	39	2.4
3.5% FCM yield				
Multiparous cows[a]	70	72	73	1.8
Primiparous cows	61	61	62	1.8
1992				
Grain DM offered	20	18	17	
Grain DM consumed[a]	18	14	14	.4
Forage DM offered[c]	34	37	34	
Forage DM intake	28	29	22	2.4
Total DM intake[a]	46	42	38	2.2
3.5% FCM yield				
Multiparous cows	66	64	60	1.8
Primiparous cows	52	54	50	1.8
1993				
Grain DM offered	24		20	
Grain DM consumed	23		20	.7
Forage DM offered[c]	32		39	
Forage DM intake	25		29	2.6
Total DM intake	48		49	2.4
3.5% FCM yield				
Multiparous cows[a]	74		81	.7
Primiparous cows	61		63	.7

[1]SE = standard error of mean.
[a]Alfalfa silage fed cows are different from pasture fed cows ($P < .01$).
[b]Alfalfa pasture fed cows are different from grass-legume pasture fed cows ($P < .05$).
[c]Forage offered and consumed by alfalfa silage fed cows was measured directly. Forage offered and consumed by pasture fed cattle was estimated by measureing herbage DM yield above 5 cm stubble height before and after grazing.

Table 5. Feed intake and milk production for dairy cows top-grazing either alfalfa or orchard grass pastures. (Conrad et al., 1984)

Forage source	Concentrate	Forage intake	Milk yield
	--------------------------lb/day----------------------------		
Alfalfa pasture	0	41	44
	10	35	53
	22	22	68
Orchard grass pasture	0	38	29
	13	33	38
	22	23	47
Alfalfa silage	18	22	62

Priority one: Pasture management systems that optimize forage yield and quality

(forage species, management practices)

↓

Priority two: Supplement pasture based diets to meet energy requirements

↓

Priority three: Balance diets for undegradable protein

Figure 1. Priorities for pasture based dairy systems

Why Is It Important to Know How Feeding Alters the Fatty Acid Content of Milk?

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Traditionally the dairy industry has been concerned with the total amount of fat in milk, but not the composition of the fat. Composition has been an issue left for discussion mainly by those in academics. It has been known for nearly a century that feeding could influence composition of the fat and its quality for making butter (Smith et al., 1916). Since the development of the gas chromatograph over 40 years ago, the effect of feeding on milk fatty acid composition has been studied intensively as an approach to understand the regulation of milk fat synthesis and composition (Jensen, 1992). Milk fat has long been accused of being atherogenic because of its cholesterol and saturated fatty acid contents. More recent research has modified that image of milk fat (Berner, 1993). Finally, some of the most exciting research on milk fat shows that it contains numerous potentially anticarcinogenic agents (Parodi, 1997).

It is clear that knowing the composition of milk fat provides information on 1) the regulation of its synthesis; 2) usefulness for specific manufacturing purposes; and 3) effects on health and nutrition.

The point of this presentation will be to describe some of the unique properties of milk fat and to give examples of how the composition of milk fat can be changed by feeding to accomplish specific purposes. This topic has been reviewed in depth on several occasions (German et al., 1997; Grummer, 1991; Hawke and Taylor, 1983; Kennelly, 1996; Palmquist et al., 1993).

The Composition of Bovine Milk Fat

Over 400 different fatty acids have been identified in milk fat, but only about a dozen of these occur in concentrations greater than 1% (Jensen, 1992). Typical fatty acid composition of milk fat, showing the major components and some minor ones of particular interest, is in Table 1. The fatty acids of short and medium chain length (4 to 14 carbons) are synthesized in the mammary gland from acetate and β-hydroxybutyrate, which are derived from the ruminal fermentation; these comprise about 30% by weight of the total milk fat. Palmitic acid (16:0) arises variably from mammary (de novo) synthesis and from dietary or adipose fatty acids; thus, typically 40 to 50% of milk fat is synthesized de novo, utilizing ruminal fermentation products as substrate. The long chain fatty acids (variably 16:0 and 18 carbons) are derived from the diet and constitute 40 to 60% of milk fat, depending upon diet and energy balance of the cow.

The great number of different fatty acids, with varying chain length, unsaturation, and geometrical structure, contribute to varying physical, as well as chemical, characteristics of milk fat. An

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elementary example is that shorter chains or increasing unsaturation, or both, lower the melting point of the fat. In all cases (except one isolated occurrence in Sweden), the milk fat is liquid at the body temperature of the cow (39°C, or 102°F).

Equally important for physical structure, but more difficult to measure, is the arrangement of the fatty acids in the glyceride. Milk fat is >98% triacylglycerol ("triglyceride"), in which three fatty acids are esterified to the free hydroxyl groups of glycerol. The arrangement of different fatty acids on the glycerol impart different physical characteristics to the triglyceride molecule (German et al., 1997). Because the glyceride molecule is not symmetrical, the potential number of different arrangements, or isomers, is greater than 400^3, or 64 million (Jensen, 1992). The actual number is less than this because the fatty acids are not distributed randomly on the glycerol. Rather, the arrangement is directed by the presence and relative activities of enzymes that function specifically for each of the three glycerol positions. There is much less knowledge of feeding effects on glyceride structure than on the fatty acid composition of milk because determination of glyceride structure is technically much more difficult to accomplish.

Causes of Variation in Milk Fat Composition

Breed differences. It has long been known that milk fat from Jersey cows is harder than that from Holstein cows fed under similar conditions (Banks et al., 1989; see Figure 1). Milk fat from Jersey cows has greater amounts of fatty acids synthesized in the mammary gland, including 16:0, and has a lower ratio of 18:1/18:0 (Beaulieu and Palmquist, 1995). Large amounts of 18:0 are formed in the rumen, are subsequently absorbed, and are desaturated by the enzyme stearoyl-CoA desaturase (also more generally called delta-9 desaturase). It currently is of interest to determine whether the activity of this enzyme is lower in Jersey cows. DePeters et al. (1995) reported evidence that the ratio of 18:1/18:0 in milk fat is genetically regulated.

Stage of lactation. In the first few weeks of lactation, cows are in a negative energy balance. Although the fatty acids mobilized from body stores are oxidized, a large amount also are taken up directly by the mammary gland and incorporated into milk fat. These increase the proportion of long-chain (16 and 18 carbon) fatty acids in milk fat; they also may inhibit the de novo synthesis of short and medium chain (6 to 14 carbon) fatty acids. Milk fat from cows in a negative energy balance usually also has a higher ratio of 18:1/18:0. Effects of lactation stage on milk fat composition clearly are dependent on energy balance. Typical changes are shown in Figure 2. The greatest amount of this effect is completed within the first 3 to 4 weeks of lactation; however, continued changes have been reported up to 3 to 4 months of lactation (Lynch et al., 1992; Palmquist et al., 1993).

Feeding effects. The effects of feeding are many and varied; most involve effects of different amounts and types of dietary fat or changes in the ruminal fermentation or both (Palmquist et al., 1993). Because the literature on this topic is so large, only a few examples will be given. Dietary fats are composed of varying amounts of 16 and 18 carbon fatty acids; 18 carbons predominate, but different fat sources differ greatly in their degree of unsaturation of the 18 carbon fatty acids (Table 2). Dietary fats increase the proportions of the long-chain fatty acids in milk fat; however, synthesis of the short- and medium-chain fatty acids also may be inhibited to varying degrees by the increased uptake of long-chain fatty acids. In this case, the total yield of milk fat may not increase or may even be decreased. By feeding a supplemental fat with relatively higher or lower 16 or 18 carbon fatty acids, the chain length of predominant fatty acids in milk fat can be influenced. For example, feeding Megalac® (Church and Dwight Co., Inc., Princeton, NJ), a fat containing a high proportion (50%) of 16 carbon fatty acid, will increase 16:0 in milk fat. Similarly, feeding fats higher in 18 carbon fatty acids will increase these in milk fat.

Ruminal biohydrogenation. As shown above, many dietary fats contain considerable amounts of unsaturated fatty acids. Under usual feeding conditions, however, these unsaturated fatty acids do not appear in milk because they are extensively converted (biohydrogenated) to more saturated fatty acids, primarily stearic acid (18:0), by the ruminal microbial population (Jenkins, 1993). A certain amount of the fatty acids may be only partially biohydrogenated, yielding various unsaturated isomers that may be absorbed and incorporated into milk fat. Two of the most important intermediates are trans-11 18:1 and cis-9, trans-11 18:2 (conjugated linoleic acid, **CLA**). These intermediates seem to occur in greater amounts when high amounts of unsaturated oils or highly acidic conditions occur in the rumen. The resulting isomers have important effects on total milk fat yield and composition. Recently, it has become clear that the low milk fat percentage which often occurs when high fat diets are fed is a result of trans monoenoic (trans 18:1) fatty acids formed by incomplete biohydrogenation (Gaynor et al., 1995). Though feeding increased amounts of unsaturated oils often increases the amount of trans-11 18:1 found in milk fat (Enjalbert et al., 1997; Kennelly, 1996; Palmquist, et al., 1993; Precht and Molkentin, 1997), more recent evidence suggests that the trans-10 18:1, which occurs in greater amounts in the acid rumen, is the agent which inhibits synthesis of the short- and medium-chain fatty acids in the mammry gland and induces milk fat depression (Grinnari et al., 1998). Progress or specific identification of fatty acids is slow because separation and identification of the two positional isomers of the trans monoene is technically difficult.

An important consideration for the composition of milk fat, and of increasing interest currently, is the conversion of the high amounts of absorbed stearic acid (18:0) to the monounsaturated oleic acid (18:1) by delta-9 desaturase. This enzyme increases the ratio of 18:1/18:0 in milk fat and lowers the melting point (softens) of the fat as well.

Changing Milk Fat Composition to Improve Manufacturing Properties

The dairy industry has long been interested in improving the spreadability of butter. In European feeding management systems, “winter” butter is always much harder than “summer” butter from cows fed mainly by grazing pasture (Precht and Molkentin, 1997). Fresh green forage is higher in fat compared to stored forages, producing a milk fat with higher oleic acid (18:1) content, and thus softer. We now know that softer butter can be produced by feeding supplemental fats with a high proportion of 18 carbon fatty acids. However, this is only a partial solution to the goal of having a softer butter because changing the fatty acid composition changes the structure (arrangement of fatty acids in the glyceride), which influences the plasticity (temperature range of softness;

spreadability) of the fat (German et al., 1997). We know less about the control of this factor.

Just as increasing 18-carbon fatty acids in the diet increases these in milk and causes a softer fat, the fat can be made harder by feeding a fat high in 16-carbon fatty acids (such as Energy Booster 100® or Megalac®). Increased 16:0 in the diet may increase milk fat percentage (Hansen and Knudsen, 1987; Kinsella and Gross, 1973); a harder fat increases the stability of whipping cream (Banks et al., 1989). An interesting application is that processors of Parmesan cheese in Italy specify that cows shall be fed Megalac®; the harder milk fat produces a cheese more desirable for grating.

The potential for changing milk fat composition for specific manufacturing needs by feeding is greater than the knowledge of the processing industry for the specific composition needed for particular applications. In other words, it probably is possible to produce specific fatty acid composition when processors know what they want.

Changing Milk Fat Composition for Specific Health Effects

Milk fat has long been condemned as being not "heart healthy" because of its high content of cholesterol and saturated fatty acids (Berner, 1993). Newer knowledge suggests that the cholesterol content is of relatively small concern and that only certain of the saturated fatty acids, namely lauric (12:0), myristic (14:0), and palmitic (16:0), consistently raise plasma cholesterol in susceptible persons (Salter and White, 1996; Spady et al., 1993). More recent research has shown that there are numerous components of milk fat that are potential anticarcinogenic agents (Parodi, 1997). These include CLA, sphingomeyelin, butyric acid, and ether lipids. Among these, present knowledge to change the amount of CLA in milk fat is greatest. This isomer of linoleic acid, formed mainly as a product of the ruminal biohydrogenation process, is the most potent natural anticarcinogen in foods (Ip et al., 1994); its most important dietary source is milk fat (Banni et al., 1996; Chin et al., 1992; Parodi, 1994). Under usual feeding conditions, CLA occurs in milk fat in amounts of 0.4 to 0.8% of the fat. Feeding unsaturated oils increases the concentration 2 to 3 fold (Jiang et al., 1996; Kelly and Bauman, 1996); highest concentrations are usually found in milk fat from cows grazing lush pasture. In addition to its anticarcinogenic effects, CLA has been reported to influence body composition (less fat, more muscle), improve bone growth, and stimulate immune function (Doyle, 1998). In unreported studies from Cornell University (Bauman, personal communication, 1998) and our laboratory, it is clear that the trans-11 18:1 fatty acid found in milk fat can be converted to CLA by action of the delta-9 desaturase enzyme in both bovine and rodent species. A recent report from Finland (Salminen et al., 1998) provides indirect evidence for the same conversion to occur in humans. This should be a positive factor for the image of milk fat because trans-11 18:1, having a negative image (Gurr, 1996), is changed in significant amounts to CLA, with a strong positive image.

Changing Milk Fat Composition by Feeding "Rumen-Protected Lipids"

About 1970, Australian scientists developed a procedure to protect dietary unsaturated fatty acids from ruminal biohydrogenation by encapsulating the fat in a formaldehyde-crosslinked protein matrix.

Extensive research on dairy product and meat samples from ruminants fed this supplement showed that highly unsaturated products could be produced -- up to 20% linoleic acid (18:2) in milk fat compared to less than 3% for milk fat from cows fed conventional diets (McDonald and Scott, 1977). Their objective was to produce "heart-healthy" ruminant foods. We conducted clinical trials with these products and showed that they could effectively reduce plasma cholesterol with proper dietary regimentation (Brown et al., 1976). A common problem with these highly-unsaturated dairy products was their susceptibility to oxidation; oxidative rancidity occurred very quickly unless stringent measures were undertaken to prevent it. More recent efforts have improved the quality of protection of the unsaturated protected fats and have used canola oil, high in oleic acid (18:1), rather than soy or sunflower, high in 18:2. Products from protected canola have increased 18:1 rather than 18:2 and, therefore, are more stable to oxidation. The contents of 14:0 and 16:0 were decreased 20 and 25%, respectively, by feeding the protected canola supplement (Table 3). Thus, the new products have improved processing quality and focus on changing the specific fatty acids believed to influence plasma cholesterol concentration in susceptible subjects (Ashes et al., 1992). These food products are commercially available in Australia.

Formaldehyde-protected protein feed supplements have not been adapted in the United States, at least in part because of health and environmental concerns associated with using formaldehyde in feedstuffs. An alternate procedure to protect unsaturated fatty acids from biohydrogenation, based on forming the amide derivative, is under intensive investigation and development at Clemson University (Jenkins et al., 1996). This technology has the potential to increase concentration of specific fatty acids in milk fat.

Most conventional feed fats, whether yellow grease or tallow, or the oilseeds, are extensively biohydrogenated in the rumen. An exception is whole soybean. Although lipolysis and biohydrogenation of soybean fat occurs in the rumen, a significant amount of 18:2 and 18:3 escape ruminal metabolism and are incorporated into milk fat (Tice et al., 1994). We have observed 18:2 as high as 5 to 7% in commercial milk fat samples, compared to less than 3% for typical milk fat. These higher contents of 18:2 have been associated with oxidized flavor in research trials (Charmley and Nicholson, 1994) and in some commercial milk products (Palmquist, 1997).

Current Status of Research

A few examples of why it is useful to be able to manipulate milk fat composition have been provided. Since 1994, a regional research committee (W-181) has been working cooperatively to investigate the factors regulating milk fat composition, to develop predictable feeding systems for manipulation of milk composition, and to study the functional characteristics of modified milk fat for various commercial dairy products. This committee has involved scientists from 12 states, Alberta, Manitoba, Australia, Denmark, and Finland. Scientists from industry and Dairy Management, Inc. have been included and industry representation has been expanded. The project is currently in revision and it is anticipated that cooperation with nutrition scientists to study metabolic effects of consuming modified dairy products may be increased as well. Any effort to produce modified milk fat products by changing feeding practices will require integrated effort of feed manufacturers, dairy farmers, milk processors, and marketers. Although these activities are beyond the scope of programs for the regional research committee, members of the committee are cooperating in such development.

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Table 1. Milk fatty acid composition (percentage by weight) from commercial dairy herds fed no supplemental fat, whole soybeans, or other fats. (Mean of monthly bulk tank samples taken Dec. to June).

	No Fat	Whole Soybeans	Other Fat
n	11	15	25
Fatty acid[1]			
4:0	4.95	4.94	4.91
6:0	3.00	3.03	2.88
8:0	1.65	1.65	1.55
10:0	3.61	3.52	3.26
12:0	3.96	3.72	3.50
14:0	11.38	10.45	10.54
14:1	1.03	0.82	0.92
15:0	1.11	0.98	1.02
16:0	30.96	28.23	29.63
16:1	1.59	1.26	1.45
18:0	11.05	13.20	12.32
18:1t	1.88	1.88	2.16
18:1c	19.33	19.76	20.52
18:2	2.69	4.10	2.94
18:3	0.37	0.74	0.46
CLA	0.46	0.55	0.66

[1]t = trans fatty acid, c = cis fatty acid, and CLA = conjugated linoleic acid.

Table 2. The fatty acid composition (percentage by weight) of some typical fat supplements. (Palmquist, 1988).

	Fatty acid						
	14:0	16:0	16:1	18:0	18:1	18:2	18:3
Fat supplements							
Animal-vegetable blend	2.2	23.8	1.6	16.8	31.7	14.9	1.7
Beef tallow	3.0	25.8	6.1	18.8	39.7	4.5	1.0
Palm oil	1.5	42.0	-	4.0	43.0	9.5	-
Oil seeds							
Cottonseed	0.8	25.3	-	2.8	17.1	53.2	0.1
Canola	-	4.3	0.3	1.7	59.1	22.8	8.2
Soybean	0.2	10.7	0.3	3.9	22.8	50.8	6.8

Table 3. Effect of dietary protected canola supplement (PCS) on the fatty acid composition of milk[1]

Fatty acid	Content[2] Control	PCS
	---------------------- (% of total) ----------------------	
$C_{4:0}$	3.1	3.2
$C_{6:0}$	2.4	2.4
$C_{8:0}$	1.9	1.9
$C_{10:0}$	3.4	3.2
$C_{12:0}$	4.3	3.6
$C_{14:0}$	11.8	9.5
$C_{16:0}$	26.7	19.9
$C_{16:1}$	4.5	3.3
$C_{18:0}$	7.1	9.2
$C_{18:1}$	23.8	29.2
$C_{18:2}$	2.2	4.9
$C_{18:3}$	1.6	2.6

[1]Adapted from Ashes et al. (1992).
[2]Percentages are normalized to mean recovery of 92.8%.

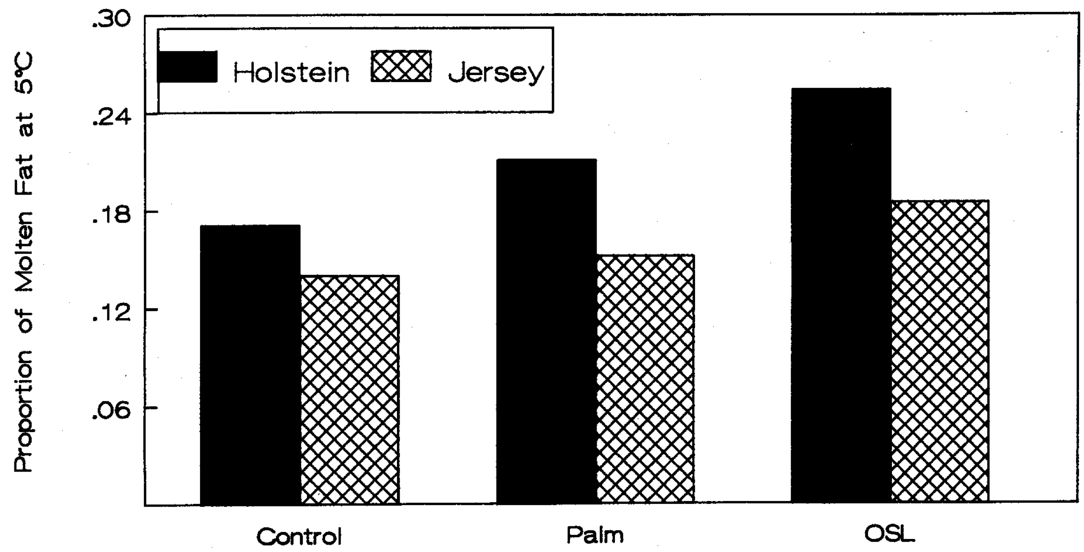

Figure 1. Relative proportion of milk fat that was molten at 5°C for different dietary supplements and breeds. Control, no supplemental fat; Palm, palm oil supplement; OSL, means of separate treatments with olive, soy and linseed oil supplements. Taken from (Palmquist et al., 1993) with permission.

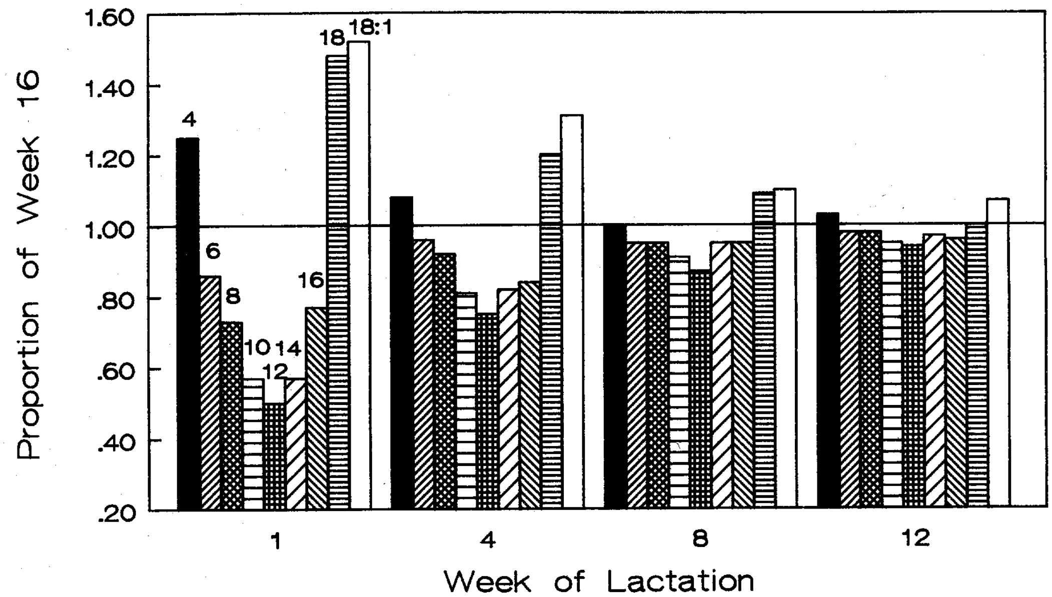

Figure 2. Concentrations of individual fatty acids in milk at weeks 1, 4, 8 and 12 of lactation, as a proportion of their concentrations at week 16 of lactation. Taken from (Palmquist et al., 1993) with permission.

Prevention of Udder Edema in Dairy Cows

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The periparturient period is especially important for the health of dairy cows. Among health problems occurring during this period is an accumulation of excessive interstitial fluid in extravascular spaces of the udder and adjacent tissues of some animals. Occurrence of udder edema varies greatly in different herds with incidences ranging from 18 to 96% of all cows observed at calving (Al-Ani and Vestweber, 1986). Although the swelling usually diminishes after parturition without special care, management problems and permanent damage are likely (Vestweber and Al-Ani, 1983).

Physiology of Udder Edema

Intravascular and interstitial fluids

Over a century ago, Starling (1896) described the basic principals regulating movement of fluids between intravascular circulation and adjacent tissues. During the intervening 102 years, it has been established that relative concentrations of solute in intracellular and interstitial fluids markedly influence colloidal pressure, fluid retention, and edema (Mobarhan, 1988). Movement of fluid between blood vessels and interstitial fluid is controlled by a balance between hydrostatic and osmotic pressures (Staub, 1978). When both pressure and premeability are normal, the endothelial barrier restricts transfer of both fluids and solutes. Starling's (1896) equation as interpreted by Vestweber and Al-Ani (1983, 1984) shows fluid transfer from intravascular to interstitial spaces is controlled by changes in either hydrostatic pressure or vascular permeability.

Basic principals of edema formation have been reviewed by Vestweber and Al-Ani (1983). Decreased plasma colloidal pressure, increased capillary blood pressure, obstruction of lymphatic drainage, and retention of sodium and water were listed as basic causes of generalized edema. When increased capillary pressure or obstruction of lymphatic drainage are localized, edema may also be localized as in udder edema.

Hydrostatic pressure

Greater incidence and persistence of udder edema in first-calf heifers than in multiparous cows may result from the less well developed vascular circulation in heifers (Emery et al., 1969). Vascular changes occur rather abruptly during latter stages of a heifer's first pregnancy. Mammary blood flow increases at least three-fold during 2 wk before calving (Al-

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Ani and Vestweber, 1986). Vestweber and Al-Ani (1985) compared milk vein blood pressures in eight cows with udder edema and three control cows. Venous blood pressure increased between 2 wk prepartum and calving by approximately 35% in edematous cows but remained constant in cows without edema. At parturition, mammary blood flow of edematous cows averaged only 85% that of control cows. It seems reasonable that elevated arterial blood flow to the udder in association with decreased venous blood flow from the udder would elevate capillary hydrostatic pressure.

Osmotic pressure

Osmotic pressure resulting from the higher protein content of blood serum relative to interstitial fluid (Vestweber and Al-Ani, 1984) opposes hydrostatic pressure. Increased hydrostatic pressure without a corresponding change in osmotic pressure could increase interstitial fluid volume if additional fluid is not removed by the lymph system. In addition, increased permeability of the endothelial barrier resulting from some injury would render it less restrictive to both fluid and proteins. Decreased osmotic pressure due to a decrease in protein concentration in blood serum relative to interstitial fluid could allow hydrostatic pressure to move fluid into tissues. If accumulation of edematous fluid is determined by hydrostatic and osmotic pressures, increases in either pressure or vascular permeability could result in edema (Vestweber and Al-Ani, 1983, 1984).

Increased vascular permeability is considered more likely than increased hydrostatic pressure to elevate protein in interstitial fluid relative to serum (Staub, 1974). Therefore, relatively high serum to interstitial fluid ratios of protein in edematous cows has been considered as evidence for a lesser role for change in vascular permeability in development of udder edema (Vestweber and Al-Ani, 1984). Declines in serum protein between 2 wk prepartum and calving were similar for nine edematous and three non-edematous cows. Unfortunately, interstitial fluid for comparison with serum is available only for edematous cows.

Causes of edema

Although the exact cause of udder edema has not been identified, a number of physiological and management factors have been associated with its occurrence. Predisposition to edema may be inherited, decrease with increasing parity, and be more likely in older first-calf heifers. Excess prepartum intakes of energy, sodium, or potassium may also increase likelihood of edema. Research relative to these factors has been reviewed extensively (Al-Ani and Vestweber, 1986; Vestweber and Al-Ani, 1983) and will not be repeated here. Rather, we will propose an alternate hypothesis relating udder edema to oxidative stress.

Oxidative Stress

Partial reduction of oxygen during metabolism

Although oxygen is essential for aerobic life, it can be toxic under certain conditions. Animals do not use energy in feed directly for maintenance and productive purposes but first convert it into adenosine triphosphate (**ATP**) which releases energy as needed. The process has been compared with deposits into or withdrawals from a bank with ATP serving as the energy currency (Gutteridge and Halliwell, 1994). The ATP is produced by oxidative phosphorylation, a process driven by electrons derived from metabolism of feed.

Energy released from these electrons as they are transferred down a chain of enzymes in animal cells is used to generate ATP. At the end of the chain, spent electrons are combined with oxygen to form its completely reduced metabolite, water. Air-breathing animals have achieved great energetic efficiency by using oxygen to accept electrons in this manner.

Problems may arise when oxygen is not completely reduced to water. It has been estimated that 2 to 5% of the electrons may escape from intermediate carriers in the chain and partially reduce oxygen to a free radical, superoxide (Levine and Kidd, 1985). Other sources of superoxide (O_2-) include mechanisms which use oxygen to detoxify foreign substances in the body, other oxidative enzymes, and spontaneous nonenzymatic oxidation of biological molecules. Anything which increases metabolic rate or activity of oxidative enzymes could increase the number of electrons transferred and amount of oxygen consumed. Rapid growth, high milk production, or excessive exposure to aflatoxins, for example, could thus elevate generation of O_2-. Superoxide is reduced further to hydrogen peroxide (HOOH). Both O_2- and HOOH are unavoidable products of normal metabolic processes and are not always harmful if metabolized properly. Neither O_2- nor HOOH are sufficiently reactive by themselves to initiate peroxidative chains so damage by them is believed to result from their conversion into more reactive free radicals. It is in this conversion that catalytic transition elements, especially Fe, are believed to have harmful effects on oxidative metabolism (Gutteridge and Halliwell, 1994).

Role of iron in oxidative problems

The ability of Fe to transfer single electrons in controlled biological oxidations is essential for life as we know it, but it also gives Fe a pivotal role in harmful oxidative reactions. Iron normally is safely complexed in specific molecules which keep it away from the initial partially reduced oxygen metabolites, O_2- and HOOH. Release of catalytic Fe becomes more likely under conditions of dietary imbalance, trauma, or stress often accompanying calving (Madsen et al., 1990). Saturation of safe binding sites (Gutteridge and Quinlan, 1993) by excessive Fe intake may also contribute to the problem. When catalytic Fe comes in close proximity with O_2- and HOOH, O_2- reduces Fe^{+3} to Fe^{+2} which splits into a hydroxyl ion and an extremely reactive hydroxy radical (∃OH).

Generation of ∃OH causes two distinct types of damage depending on location (Gutteridge and Haliwell, 1994). When ∃OH is produced in blood plasma or elsewhere in the "free pool", it may become the focal point of peroxidative chains which can damage cellular and subcellular membranes. In contrast, catalytic Fe nonspecifically associated with an important molecule, such as an enzyme, may catalyze ∃OH which damages the molecule at the site where iron is located.

Defense against reactive forms of oxygen

Fortunately animals possess a remarkably efficient antioxidant system which protects them against reactive oxygen metabolites and their toxic products resulting directly or indirectly from catalytic Fe (Gutteridge and Halliwell, 1994). First, O_2- and HOOH are converted into forms which do not react with catalytic Fe by superoxide dismutase and glutathione peroxidase. Secondly, Fe is oxidized to less reactive forms by ceruloplasmin and complexed safely by transferrin and lactoferrin to prevent potential reactions with O_2- and HOOH which could produce ∃OH. Thirdly, important molecules may be protected against catalytic iron by Zn^{+2} which has an outer electron makeup similar to Fe^{+2} but is not involved in electron transfer (Bray and Bettger, 1990; Oteiza et al., 1995). Nothing is perfect, so despite the protective systems described above, some O_2- and HOOH may escape enzymatic control and some catalytic Fe may exist to generate ∃OH.

A fourth level of protection consists of molecules which terminate chain reactions. Protein, primarily albumin, may account for up to half of the total peroxyl radical quenching capacity of blood plasma (Wagner et al., 1987). Other radical quenchers include lipid soluble α-tocopherol, β-carotene, and retanoic acid and water soluble ascorbate, phenolics, and urate (Gutteridge and Halliwell, 1994; Machlin and Bendich, 1987). Fifthly, cytotoxic aldehydes produced when peroxidized lipids decompose are degraded by aldehyde dehydrogenases. An example is xanthine oxidase which also helps keep Fe in the less reactive ferric form (Emery, 1991), thereby conserving reducing equivalents, α-tocopherol, and other chain-breaking antioxidants.

Source of antioxidants

Endogenous production of transferrin, lactoferrin, ceruloplasmin, serum albumin, antioxidant enzymes, and glutathione is dependent on absorbed amino acids. An adequate supply of amino acids is dependent, in turn, on adequate amounts and appropriate balance of rumen degradable (nitrogen and sulfur) and escape protein with energy. Also of endogenous origin are ubiquonone and ascorbate for which the diet must supply fiberous and nonfiberous carbohydrates in adequate amounts and balance. The diet must supply vitamin A for immune function, α-tocopherol (vitamin E), and β-carotene as chain-breaking antioxidants, Cu, Zn, and Mn for superoxide dismutase, Se for glutathione peroxidase, Fe for catalase, Fe and Mo for xanthine dehydrogenase, Zn to displace catalytic Fe, and Mg and Zn to stabilize membranes and maintain cellular integrity.

Oxidative stress and disease

Pitzen (1993) has employed the prooxidant to antioxidant ratio (**PAR**) to minimize oxidative stress and related problems in dairy cows. The PAR increases when prooxidants such as Fe exceed antioxidants and cofactors such as vitamin E, β-carotene, Cu, Zn, Se, and Mn. Pitzen's (1993) approach is to lower prooxidant intake when possible, but when this is difficult, such as is often the case with Fe, it may be necessary to increase antioxidant concentrations to counteract the excessive prooxidant.

Involvement of oxidative stress in etiologies of certain disorders of dairy cattle is suggested by reductions in incidence of retained placenta (Harrison et al., 1984) and mastitis (Smith et al., 1984; Weiss et al., 1997) when the antioxidant nutrients vitamin E and Se are supplemented. Analysis of records from more than 61,000 cows suggests that udder edema may share common causes with retained placenta and mastitis (Gröhn et al., 1989). Our hypothesis is oxidative stress could increase severity of udder edema either directly by damage to membranes or indirectly by altering steroidogenesis.

Possible Association Between Oxidative Stress and Udder Edema

Oxidative stress and membrane damage

Reports that concentrations of protein and globulin in blood fall as cows near parturition (Larson and Hays, 1958; Larson and Kendall, 1957; Vestweber and Al-Ani, 1984) suggest the possibility that vascular permeability to proteins may have increased. Intravenous infusion of plasma proteins was effective in treating udder edema (Larson and Hays, 1958). These observations led Mueller et al. (1989) to investigate effectiveness of vitamin E, an important antioxidant in membranes, in reducing severity of udder edema in primigravid heifers. Forty heifers were fed fescue and orchard grass hay free choice plus 8 lb/day of commercial dairy concentrate. Beginning 6 wk before expected parturition and continuing daily until calving, half of the heifers were given 1000 IU of vitamin E as d-α-tocopheryl acetate by gelatin capsule. The remaining heifers served as a control. Concentrations of globulin and total proteins in serum were measured using materials and methods in commercial kits (Total Protein No. 540 and Total Globulin No. 560, Sigma Chemical Co., St. Louis, MO).

Calves remained with their dams for 24 hours. At the PM milking on 1, 3, 7 and 14 days after calves were removed, milk yield, edema score, and udder measurements were recorded. Each heifer was scored for edema prior to milking using a scale of 0 (no edema) to 4 (very severe edema) by a single evaluator. Udder floor areas were measured, before and after the PM milking to objectively quantify severity of edema. Sheets of paper were pressed against wet teat ends before and after milking (Seykora and McDaniel, 1986). Area of the quadrilateral defined by the four spots was determined by connecting two spots with a diagonal line from which perpendicular lines were drawn to each of the remaining two spots (Figure 1). The sum of the areas of the resulting four right triangles was then calculated. Percentage decrease in udder floor area after milking was then determined. It was assumed that the more rigid and edematous the udder, the less udder floor area would decrease with removal of milk.

Udder edema, as evaluated by less decrease in udder floor area after milking, tended to be less severe for vitamin E supplemented heifers than for controls (Table 1) during the first three measurements. Differences were statistically significant on day 3 (day 4 of lactation). Milk yields corresponding to udder measurements were higher for vitamin E supplemented compared with unsupplemented heifers on the first 3 days and tended to be higher on day 7 and 14. Daily milk yield for vitamin E supplemented vs unsupplemented heifers averaged 56.3 vs 46.4 lb ($P < .01$) through the first 12 wk of lactation. This suggests incomplete evacuation of edematous udders during the critical period of early lactation could be reflected in lower milk yield throughout lactation.

Serum total protein and globulin concentrations at parturition were lower in 14 heifers with mild to severe edema than in 26 heifers without edema (Table 2). This contrasts with an earlier comparison (Vestweber and Al-Ani, 1984) between nine edematous and three nonedematous cows in which these measurements did not differ. Lower concentrations of protein in serum of edematous heifers is in harmony with increased vascular permeability allowing protein to leak into interstitial spaces. This could reduce osmotic forces which oppose intravascular hydrostatic pressure and allow edematous fluid to accumulate.

Udder edema generally appears between 2 wk prepartum and calving during which period blood flow to the mammary gland increases three-fold (Al-Ani and Vestweber, 1986). We suggest the resulting increase in oxygen supply to the rapidly developing mammary gland over such a short period could produce a condition analagous to ischemia-reperfusion injury. Ischemia-reperfusion injury accompanies restoration of blood flow to a tissue following a reduction or blockage (Simpson et al., 1987). Tissue damage results not so much from oxygen deprivation during the blockage as from free-radical reactions caused by the surge of oxygenated blood following restoration of circulation. Neutrophils infiltrate tissues and, with xanthine oxidase stimulated by increased oxygen, produce O_2- and HOOH from which the potent inducers of lipid peroxidation, #OH radicals, are produced (Simpson et al., 1987). Peroxidation of polyunsaturated fatty acids in membranes compromises their integrity. A similar reaction accompanying increased blood flow to the mammary gland of heifers nearing parturition may contribute to edema.

Oxidative stress and altered steroidogenesis

All steroid hormones are derived from cholesterol by modifications produced by enzymes dependent on cytochrome P-450. Susceptibility of these steroidogenic enzymes to lipid peroxidation (Staats et al., 1988; Takayanagi et al., 1986) could alter synthesis of steroid hormones under oxidative stress. Hydroxylases specific to cytochrome P-450 appear to differ in their vulnerability to free radical attack. When adrenal microsomes were depleted of vitamin E in vitro, 17α-hydroxylase and 17,20-lyase were among the enzymes most sensitive to inactivation (Takayanagi et al., 1986). Fetal adrenal cortisol, which increases markedly preceding parturition (Casey et al., 1985), acts on the placenta to increase activities of 17α-hydroxylase and 17,20-lyase. The 17α-hydroxylase is necessary for cortisol synthesis, and 17α-hydroxylase and 17,20-lyase are required in both pathways leading to 17β-estradiol.

Although speculative at this point, unequal vulnerability of specific steroidogenic enzymes to oxidative stress could contribute to udder edema (Miller et al., 1993). Steroidogenesis proceeds by different pathways and inadequacy of a key enzyme for one pathway may misdirect the reaction (Bhagavan, 1978). For example, if 17α-hydroxylase and 17,20-lyase are damaged more than 21-hydroxylase (Takayanagi, 1986), adrenal lipid peroxidation can be more inhibitory of cortisol, androgen, and estrogen than of mineralocorticoid synthesis. A defect in synthesis of cortisol with the resultant increase in adrenocorticotropic hormone (ACTH) could also provoke overproduction of corticosterone and 11-deoxycorticosterone (Yanase et al., 1991). This could cause Na retention and expansion of blood volume.

Individuals afflicted with a recognized congenital deficiency of 17α-hydroxylase and 17,20-lyase become edematous but fail to develop sexually (Yanase et al., 1991). It seems reasonable that relative impairment of these enzymes by oxidative stress could contribute to formation of udder edema. In this connection, it is interesting that udder edema score was negatively correlated with plasma 17β-estradiol (Malven et al., 1983). Excess dietary K could aggravate the edema via the renin-angiotensin system by increased K excretion accompanied by Na and water retention (Sanders and Sanders, 1981).

We tested our hypothesis that oxidative stress may contribute to udder edema via alteration of steroidogenesis in a comparison with 38 periparturient heifers. The heifers were divided into two groups with udder edema either more severe or less severe than the average of all heifers on the basis of udder floor measurements as described previously. Blood plasma sampled at calving was assayed for antioxidant activity (Glazer, 1988), progesterone, 17β-estradiol, and corticosterone (Diagnostic Products Corp., Los Angeles, CA).

Relationships among udder edema, plasma antioxidant status, corticosterone, 17β-estradiol (E_2), and progesterone (P_4) were evaluated using odds ratios (Fletcher et al., 1988). Heifers with above average plasma antioxidant status were only 21% as likely as heifers below average in this measurement to develop above average udder edema (Table 3). Antioxidant status was not related to corticosterone, E_2, or P_4 in plasma. Ratios of corticosterone to E_2 or P_4 were then calculated individually for each heifer. Antioxidant status and corticosterone to P_4 ratio were not related. However, heifers with above average compared with below average antioxidant status were only 16% as likely to have an above average corticosterone to E_2 ratio. Heifers with an above average corticosterone to E_2 ratio were almost four times more likely to have udder edema (Table 3). It should be remembered that E_2, but not corticosterone or P_4, is dependent on 17α-hydroxylase and 17,20-lyase (Yanase et al., 1991), two enzymes among the ones most vulnerable to oxidative stress (Takayanagi et al., 1986). These results, therefore, provide indirect evidence in support of the concept that oxidative stress may contribute to udder edema through selective damage to steroidogenic enzymes.

Vitamin E and Zn as antioxidants

Fifty-six primigravid heifers, managed as described previously, were divided into seven blocks of eight animals according to expected calving date. Eight treatments were assigned randomly within block and given daily by gelatin capsule during the last 6 wk prepartum included all combinations of vitamin E, Zn, and Fe in a 2x2x2 factorial arrangement. Daily amounts of supplements were 1000 IU vitamin E from 2 g of d,lα-tocopheryl acetate; 800 mg of Zn, half from 4 g Zn methionine and half from 1.13 g $ZnSO_4$; and 12 g Fe from 60 g $FeSO_4{\bullet}7H_2O$. For 1100 lb heifers consuming 1.8% of body weight, these amounts of trace minerals would provide 90 ppm of Zn and 1300 ppm of Fe in dietary DM intake.

Decrease in udder floor area was measured as described previously. Blood plasma collected at calving was assayed for α-tocopherol (Hidiroglou, 1989) and unsaturated iron-binding capacity (**UIBC**) using materials and methods from a commercial kit (Sigma Diagnostics, St. Louis, MO).

Heifer groups were compared according to whether or not vitamin E or Zn were supplemented in the presence or absence of excess Fe (Figure 2). Severity of edema in each heifer was determined in relation to the average within a comparison. It was assumed a rigid, edematous udder would decrease in size after removal of milk less than a nonedematous udder. Smaller decreases in udder floor area thus represent increasing severity of udder edema. Strengths of associations among prooxidants

(Fe), antioxidants (Zn and vitamin E), plasma α-tocopheral, UIBC, and udder edema were calculated as odds ratios (Fletcher et al., 1988). Statistically significant odds ratios denote positive relationships when greater than one and negative relationships when less than one. Take, for example, two groups of heifers, one supplemented and the other unsupplemented with vitamin E. Within each group are heifers with udder edema more severe or less severe than the average. An odds ratio of 0.22 calculated from numbers of heifers in the four subgroups indicates supplemented heifers are only 22% as likely as unsupplemented heifers to have udder edema more severe than average.

When Fe was not excessive, heifers supplemented with vitamin E were only 19% as likely as unsupplemented heifers to have edema more severe than average (Figure 2). Supplemental Zn did not appear to reduce severity of udder edema when Fe was not excessive. In contrast, when Fe was excessive, vitamin E was ineffective in reducing severity of edema, but heifers supplemented with Zn were only 17% as likely to have greater than average severity of udder edema as unsupplemented heifers. When effects of supplemental vitamin E or Zn were compared regardless of Fe intake, severity of udder edema was reduced by vitamin E but not by Zn.

Supplemental vitamin E increased plasma α-tocopherol which in turn was associated with less severity of udder edema (Figure 2). Although dietary Fe level did not appear to be directly related to udder edema, it was negatively related to UIBC. This suggests greater Fe intake more completely saturated plasma Fe-binding sites leaving less available for binding additional Fe. Heifers with higher UIBC (more sites available to bind additional Fe) were only 30% as likely as heifers with below average UIBC to have udder edema.

Differing responses of udder edema to vitamin E or Zn may indicate different types of damage in presence or absence of excess Fe. When excessive, Fe may be more likely to become associated with sensitive sites on important molecules resulting in ∃OH generation and site specific damage. This type of damage differs from damage initiated by ∃OH generated in the free pool in that it is not prevented by ∃OH scavengers such as vitamin E. When Fe is not excessive, or if sensitive sites are occupied by a metal incapable of supporting ∃OH production, site-specific damage is less likely. In this case, vitamin E can terminate ∃OH generated in the free pool against which Zn is ineffective.

Site-specifically damaged molecules may initiate chain reactions which can be terminated by vitamin E, but the initial molecule is still damaged. Prevention of site-specific damage therefore would depend upon prevention of ∃OH generation at the site. Zinc, which is not involved in electron transfer, and has coordination flexibility should be ideal to compete with catalytic Fe at sensitive locations (Bray and Bettger, 1990). If changes in equilibrium between Zn and Fe are involved (Miller et al., 1996), then damage induced by catalytic Fe should be less likely if available Zn is adequate. Zinc does not interrupt free-radical chains, however, for which vitamin E is needed. Vitamin E and Zn thus compliment each other in antioxidant functions.

Implications

Research reviewed by Al-Ani and Vestweber (1986) and Vestweber and Al-Ani (1983) suggests management practices to minimize udder edema include limiting prepartum intakes of salt and high potassium feeds and avoiding excessive prepartum conditioning. Severity of udder edema may also be increased by prooxidants such as excess Fe but decreased by antioxidants such as vitamin E and Zn. Modern management practices may expose dairy cows to excessive proxidants so antioxidant requirements may be higher than generally recognized. Intakes of antioxidant nutrients sufficient to control prooxidant/antioxidant balance effectively may exceed amounts contained in average feedstuffs. Supplementation with all known nutrients required for antioxidant defense in adequate and balanced amounts would therefore be beneficial.

Protein and energy in optimum amounts to meet amino acid requirements for manufacture of Fe complexing agents and other endogenously produced antioxidants is of basic importance. Potential prooxidants including aflatoxins, pesticides, products of heat damaged feed, and excessive Fe and Mo should be avoided as much as possible. Finally, mineral and vitamin supplements are needed. Based on present knowledge for dairy cows, and under average conditions, 0.3 ppm Se, 20 ppm Cu, 60 ppm each of Zn and Mn, and 0.25% Mg in dietary DM plus at least 1000 IU/day of vitamin E appear to be adequate. Additional vitamin E may partially compensate for inadequacies of other antioxidants under some conditions, but cost effectiveness should be considered. Cellular oxidation/reduction balance may vary depending on environment, diet, disease, and other factors so it may be necessary to adjust amounts of these nutrients accordingly.

Summary

Udder edema is caused by excessive accumulation of fluid in extravascular spaces of the udder and surrounding tissues. Usual recommendations for minimizing the problem include avoidance of excessive salt, potassium, or body condition before calving. Increasing evidence suggests oxidative stress may also contribute to udder edema. Oxidative stress results when partially reduced metabolites of oxygen produced during normal metabolism and increased by prooxidants, such as excess dietary Fe, exceed the cow's antioxidant defense mechanisms. When reactive oxygen metabolites are not safely controlled, lipid peroxidation, damage to critical molecules, and ultimately disease conditions may result. Possible changes relative to udder edema include injury to membrane integrity or damage to specific steroidogenic enzymes, thereby altering synthesis of steroid hormones. Avoidance of potential prooxidants when possible and supplementation with all known nutrients required for antioxidant defense is thus important. Vitamin E, vitamin A, and β-carotene must be supplied by the diet whereas vitamin C and glutathione may be of endogenous or dietary origin. Most other antioxidant molecules are produced endogenously, but dietary nutrients essential for their manufacture include protein (N and S), energy, Cu, Zn, Mn, Se, and Mg. The Fe and Mo are also essential but can be prooxidants when present in excess amounts.

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Table 1. Milk yield at PM milking and decrease in udder floor area after milking in heifers supplemented or unsupplemented prepartum with vitamin E (Mueller et al., 1989).

	Udder shrink			Milk yield		
Day[1]	Control	Vitamin E	*P* > *F*	Control	Vitamin E	*P* > *F*
	(%)			(kg)		
1	14.7	22.9	0.10	3.6	6.9	0.02
2	19.0	24.5	0.16	4.7	8.4	0.01
3	16.0	24.4	0.02	6.0	8.2	0.01
7	24.4	26.6	0.57	7.8	9.7	0.10
14	38.4	39.2	0.86	10.3	12.3	0.08

[1]Day plus 1 equals day of lactation.

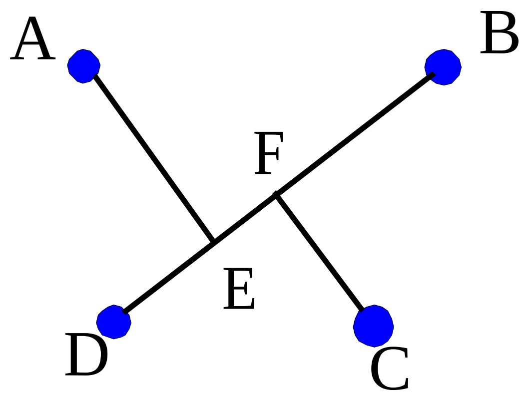
Table 2. Total protein and total globulin in serum of heifers with (score $\geq$ 1.0) or without (score $<$ 1.0) udder edema (Mueller et al., 1989).

	Udder edema		
	No	Yes	*P* > *F*
Number of heifers	26	14	
Total protein (g/dl)	6.58	6.11	0.001
Total globulin (g/dl)	3.20	3.03	0.03

Table 3. Odds ratios[a] describing relationships among steroid hormones and udder edema in periparturient heifers (J.K. Miller, Univ. of Tennessee; Unpublished).

	Plasma antioxidants	Udder edema
Udder edema	0.21[b]	----
Corticosterone (C)[c]	1.12	2.14
Estradiol (E_2)[d]	1.11	0.42
Progesterone (P_4)[c]	1.20	1.37
C/E_2 ratio	0.16[b]	3.89[b]
C/P_4 ratio	0.64	1.62

[a]If statistically significant, the relationship denoted by an odds ratio is positive if >1.0 and negative if <1.0.
[b]*$P < 0.05$.*
[c]Synthesized independently of 17α-hydroxylase or 17,20 lyase.
[d]Synthesis dependent on 17α-hydroxylase and 17,20 lyase.



Udder floor area =

$$\frac{(AE \times DE) + (AE \times EB) + (CF \times DF) + (CF \times EF)}{2}$$

Figure 1. Measurement of udder floor area. The four spots at A, B, C, and D represent spots resulting from lightly touching paper to wet teat ends.

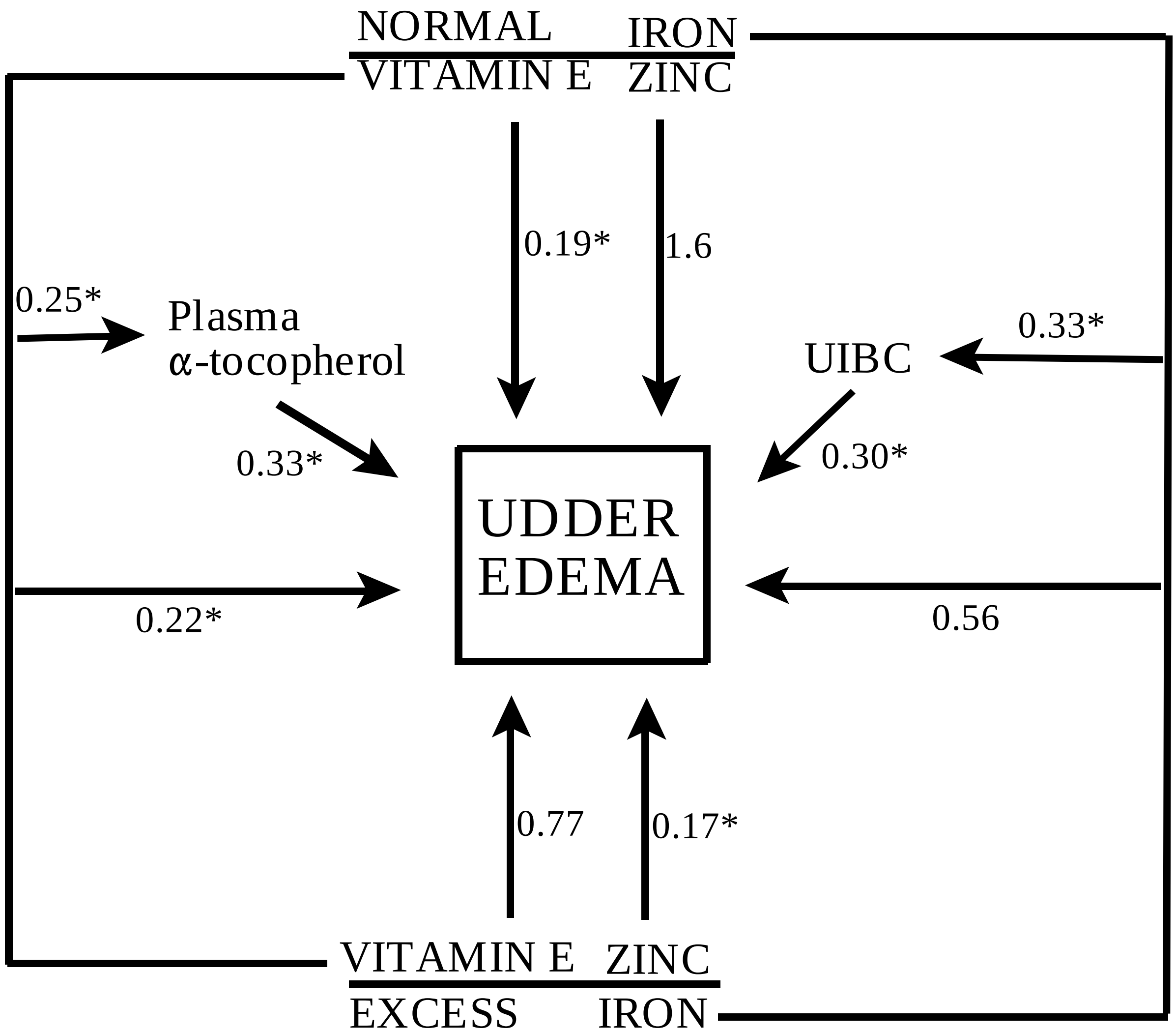


Figure 2. Odds ratios (**P* < *.05*) describing relationships among udder edema, intakes of Fe, Zn, and vitamin E, plasma α-tocopherol, and unsaturated iron-binding capacity (UIBC) in periparturient dairy heifers (J.K. Miller, Univ. of Tennessee; unpublished).

Dry Matter Intake of Dairy Cattle: Prediction, Performance and Profit

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Introduction

Feed intake is a fundamental aspect of nutrition since it sets the input of all nutrients, thus determining animal performance and farm profit. Improved milk yield of high producing dairy cows is limited primarily by the intake of energy. Elevated energy intake can only occur through increases in feed intake or substitution with high energy feedstuffs. The complexity of factors which control feed intake make it difficult to easily identify feed intake limits. However, certain feed, animal, management, and environmental factors are known to restrict intake, and understanding these factors will assist the on-farm nutritionist with opportunities to improve intake. Dairy cows will eat to physical fill or energy demand, which ever is first limiting. An understanding of the factors affecting feed intake make ration formulation, problem diagnosis, and profit projections more precise. Accurate measurement or prediction of feed intake for dairy cows is essential for the formulation of balanced economical diets, diagnosis of production losses, and projections of performance. Improved intake prediction equations which account for milk production, body weight (**BW**), ambient temperature, days in milk, pregnancy, and body weight change are available that enhance the prediction of feed intake for lactating dairy cows. The purpose of this paper is to review the factors that effect dry matter intake (**DMI**) and quantify the association with DMI prediction. A systematic method to diagnose and resolve DMI problems on a dairy farm is presented.

Feed Intake Prediction

Prediction equations for DMI of lactating dairy cows have been derived mostly by regression techniques applied to historical data. Common DMI prediction equations utilize BW and fat-corrected milk as variables in the prediction equations (Table 1; Fox et. al., 1992; Kertz et.al., 1991; NRC, 1989; VandeHaar et al, 1992). Body weight change, milk protein yield, dietary fat content, ambient temperature, and early lactation lag have been utilized in other equations to improve DMI prediction (Table 1; Roseler et al., 1997b; Weiss 1991). A modified NRC (1989) equation (Table 1) was identified to have good prediction precision when tested against research data (Roseler et. al., 1997a). However, early lactation DMI was overpredicted by this equation and underpredicted for cows in late lactation. A set of parity sensitive equations (Table 1; Equations 6 to 9) were developed which improved the prediction of DMI for high producing Holstein dairy cows fed

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energy dense rations (Roseler et al., 1997b). Equations 8 and 9 (Table 1) are easily applied at the farm since the inputs can be easily measured. These equations utilize a combination of calving BW, parity, total milk protein yield, and days in milk to predict DMI for a group of 30 or more same parity cows. These equations have been shown to be more robust and improve DMI prediction of high producing Holstein cows (Fuentes-Pila et al, 1996).

Feed Intake Prediction Precision

Accuracy of DMI prediction is very important in ration formulation. Equations 6 and 7 (Table 1) predicted within 3 to 8% of actual DMI for same parity high producing cows (Roseler et al., 1997b). The DMI prediction was within 1 to 2 lb of actual DMI for equations 8 and 9 (Table 1) when applied to a large New York commercial dairy farm where cows were grouped by parity (Figure 1). Actual on-farm DMI was measured in each group on two consecutive days each month for 12 months. Prediction precision was highest for mid and late lactation cows under thermal neutral conditions (Figure 1). The modified NRC equation (Equation 1, Table 1) had a systematic underprediction of DMI for the same group of cows (Figure 1).

A DMI equation that underpredicts actual DMI provides rations with excessive nutrient content and elevated costs. A DMI equation that overpredicts actual DMI provides rations that are nutrient deficient, resulting in reduced performance. The economic losses are high, whether from elevated feed costs or reduced performance, of imprecise DMI in the formulation of dairy rations. Therefore, the value of knowing DMI, whether predicted by equation or actually measured, is important economically. A four or eight percent under estimation of DMI on a group of 100 cows can cost from $420 to $510 per month on a 80 lb/day milk production level (Table 2). Under estimation results in losses from excess nutrient fortification. A four or eight percent over estimation of DMI on a group of 100 cows can cost from $390 to $1500 per month on a 80 lb/day milk production level (Table 2). The cost associated with over prediction of DMI is the potential loss in milk production. It is less costly to slightly under estimate DMI than over estimate DMI (Yungblut et al., 1981). This is especially critical for early lactation cows where reduced nutrient content will reduce total lactation yield.

Feed Intake Control

Feed intake in lactating dairy cows is controlled by the brain. A dairy cow's daily DMI is determined by meal frequency and amount consumed per meal. A host of sensory, hormonal, physical, and metabolic feedback stimuli to the brain determine the total daily DMI. A typical dairy cow will consume nine to twelve meals per day. A cow stops eating each meal through satiety signals to the brain. High producing dairy cows eat the same number of meals as lower producing cows, but the amount per meal is larger (Dado and Allen, 1995). Dairy cows spend about 5.5 hours/day eating ten meals, 8 hours/day ruminating, and 10.5 hours/day resting and other activities (Dado and Allen, 1995). Management or feeding activities that encourage an additional meal within the day or lengthens each meal will enhance DMI and performance.

Long term control

Although daily DMI is determined by meal size and frequency, it is also modified by long term feedback signals to the brain. Long term feed back signals that reduce DMI include excessive body condition (fat) score, physical fill restrictions (feed induced/pregnancy/internal fat), high environmental temperature, and ration energy density (Figure 6). These factors can be managed on most farms to assist in maximizing DMI, although several weeks or months may be required to adjust high body condition.

Cows will stop eating because they have met their energy requirements or have met a physical fill limit. Conrad et al. (1964) determined that the point at which the physical fill and energy requirement controls were determined in dairy cows was based upon a ration digestibility of 68%. A ration energy content above 68% digestibility (~ .68 Mcal/lb NE_L) reduced DMI but total caloric intake was constant. A ration energy content below this level reduced total intake through physical fill constraints.

Factors Effecting Feed Intake

The major factors that determine DMI and the amount of variance (relative importance) explained by each factor are milk yield (45%), feed and management (22%), BW (17%), climate (10%), and body condition score (6%) (Figure 2). The relative importance values were obtained from principal component analysis of a comprehensive database of 241 high-producing Holstein dairy cows (Roseler et al., 1997b).

Milk yield

The nutrient demand for milk production in early lactation is high. A common question is, "Does a high DMI drive milk production or does high milk production drive DMI?" A high DMI demand occurs as a result of the high nutrient demand. However, DMI in early lactation does not increase instantly due to the high nutrient demand. Body condition loss, compensatory organ changes, hormone changes, and physical fill limits cause DMI to rise slowly to where maximum DMI occurs after peak milk yield. Peak DMI occurs at 24 weeks (168 days) and 15 weeks (105 days) for primiparous and multiparous Holstein cows, respectively (Table 3). These values are higher than suggested by NRC (1989). Cows supplemented with bST will have higher DMI and the maximum DMI week occurs later at 33 weeks (231 days) and 20 weeks (140 days) after calving for primiparous and multiparous, respectively (Table 3). Dry matter intake peaks at approximately 6 weeks (42 days) and 10 weeks (70 days) after peak fat-corrected milk for multiparous and primiparous cows (Table 3). Based upon common DMI prediction equations, DMI will change 2.5 to 3.5 lb for every 10 lb of milk production.

Body weight

The energy required to maintain a lactating dairy cow with a 10% activity allowance is calculated as 80 kcal of NE_L per kilogram of metabolic BW ($BW^{0.75}$). Dry matter intake prediction equations utilize a percentage of BW to represent the basal DMI to meet energy maintenance requirements. Every 100 lb of BW will elevate DMI approximately 1 to 1.5 lb. High producing Holstein cows fed energy dense diets indicate DMI will rise only 0.5 lb/100 lb of BW, possibly due to physical limits of high producing cows (Roseler et. al., 1997b).

A maximum DMI limit of 1.0% of BW in forage NDF is used to predict maximum potential fill capacity when traditional forages are fed (Mertens, 1992). A minimum forage NDF level (0.7% of BW) will ensure adequate fiber in the diet to prevent rumen upsets. The relationship of forage NDF to BW will be modified by particle length, breed, mature body size, and byproduct roughage feeding (Mertens, 1992).

Body weight change

Body weight change is the accumulative sum of tissue growth, internal organ changes, changes or shifts in body composition (fat, protein, or water), and gut fill. Feed intake will increase with increases in tissue growth and gut fill. The level of DMI change with changes in body weight (correlation) varies depending upon parity. Primiparous dairy cows have more positive increases in DMI with changes in BW than multiparous cows (Table 4). Generally, DMI will increase +0.7 to +0.8 pounds for every 1 lb of daily gain (Table 1; Equations 6 and 7). The DMI equation of Weiss (1991) (Table 1, Equation 3) utilizes a DMI of 2.2 lb per pound of daily gain. The Spartan equation (Table 1, Equation 5) utilizes one pound of DMI per pound of daily gain.

Body condition score

Research in England (Garnsworthy and Topps, 1982) found that fat cows compared to thinner cows at parturition had a longer delay between peak milk yield and peak DMI and greater BW loss. The relationship of body condition score (**BCS**) with DMI varies with parity and stage of lactation. Mature cows have a greater decrease in DMI with higher BCS at calving than first lactation cows (Table 4; Roseler et al., 1997b). Based upon regression analysis, mature Holstein dairy cows calving with a BCS above a 3.75 would expect to have a daily depression of DMI of approximately 1.5 to 2.0% (0.7 to 0.9 lb) for each one-quarter BCS above 3.75 (Roseler et.al, 1997b). Therefore, a group of cows with a BCS of 4.5 at calving would be expected to have 2.1 to 2.7 lb (46 lb x 1.75% x 3 units) less DMI per day than cows with BCS of 3.75 or less. The BCS cutoff of 3.75 is an arbitrary delineation extrapolated from regression analysis and previous research (Garnsworthy and Topps, 1982). Obese cows will also have a slower rise in DMI (Garnsworthy and Topps, 1982). The days in milk section will describe a DMI lag to account for obese cows that have slow DMI increases in early lactation.

Environment

Effective ambient temperature is the ambient temperature modified by humidity, solar radiation, and wind. Feed intake will begin to increase when temperatures drop below 40°F and begin to decline above 75°F (NRC, 1981). A temperature humidity index chart has been developed to indicate the various stress levels of lactating dairy cows, but DMI is not quantified (Figure 3). The relationship of temperature, humidity, and night cooling to DMI in lactating dairy cows has been quantified (Table 5; Roseler et al., 1997b). Night cooling will modify the negative effects of high temperature and humidity. The intake adjustment factors in Table 5 can be applied to DMI prediction equations and will describe the long term relationship of humidity, ambient temperature, and night cooling.

The effect of short term environmental changes are difficult to predict. Dairy cows not adapted to hot weather and exposed to short periods (1 to 3 days) of environmental heat stress will have greater losses in DMI than predicted from the values in Table 5. Beef cows require from 4 to 21 days to adapt to a thermal change (Senft and Rittenhouse, 1985), and dairy cattle would have similar adaptation times depending upon effectiveness of housing and ventilation design.

Monthly temperatures and humidity can be used to adjust DMI. The correlation of DMI with temperature and humidity is similar for current weekly temperature and previous monthly ambient temperature (Table 6). Based upon this relationship, previous month temperature values can be used to adjust DMI for effects of environement (Table 5).

Cold environmental temperature will increase DMI by 1 to 1.3% (Table 5). Cold temperatures have been shown to increase rate of feed passage, reduce digestibility, and increase DMI (Kennedy and Milligan, 1978; NRC, 1981). The effect of cold stress is less variable in cows housed in enclosed freestall barns. Wind exposure and wet, dirty hair coat will increase maintenance requirements, and subsequent DMI can increase up to 15% (Fox et al., 1988).

Light intensity and hours of light can alter milk yield and DMI. Dairy cows exposed to 18 hours of light per day compared to a typical winter day of < 13 hours had 4.6 lb more milk per day (Dahl et al., 1997). The longer light period induced alterations in insulin-like growth factor (IGF) hormonal status. Feed intake was the same for both light treatments in this 4 month study.

Days in milk

A systematic overprediction of DMI for cows in early lactation is characteristic of many prediction equations. The time lag between maximum daily milk output and peak DMI differs by parity (Table 3). The time from calving to peak milk will change based upon parity, cow health, management, and transition feeding. Standard lactation adjustment factors utilize days in milk to adjust early lactation DMI (Tables 1 and 7; Equations 3, 5 to 9). An early lactation adjustment factor was developed using days in milk and time of peak milk to improve DMI prediction of post fresh cows. The time (month) of peak milk can be easily obtained from historical milk production records on the farm. If previous records are unavailable, then the second month can be utilized as the default. This default intake lag adjustment is similar to other DMI adjustment factors (Table 7) but has been shown to be more precise and robust (Fuentes-Pila et al., 1996). The adjustable lag proposed by Roseler et al. (1997) will improve DMI prediction of post fresh groups where a rapid increase in milk production (peak at week 1 to 4) or a delay in peak yield occurs (peak at week 9 to 12). A slow rise in DMI may indicate problems associated with metabolic or health problems or obese cows (BCS > 4.0) that have a slower rise in DMI.

Feed

High NDF, low energy rations will have reduced DMI through the filling effect of the diet. Conversely, low NDF, high energy rations will regulate DMI to the point of meeting energy demands. The best ration NDF will optimize DMI at the most economical inputs.

Maximum NDF constraints are established to meet milk yield and growth requirements. The maximum NDF requirement for mid and late lactation cows is 1.1% of BW (Mertens, 1992). Early lactation mature cows (10 & 60 DIM) will have lower NDF/BW capacity (0.87% to 1.0% BW) as will first lactation cows (0.78% to 0.90%) (Mertens, 1992).

Minimum NDF ration levels are used for balancing high milk production or when inexpensive grains and byproducts are available or both. Adequate levels of effective NDF (**eNDF**) are essential in dairy cattle diets for maintaining proper rumination, rumen pH, DMI, and health. To maintain adequate DMI, minimum NDF rations should contain 65% to 75% NDF from long or coarsely chopped forage, contain at least 25% total NDF, provide supplemental buffer, and contain some high-fiber concentrate feedstuffs. When minimum NDF rations are fed, the on-farm nutritionist should establish a routine monitor for milk fat percentage, chewing activity, manure consistency, feed bunk refusal consistency, group DMI, and bulk tank fluctuation. Whole herd bulk tank fluctuations greater that 3 to 4 lb per cow per day calculated from a 7 day (weekly) rolling average may indicate a herd DMI problem. Mertens (1997) has proposed a system for measuring feeds and determining cow requirements for eNDF and physical effective (**peNDF**). Quantification eNDF and peNDF will assist the on-farm feed specialist in formulating minimum NDF rations to achieve optimal performance and DMI.

Byproducts

The use of high fiber concentrates and byproducts with less traditional forage sources requires a formulation system that accounts for not only NDF levels but also non structural carbohydrate (**NSC**) or total rumen available carbohydrate™. The fractional components of NDF and NSC from various byproducts, forages, and grains will have different digestion rates which can be used in various combinations to formulate rations for optimal rumen fermentation and maximum DMI. Proper rumen carbohydrate balancing maximizes rumen carbohydrate digestion, stabilizes pH, and improves DMI. Compensatory intake gains do occur in growing beef cattle (Forbes 1986) and also occur in dairy cattle fed high forage byproduct sources. These DMI increases cannot be explained by the traditional 1.0% forage NDF limits since intake will exceed these levels. Research with forage byproducts has indicated mixed production results possibly due to diet formulation (Armentano, 1997; Harmison et al., 1997). Field observations on 10 herds (~1200 cows) in the midwest indicate production (+6 to 8 lb milk/cow/day) and DMI advantages (+2 to 3 lb/cow/day) to feeding high fiber byproducts when formulated properly. Several of these herds have been feeding up to 75% of the total DMI as forage substitute for over one year with no losses in health or production. Health and production losses occur when lack of effective NDF, total starch level and minerals are not balanced in byproduct diets.

Protein

Optimal levels of soluble, degradable and peptide protein in the rations of lactating dairy cows will enhance rumen fiber digestion and optimize DMI. Deficient levels of rumen available protein™ will decrease fiber digestion and reduce DMI. Excessive levels of dietary protein decreases energy efficiency through excess urea synthesis and may reduce DMI through ammonia toxicity or blood amino acid imbalances or both (Harper, 1956). Excess dietary urea may reduce DMI either through palatability or ammonia level (Oelberg, 1985). Formulation of ideal patterns (no excess and no deficiency) of duodenal amino acids for cattle may provide for improvements in DMI in dairy cattle.

Water

Water restriction whether through limited availability or poor water quality will reduce DMI. Dairy cows will consume up to 30% of the daily water requirement within the first hour after leaving the milking parlor. Each group of cows should have a minimum of 4 linear feet of water space per 20 cows and a minimum of two water tanks in two locations per group. High sulfate or sodium, or excessive hard water, can reduce water consumption and DMI (NRC, 1989). Commercial water softeners can improve water quality where minerals levels are high.

Expected water consumption can be calculated for dairy cows using the following equations (Beede, 1992):

Total water intake (lb/day) = .90 x milk yield (lb/day) + 1.58 x DMI (lb/day) + 0.11 x (sodium intake, g/day) + 2.64 x (0 F/1.8 - 17.778, average minimum temperature) + 35.25

Drinking water intake (lb/day) = Total water intake - ration water intake

Fat

Supplemental fat feeding has indicated variable DMI responses when fed in the diets of lactating dairy cows. Stable or increased DMI with added dietary fat elevates caloric intake and is beneficial. Depressions in DMI with fat feeding are the result of altering physical fill effects of the cow or increasing total energy density of the diet. Excessive levels of unsaturated vegetable fats can lead to reduced fiber digestion, reduced microbial protein, reduced foregut stasis and reduced DMI (Pantoja et al., 1996; Smith et al., 1993). Rumen protected fats fed to high producing cows have shown no change in DMI (Macleod et al., 1977) or reduced DMI (Chouinard et al., 1997). Rumen protected fats will not reduce DMI as a result of altered rumen fiber digestion since they are inactive in the rumen.

Minerals

Sulfur levels in excess of 0.35% of dietary DM can reduce DMI (NRC, 1989). Water containing high sulfate levels can reduce DMI through reducing total water consumption. High silica, dirt, or ash consumption can reduce intake through reducing feed passage rate and decreasing physical fill capacity.

Silage

Total ration moisture concentration above 50% will reduce intake (Chase, 1979). The mechanism for this reduction has been attributed to water based compounds which reduce palatability. High moisture silages are prone to clostridial fermentation which will contain silage amines, putrescene, butyric acid, and ammonia. Water added to a total mixed ration (**TMR)** just prior to feeding reduced DMI as a result of reduced palatability and increased sorting (Lahr et al., 1983). No depression in DMI was observed in a TMR of up to 65% moisture when the water was added to the concentrate portion of the TMR 24 hours prior to feeding (Robinson et. al., 1990).

Additives

Molasses products may enhance poor quality feedstuffs and improve DMI. When cows were provided a choice of a 1.5% sugar added TMR (treated) or nontreated TMR, they preferred the treated, but when cows were fed without sugar, DMI was not different (Murphy et al., 1997). Yeasts, probiotics, and microbial additives may enhance DMI of cattle fed under stressed conditions. Feed intake response to microbial additives by lactating dairy cattle is variable depending upon the ration, environment, animal health, and previous performance. Niacin has been indicated to improve DMI of heat stressed cattle (Di Constanzo et al., 1997). Ionophores fed to beef cattle on high grain diets have reduced DMI and adapted dairy cattle on high energy diets have indicated a reduction in DMI (Ramanzin et al., 1997). Cattle not adapted to monensin may respond with a rapid transient DMI depression.

Molds

Feed contaminated with mold toxins may reduce DMI if present in the diet of dairy cows at sufficient quantities. Aflatoxin is a potent toxin (> 50 ppb) and at low levels can cause diahhrea, reduce DMI, and cause irreversible liver damage. Vomitoxin (DON) must be present in higher levels (> 500 ppb) to reduce DMI in dairy cattle (Whitlow and Hagler, 1997). The degree of DMI loss is a function of toxin level and time of exposure. Bentonite clays added directly to the suspect feed can have specific binding capacity for aflatoxin in reducing negative DMI effects.

Social

Management, as well as social and psychogenic factors, can reduce maximum DMI (Forbes, 1986). These factors are difficult to quantify for intake prediction purposes. The on-farm nutrition specialist must be aware of the negative implications that these social and management factors have on DMI. These factors are especially critical for first lactation cows and group changes in transition and early lactation. The effect of separating first lactation cows from mature herdmates and feeding them in a separate group was evaluated in three herds. First lactation cows fed in a separate group spent 10 to 15% more time eating, consumed 0.5 to 2.0 more meals per day, increased DMI by up to 20%, and milk yield increased 5 to 10% over herdmates grouped with mature cows (Krohn and Konggaard, 1979).

Health / Management

Disease conditions such as ketosis and milk fever are accompanied by DMI reductions. Mastitis, metritis, pneumonia, and other fever induced infections will reduce DMI. Field observations indicate that when an entire herd is vaccinated, a transient 2 to 3 day DMI reduction of up to 15% to 25% can follow. Proper ration NDF, feed access, and nutrient levels are important when a whole group or herd vaccination is initiated.

Total mixed rations and frequent feeding can enhance DMI through more consistent rumen fermentation. Alterations in daily meal patterns and meal size can alter total daily DMI through rumen pH fluctuations, blood NEFA levels, and hormone levels. Continous access to a fresh TMR will enhance more frequent, consistent meal patterns throughout the day and enhance DMI.

Grouping Cows Based Upon DMI

Accurate DMI and proper grouping of cows provides for more precise ration formulation, lower feed costs, and better performance. The relationship of DMI to milk yield has a large effect on grouping cows by ration nutrient density. Grouping cows on nutrient density (energy and protein), partitions cows into categories; high producing mature cows (1500 lb BW) and small first calf heifers (1100 lb BW) with moderate milk yield have similar nutrient density requirements. Since first lactation cows have a slower rise in DMI, days in milk needs to be considered in grouping cows. Feed intake peaks later and increases more slowly for first lactation cows in early lactation than mature cows (Table 3). A separate first lactation heifer group could be justified based upon stage of lactation (Grant and Albright, 1997).

Transition Cows

Feed intake of prefresh cows is depressed (Bertics et al., 1992) and extremely variable (Figure 4). Figure 4 represents data from individual cows fed a TMR. Feed intake will be lower for pre-calving heifers (open circles in Figure 4) compared to multiparous cows. Heifers should be maintained on a higher nutrient density of energy and protein to meet recommended requirements. The Spartan version 2 (1992) ration program utilizes a percent BW to predict DMI of dry and prefresh cows. Predicted DMI (Spartan, 1992) is calculated as:

DMI (lb/day) = 2.0% x BW x A + B x ADG (lb/day), where

A = days till fresh. If A < 60 then A = .75 + .25 x days till fresh/60,

If A > 59 then A = 1, and B = 1 if average daily gain (ADG) > 0, else B = 0.

This equation was used to evaluate a group of 21 mature and 14 first lactation Holstein cows (Figure 4) where DMI was measured daily and BW was recorded at two week intervals. The prediction of DMI using the above equation explained 59% of the variation in actual DMI (Figure 5). The solid squares in Figure 5 represent the predicted versus actual DMI with the open circles and plus symbol representing the individual bias (predicted - actual). The equation over predicted DMI for pre-calving (first-lactation) heifers by about 50% (5 to 10 lb). The Holstein heifers used in this study were well framed, with average BW in the precalving period of 1370 lb (range 1120 to 1510 lb). Pre calving heifers do not have the same body capacity as multiparous cows and using the same percentage of BW as a mature cow is not accurate. Adjusting the Spartan equation (1992) to 1.4% of BW as DMI for first calving cows improved the DMI prediction and improved the variance explained to 72%.

Problem Solving

The on-farm nutritionist is often plagued with challenges to improve DMI. Because many factors alter DMI, a systematic approach to analyzing DMI depressions is helpful. A schematic feed intake model (Figure 6) provides a structure for categorizing factors that alter DMI of dairy cows. The schematic can be useful in identifying constraints to maximum DMI on the farm and for diagnosing the "weak link" or bottleneck to optimum performance. The on-farm consultant can utilize the schematic to progressively evaluate the various feed, animal, management, and environmental factors that alter DMI. Accurate assessment and diagnosis of dairy herd DMI fluctuations and losses improve the accuracy of corrective recommendations.

Summary

Accurate measurement and monitoring of DMI for lactating dairy cows is very important for economical, balanced rations. The excess feed cost or potential milk yield losses to inaccurate DMI is high. Maximum DMI can be attained through proper management of BCS, hot temperatures, lighting, ration NDF level and type, diet protein quality, water quality and quantity, silage quality, ration mineral levels, spoilage and feedstuff quality, metabolic disease, cow grouping, and group changes. These factors can be to provide optimal DMI for maximum economic returns on the dairy farm.

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Table 1. Common feed intake prediction equations for lactating dairy cows[1].

Equation/Source		Equation
1	NRC, 1989	DMI (lb/d) = [-.293 + .372 x (FCM(lb/d)/2.2) + 0.0968 x (BW(lb)/2.2)^.75]
2	Kertz et al., 1991	if DIM < 154 DMI (kg/d) = .008037 x BW (kg) + .3134 x FCM (kg/d) + .2286 x DIM - 0.002176 x DIM^2 + 0.00000705 x DIM^3
3	Weiss, 1991	DMI (kg/d) = .011 x BW (kg) + $\left\{ \frac{2 \times (0.08 \times BW(kg)^{.75} + 0.74 \times FCM + 5 \times BWC)}{(4.1 + 0.1 \times EE)} \right\}$ Early lactation adjustment = 0.67 + 0.0972 x (4.04 x log (WIM) - 0.095 x WIM + 0.095) (see Table 7)
4	CNCPS (Fox et al., 1992)	DMI (kg/d) = 0.0185 x BW(kg) + .305 x FCM (kg/d)
5	VandeHaar et al., 1992	DMI (lb/d) = A x 0.02 x BW(lb) + 0.3 x FCM (lb/d) + B x ADG (lb/d) A = Early lactation adjustment = (1 - .2 x (80 - DIM)/80) B = 1.0 if ADG is positive, 0 if gain is negative (see Table 7)
6	Roseler et al., 1997b	(Primiparous cows) DMI (kg/d) = (3.7 + 0.012 x BW(kg) + 0.12 x BW change (kg/wk) + 12.2 x milk protein (kg/d) - 0.011 x days pregnant) x Lag[2] x Temperature Adjust[3]
7	Roseler et al., 1997b	(Multiparous cows) DMI (kg/d) = (0.6 + 0.005 x BW (kg) + 0.11 x BW change (kg/wk) + 10.4 x milk protein (kg/d) - 0.013 x days pregnant - 0.17 x wk of lactation + 4.59 x log e wk of lactation) x Temperature Adjust[3]
8	Roseler et al., 1997b	(Primiparous cows - simple) DMI (kg/d) = [4.6 + 0.011 x calving BW (kg) + 12.4 x milk protein (kg/d)] x Lag[2] x Temperature Adjust[3]
9	Roseler et al., 1997b	(Multiparous cows – simple) DMI (kg/d) = [8.4 + 0.006 x calving BW (kg) + 12.2 x milk protein (kg/d)] x Lag[2] x Temperature Adjust[3]

[1]DMI = dry matter intake, FCM = fat-corrected milk, BW = body weight, DIM = days in milk, BWC = body weight change, EE = ether extract, WIM = week of lactation, ADG = average daily gain, and CNCPS = Cornell Net Carbohydrate and Protein System.

[2]Lag = 1 - $e^{-[(0.564 - 0.124 \times \text{peak milk month}) \times (\text{wk of lactation} \times P)]}$, where factor for peak milk worth (P) equals 2.36 when peak milk occurs during the first or second month of lactation and equals 3.67 for the third month of lactation.

[3]Temperature Adjust (see Table 5).

Table 2. Economic impact of dry matter intake accuracy in the formulation of dairy cattle rations for 80 lb/day of milk production.

80# GROUP		Dry Matter Intake Estimation Accuracy				
Measure		+8%	+4%	**ACTUAL**	- 4%	-8%
DMI for ration formulation, (lb/day)	A	50.5	48.9	47.0	45.1	43.2
Ration cost, $/cwt DM	B	$6.47	$6.80	$7.10	$7.55	$7.95
Ration NE_L, Mcal/lb DM	C	.71	.735	.76	.78	.82
Crude protein, % of DM	D	16.0	16.9	17.4	17.9	18.7
Actual feed intake, lb/day[a]	E	47	47	47	46	44
Feed cost, $/cow/day	F (B/100) x E	$3.04	$3.19	$3.33	$3.47	$3.50
Potential milk change from BASE [b], lb/day	G	- 6.3	- 2.1	BASE (80 lb)	0	0
Predicted milk, lb/cow/day	H BASE - change	73.7	77.9	80	80	80
IOFC [c]	H x milk $ - F	$6.17	$6.54	$6.67	$6.53	$6.50
Change from base ($/cow/day) [d]	I	-$0.50	-$0.13	BASE	-$0.14	-$0.17
Change from base ($/100 cow/month) [e]		**-$1500**	**-$390**	0	**-$420**	**-$510**

a) Actual feed intake is what cows would actually eat. A more energy dense diet will result in less consumption.
b) Potential milk is calculated based upon the maximum level of milk from total crude protein intake.
c) Income over feed cost. Based on $12.50/cwt for milk.
d) Base IOFC - row IOFC.
e) Row I x 100 cows x 30 days per month.

Table 3. Week of maximum milk yield and dry matter intake by parity for dairy cows with and without bst[a].

	Milk Yield Peak Week	DMI Peak Week	Milk Yield Peak Week	DMI Peak Week
Lactation #	------No bST--------		--------bST[b]---------	
Primiparous[c]	**15** (3-38)	**24** (7-46)	21 (3-49)	33 (10-55)
Multiparous[c]	**9** (2-38)	**15** (6-27)	13 (1-41)	20 (5-57)

a) 241 cows from 4 locations, freestall housing (Roseler et al., 1997b).
b) bST initiated at 60 DIM.
c) Values in parenthesis are minimum and maximum values.

Table 4. Correlation[a] of dry matter intake with body weight, body weight change and body condition score by parity (Roseler et al., 1997b).

	Body Weight (lb)				Body Condition Score[d]	
Lactation #	Weekly	Calving	Weekly BW Change	Lactation BW Change[b]	Weekly	Calving
Primiparous	0.37	**0.38**	0.17	0.02[c]	**-0.15**	**-0.11**
Multiparous	-0.05	**0.27**	0.07	-0.41	**-0.35**	**-0.14**

a) All correlation coefficients are significant (P < 0.10) unless otherwise noted.
b) Lactation BW change = BW at end of lactation minus BW at calving.
c) Not significant
d) Body condition score (1 to 5 units)

Table 5. Relationship of dry matter intake with ambient temperature and adjustments for humidity and night cooling for lactating dairy cows.

	-----Description of climate category------				**Intake Adjustment (%)**	
			Night Cooling [a]		----Lactation -----	
Climate Category	Basal Temp. (°F)	Relative Humidity (%)	Y or N	Minimum Temp. (°F) [b]	First	Second+
Cold	< 40	0 - 100	N/A [c]	--	**+ 1.0%**	**+ 1.3**
Thermal Neutral with Night Cooling	40 - 75	0 - 100	YES	if < 40 (2 days) [b]	N/C [d]	N/C [d]
Thermal Neutral without Night Cooling & Low Humidity	40 - 75	< 65	NO	if > 40	**- 1.0%**	**- 1.3%**
Thermal Neutral without Night Cooling & High Humidity	40 - 75	66 - 100	NO	if > 40	**- 3.0%**	**- 3.5%**
Hot - with Night Cooling & Low Humidity	> 75	< 65	YES	if < 50 (2days) [b]	**- 1.0%**	**- 1.3%**
Hot - without Night Cooling & Low Humidity	> 75	< 65	NO	if > 50	**- 2.5%**	**- 3.0%**
Hot - with Night Cooling & High Humidity	> 75	> 65	YES	if < 50 (2 days) [b]	**- 4.0%**	**- 4.3%**
Hot - without Night Cooling & High Humidity	> 75	> 65	NO	if > 50	**- 10.5%**	**-14.0%**

a) If minimum temperature is < 40°F for a minimum of 2 consecutive days within one week, then night cooling is determined to be present.
b) A minimum temperature thermometer can be used to determine the frequency of minimum temperature on a commercial dairy farm.
c) Not applicable. Night cooling is not a factor when ambient temperature is cold.
d) No change in feed intake from predicted values with thermal neutral temperature and night cooling.

Table 6. Correlation of current weekly ambient temperature, ambient temperature of the previous month and relative humidity with dry matter intake (Roseler et al., 1997b).

	Climate Measurement Period	Mean Temperature	Relative Humidity
Dry matter intake, lb	Current week[a]	**-0.20**	**-0.10**
Dry matter intake, lb	Previous month[b]	**-0.21**	**-0.11**

a) Correlations in this row are the association of DMI of the current week with temperature and humidity of the current week.
b) Correlations in this row are the association of DMI of the current week with temperature and humidity of the previous month.

Table 7. Early lactation adjustment values from three sources for correcting feed intake prediction in early lactation[1].

	---------------EQUATION SOURCE--------------				
Week of Lactation	--------ONE[a]--------			TWO[b]	THREE[c]
	Peak Milk Month				
	First	Second	Third		
1	.77	**.65**	.59	.80	**.67**
2	.85	**.75**	.66	.82	**.78**
3	.90	**.81**	.72	.84	**.84**
4	.94	**.87**	.77	.86	**.88**
5	.96	**.90**	.81	.88	**.91**
6	.97	**.92**	.84	.90	**.93**
7	.99	**.95**	.87	.91	**.95**
8	1.0	**.96**	.89	.93	**.96**
9	1.0	**.97**	.91	.95	**.97**
10	1.0	**.98**	.93	**.97**	**.98**
11	1.0	**.98**	.94	**.98**	**.99**
12	1.0	**.99**	.95	**1.0**	**.99**
13	1.0	**.99**	.96	**1.0**	**1.0**
14	1.0	1.0	.97	1.0	1.0
15	1.0	1.0	.98	1.0	1.0
16	1.0	1.0	.99	1.0	1.0

[1]Values bolded indicate similar adjustment values.

a) Equations from Roseler et al., 1997b.

b) Equation from VandeHaar et al., 1992.

c) Equation from Weiss, 1991.

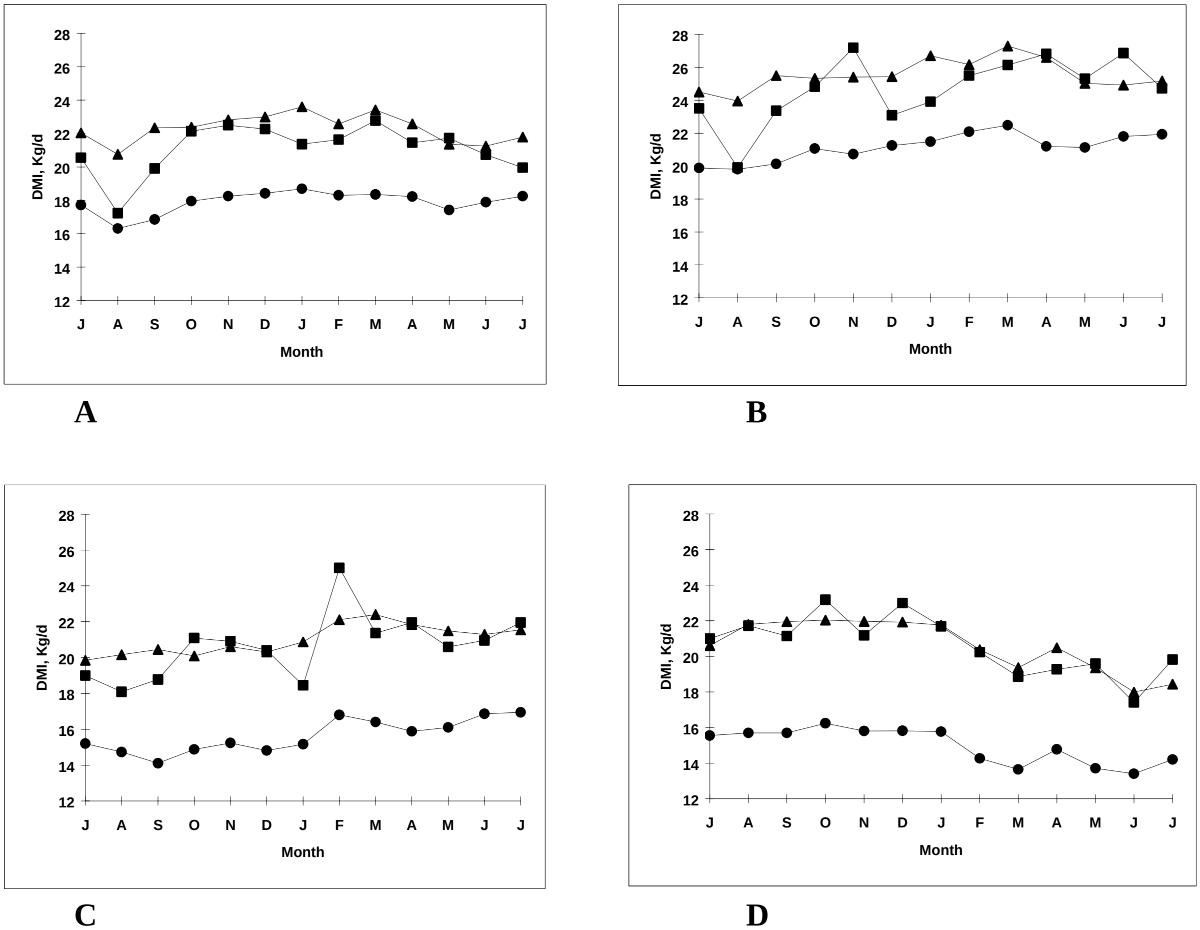
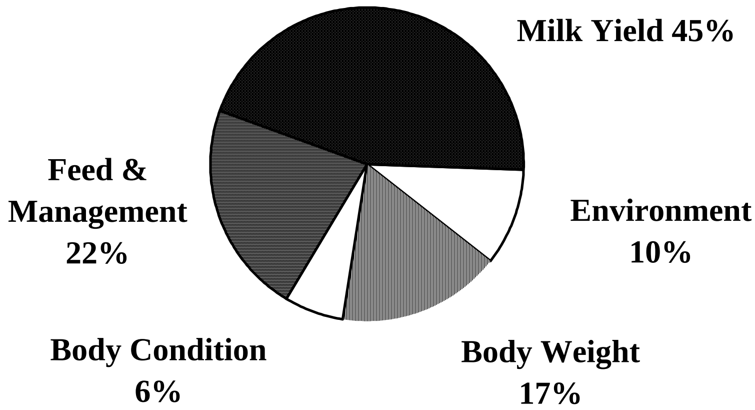


Figure 1. Relationship of monthly group DMI from a commercial dairy farm of 250 cows (squares) and the predicted DMI from NRC-equation 1-Table 1 (circle) and equation 8 and 9-Table 1 (triangle). Panel A, first calf heifers in early lactation. Panel B, in early lactation. Panel C, mature cows in midlactation. Panel D, first calf and mature cows in late lactation. Roseler et al., 1997.

Figure 2. Factors Effecting Dry Matter Intake
of Lactating Dairy Cows and Relative Importance



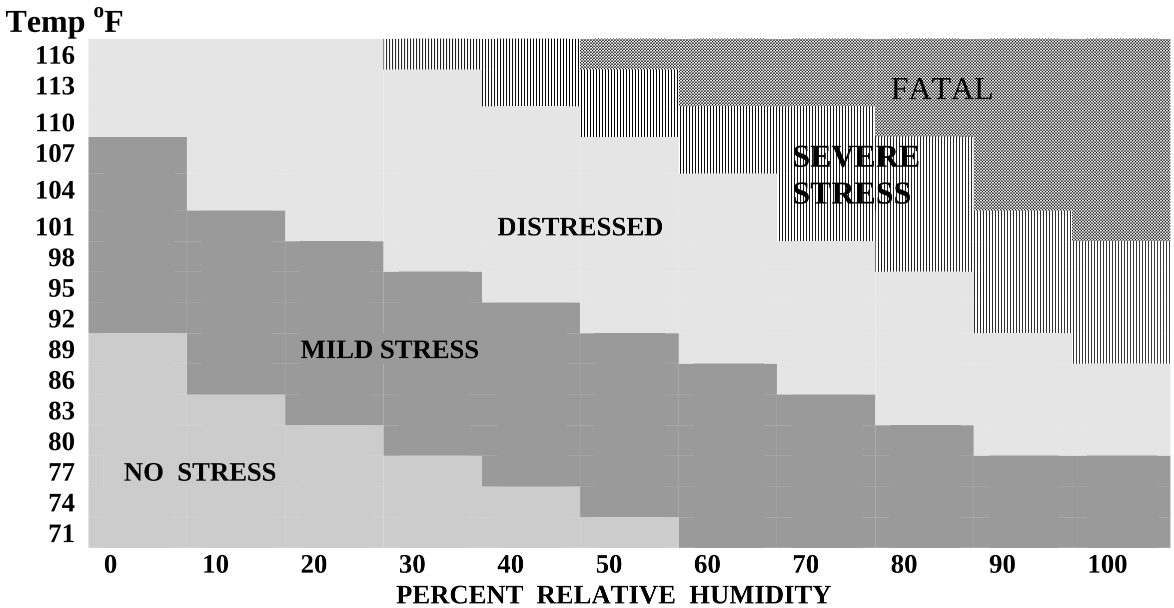


Figure 3. Relationship of temperature and humidity on stress levels of lactating dairy cows.

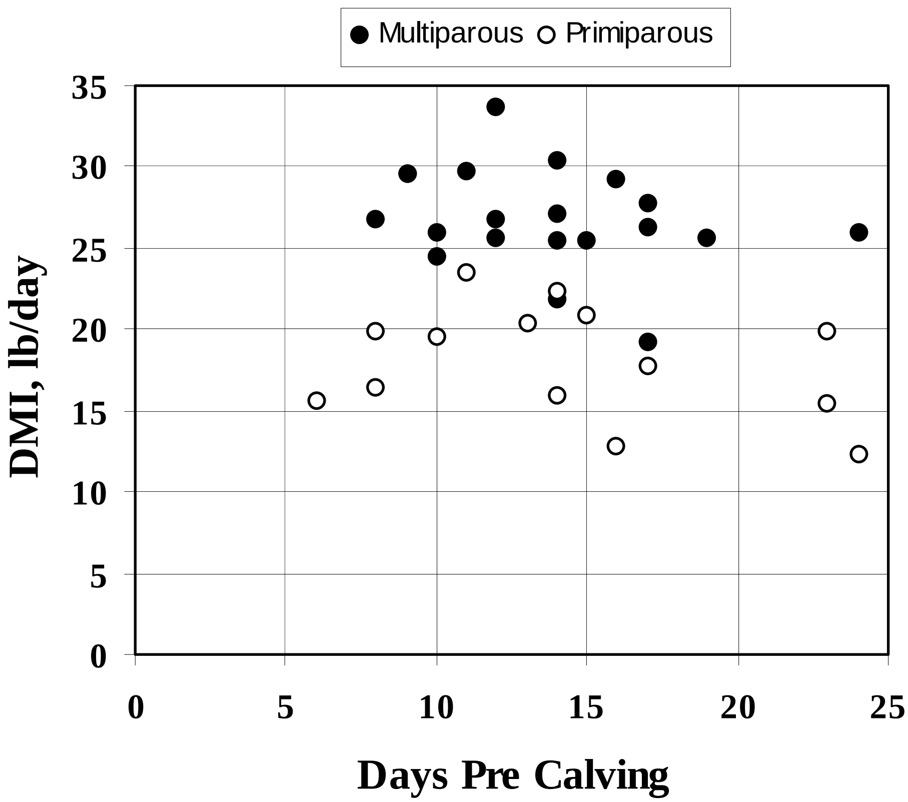


Figure 4. Dry matter intake of prefresh dairy cows.

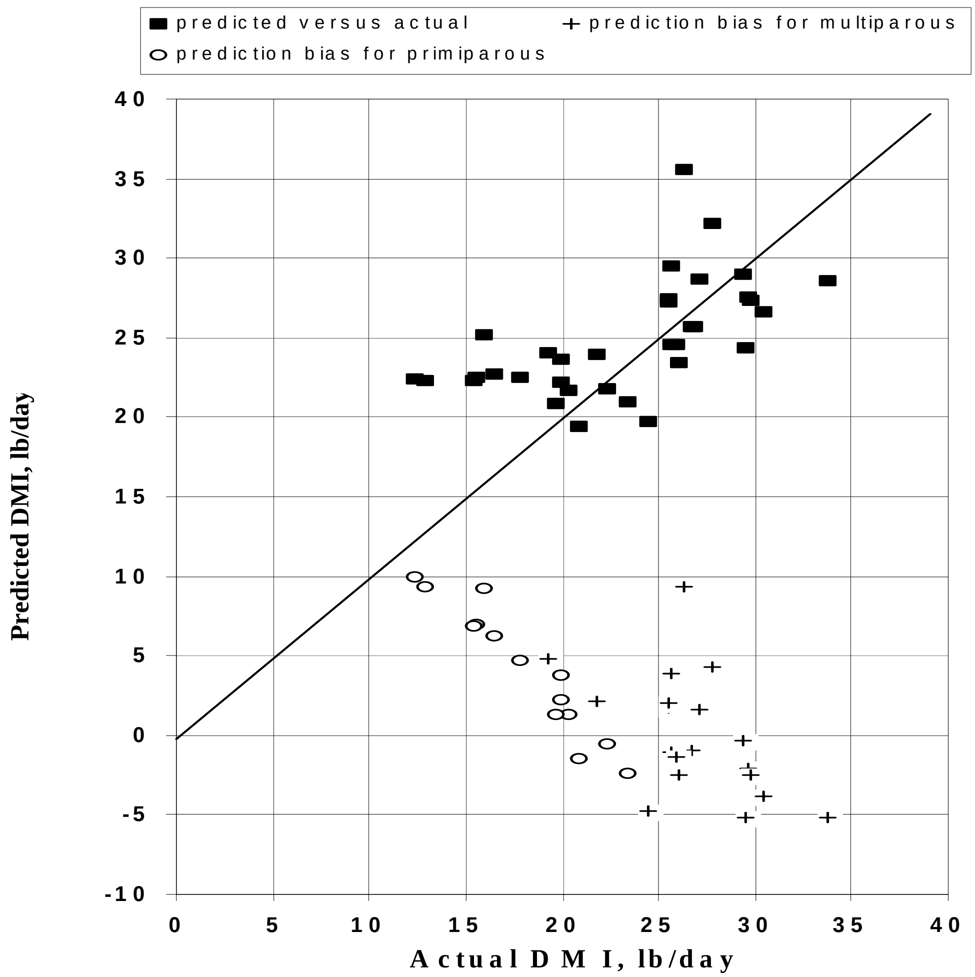
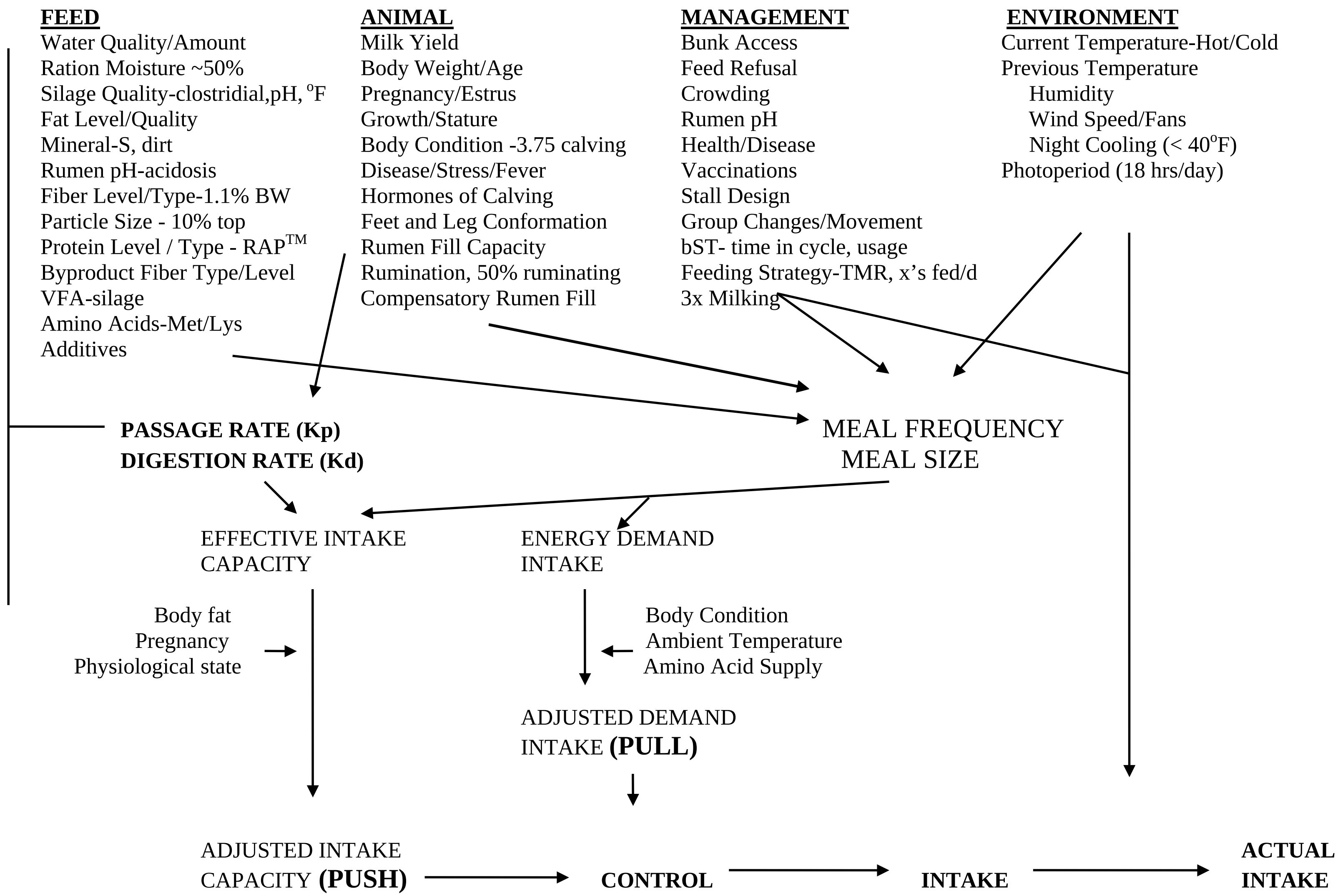


Figure 5. Actual versus predicted DMI and prediction bias (predicted - observed) of prefresh dairy cows.

Figure 6. Schematic diagram of feed intake control and factors effecting feed intake (Roseler, 1994).



Design, Selection and Use of TMR Mixers

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Introduction

Mixer design is an art. Field testing, consumer feedback, and experience are used to refine the design. Despite the information collected over years of use in the beef and dairy industry, and the yearly design changes, mixer design is still a mechanical art form.

Feeding a dairy cow is an art. Total mixed rations (**TMR**) have become the major feeding system of the dairy industry. Experienced nutritionists and research trials allow us to build better rations. Despite the information collected in research feed trials, and the use of ration balancing software, feeding a dairy cow is still a biological art form.

Mixer Design

There are approximately 25 different mixer manufacturers in the market, and in general, the mixers seem to be doing an adequate job of mixing a TMR. There has been only a handful of cases where the mixer design failed to do the job, and those mixers quickly left the market. In other cases, the mixers were used improperly (over or under mixing) which caused nutritional problems for the dairy herds. The mixer design that works best for one farm may not be the best choice for a different farm. The question "Is there a best mixer design?" is open for discussion, debate, and personal opinion. A better question would be "Which mixer is better for my situation?"

There are certainly design differences in the mixers available. Design changes are driven by market and consumer demand. Take for example the consumer demand that a mixer should be able to handle the addition of long dry hay into the ration. This has impacted the design changes of many of the mixers on today's market. In less than 5 years, this design goal has produced mixers that can process either a little hay or a lot of hay. This particular design change has caused another potential problem with misuse; particle size reduction with too long a mixing time.

Mixer design is still primarily a trial and error process with due consideration given to prior experience. The manufacturer selects a specific mixer design that is expected to perform, and field tests determine design changes and their effect on the mix.

In a summary paper on mixer design, these design and testing issues were identified:

- mixer design (type, geometry, power, time, speed, and efficiency),

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- define material changes (particle size reduction),
- define standards for comparison of mixers,
- classify and measure degree of mixing (determine the quality of the mix),
- describe the mixing process,
- correlate quality of mix with respect to time,

All of these are good research projects. Some manufacturers and researchers may have answers to parts of these problems. Some problems may not ever be solved. Nevertheless, there is no coordinated effort to bring the pieces of the puzzle together.

Function of a Mixer

The definition of mixing is the putting together of two or more substances or groups, one with another so that the particles or members of each are diffused among those of the others. "Perfect" mixing is the state in which any sample removed from the mixture has exactly the same composition (which is a state that never really occurs). The function of the mixer is to blend uniformly particles of different sizes, moisture content, and bulk density. However, segregation can occur because of the differences in particle size, density, and shape.

The mixer should allow the use of a variety of feeds to be blended into a ration that provides the desired nutritional requirements for the animal to be fed. The mixed ration should be uniformly blended so that when an animal takes a mouthful of feed, it receives a homogeneous sample of the combined ingredients. The mixed ration should prevent sorting of feeds by the animal and mask less palatable feeds. However, a mixer is limited in its ability to mix a ration by the feed ingredients that are used in the ration.

The manufacturers select mixer designs that provide for the needed "degree of mixing" in the desired time. The variation of the mix should be minimal as the feed is delivered out of the mixer. Samples pulled from the beginning, middle, and end of unloading should be the "same".

Mixing requires motion of the particles. This is done by moving particles mechanically with augers, reels, chains, and drums. The mechanical forces that mix the ration can also cause particle size reduction to occur. This particle size reduction may or may not be a beneficial or desired function of the mixing operation. New mixer designs highlighting the ability to mix in dry hay must be able to achieve two opposite goals. On one side, they must be able to cut up or tear apart long dry hay. On the other side, they must not reduce particle size so much that it impacts the roughage value of the ration.

Mixer Design Options

There are approximately 20 different companies producing TMR mixers of various designs. The industry continues to change and adapt to the market place. The mixers on the market fall into several general design categories. A description of the different trailer mixer designs follows.

Horizontal Auger Mixer

The mixer uses one, two, three, or four augers to churn the feed in a hopper. The feed moves along the flighting of the auger(s). In one and two auger mixers, the flighting moves feed toward the discharge door from both ends of the mixer. In 3 and 4 auger mixers, a counter-rotating auger and/or flighting moves feed in the opposite direction of the other augers. Feed moves from end to end and from bottom to top. The mass of feed eventually moves toward the discharge door and is unloaded when the door is opened. In many mixer designs, notched auger flighting and/or knife sections attached to the auger flighting provide the ability to cut or tear long hay into 3 to 4" pieces and incorporate it into the ration. Design differences include rotation speed of the augers, auger diameters, and auger flighting design.

Reel Mixer

The mixer combines a set of augers and a reel similar to a combine reel in a hopper. Feed is lifted and tumbled by the reel moving it to the rotating augers, which provide a mixing action, moves feed from end to end, and to the discharge door. Knife sections on the auger flights cut or tear long dry hay into 3 to 4 inch pieces and incorporate it into the ration. An option provides the ability to break up large portions of dry hay or baleage.

Tumble Mixer

The mixer is a large drum with spirals and/or pans on the interior circumference of the drum to lift and tumble the ration. A central auger moves feed from end to end and to the discharge. A large door opens to allow loading with a skidsteer or loader bucket.

Vertical Mixer

The mixer consists of a large tub with a single vertical tapered screw centered in the tub. A planetary gearbox drives the screw. Knife sections are attached to the flighting to cut material. Movable shear or restrictor plates on the tub wall provide a shear bar, increasing the ability to process and reduce the particle size of large packages of hay. These units can process rations with almost 100% dry hay. No prior processing of hay is required.

Box Mixer

The mixer uses a tub or box containing a chain and slat conveyor to tumble the feed ingredients within the tub end to end. An auger at the front of the mixer provides additional mixing and moves material to the discharge.

Mixer Cart

The mixing cart is a scaled down version of some of the mixer designs discussed above. Sizes range from 40 to 80 cubic feet (**cf**). They usually are powered by a small 8 to 18 horse power (HP) gas engine. They are used where a smaller volume of feed is needed. Research herds also find them useful for feeding cows on nutritional trials. Cart mixers come in three designs; box mixer, tumble mixer, and reel mixer.

Scales

Scales are required on a mixer to properly weigh and blend the ration. Electronic digital readout scales use load cells to weigh ingredients in the mixer and are accurate to 0.25%.

Magnet

A magnet attached at the discharge chute is used to pick up hardware before it ends up in the feed bunk. It may be standard or an option on the mixer, but should be considered part of a basic mixer system.

Mixer Testing

There is no standard method of evaluating a specific mixer design. There is no universally accepted means of comparing mixers or determining what design changes need to be made with a particular mixer to make it “better”. We don’t have a consumer report of TMR mixing equipment to compare mixers under similar conditions to answer the question “Which mixer gives the best mix?” At this time, the “cow is the test”. For an individual farm, the best advice is to have an on the farm test of the mixer(s) you are considering.

Typical tests might include using a tracer, such as salt, nutritional tests, and particle size tests. These tests are used to measure variability or uniformity of the samples taken over time. Sampling can be done at specific times during the mixing process. Always shut off the tractor and/or the mixer before pulling samples from inside the mixer. Sampling also could be done at the beginning, middle, and end of unloading. Manufacturers do use some of these tests in development of a mixer, but in general, the testing is not consistent from one manufacturer to another or comprehensive to include all mixers.

Batch Mixing

All the mixers on the market are batch mixers. In batch mixing, a ration is followed and feed ingredients are added one at a time until the required weight of each specific ingredient is reached and the batch is complete. The order of addition of feeds can affect the mixing ability and/or time of mixing. In addition, the loading point of the mixer may affect the time required to get a complete mix. Follow manufacturer’s recommendations on addition order of feeds, and the recommended mixing time.

Mixing Time

Manufacturer’s recommended mixing times range from 3 to 6 minutes. Depending on the mixer design, processing of large quantities of hay is generally done before addition of other feeds and is not part of the mixing time. Small quantities of hay may be adequately mixed during the mixing process depending on manufacturer’s recommendations. Over mixing continues to be a management problem with many TMR rations. In a survey of 49 Wisconsin herds using TMR, the average time mixing was 16 minutes and the range was 2 to 60 minutes. Additional mixing time past the recommended time only decreases the particle size and usually does not improve the mix.

Safety

Safety should also be considered in mixer design and use. Metal steps or a ladder should be used to climb up for inspection and allow for safe filling of the mixer. Open top mixers should have grates in place for preventing accidental falling into an operating mixer. Power take-off (PTO) shields should remain in place. Do not remove safety shields. Never start the mixer before locating children and coworkers at a safe distance. Do not attempt to dislodge wrapped hay from augers or other moving parts of the mixer while it is running. There has been at least one documented case in Wisconsin of a fatality involving a mixer.

Total Mixed Ration Volume

Figure 1 shows the approximate volume of feed per cow needed at varying milk production levels. Dry matter intakes for varying milk production levels were obtained from nutritionists. Please be aware that these values are estimates from a spreadsheet based on assumptions of a base TMR and densities of feeds used in the rations. Many factors affect the final ration density. The ration densities in this chart vary from 15 to 18 lb/cf (as fed.) The ration densities were calculated based on a 70% forage to 30% grain ratio, with haylage and/or corn silage for forages and high moisture ear corn as the grain. Four different rations are shown. As fed bulk densities of the feeds were assumed to be 12 lb/cf for hay silage, 14 lb/cf for corn silage, 46 lb./c.f. for high moisture ear corn, and 5 lb/cf for dry hay. The resulting TMR ration volume estimates from the spreadsheet have been checked with several manufacturer's recommendations and seem to be close to what sales people suggest for sizing a mixer.

There are differences in ration density suggested when substituting some dry hay for silage. The addition of dry hay tends to bulk up the ration. The as fed ration density decreased approximately 1 lb/cf for every 10% addition of dry hay for silage. As the TMR ration density decreases, the ration volume per cow increases, requiring a larger mixing capacity. A ration with 20% replacement of dry hay for silage also is shown. Substitution of dry hay above 20% of the ration will probably decrease the ration density as well, but it is unknown how much it will affect the density.

In one ration, corn silage was substituted for some haylage. Since corn silage tends to have a slightly higher bulk density than haylage, the as fed ration density increased approximately 1 lb/cf As the TMR ration density increases, the ration volume per cow decreases, requiring a smaller mixing capacity. The volume read from the chart for a particular ration can be used to determine the mixing capacity needed for a group of cows.

Mixer Sizing

The mixer size is dependent on the group size, ration density, production level, and the number of times each group is fed. For example, using Figure 1 with a ration which has 10% dry hay and a ration density of approximately 16 lb/cf an 80 lb per cow milk production gives a ration volume of approximately 6.5 cf/cow/day.

A group of 100 cows would require:

100 cows x 6.5 cf/cow/day = 650 cf/day

Feeding twice a day would require:

650 cf/day / 2 times feeding = 325 cf mixing capacity

This is the mixing capacity per batch of feed for this group of cows. Some farms considering feeding only once a day during some parts of the year would mean either buying a mixer large enough (650 cf) for once a day feeding or mixing two batches (325 cf) each. Economics, labor availability, and feed management will help determine the decision.

The struck or level capacity of a mixer is the total volume of the mixing compartment. Mixers are rated from 60 to 90% of the struck level capacity of the mixer depending on the manufacturer. A good estimate would be to buy a mixer based on 60 to 70% of the struck level capacity of the mixer or asking for the mixing capacity of the mixer. Always follow manufacturer's recommendations on mixer capacity. Overloading mixers beyond their rated mixing capacity increases the mixing time required to provide a uniform mix and may in some cases result in spillage and lost feed.

Mixer Costs

A survey was done to determine costs of mixers on the market in 1998. The cost data represents the manufacturer's suggested retail price (**MSRP**) for their line of mixers. Features included in the MSRP were a trailer mixer, with medium priced electronic scale, and magnet on the discharge, ready for use. The information includes 59 mixers representing 11 companies. Most companies have from 4 to 8 mixer sizes in their line. The costs of the mixers ranging in size from 120 to 900 cf were plotted in Figure 2. No comparison between companies was done. The cost data was plotted according to stated mixing capacity of each model mixer and the quoted price.

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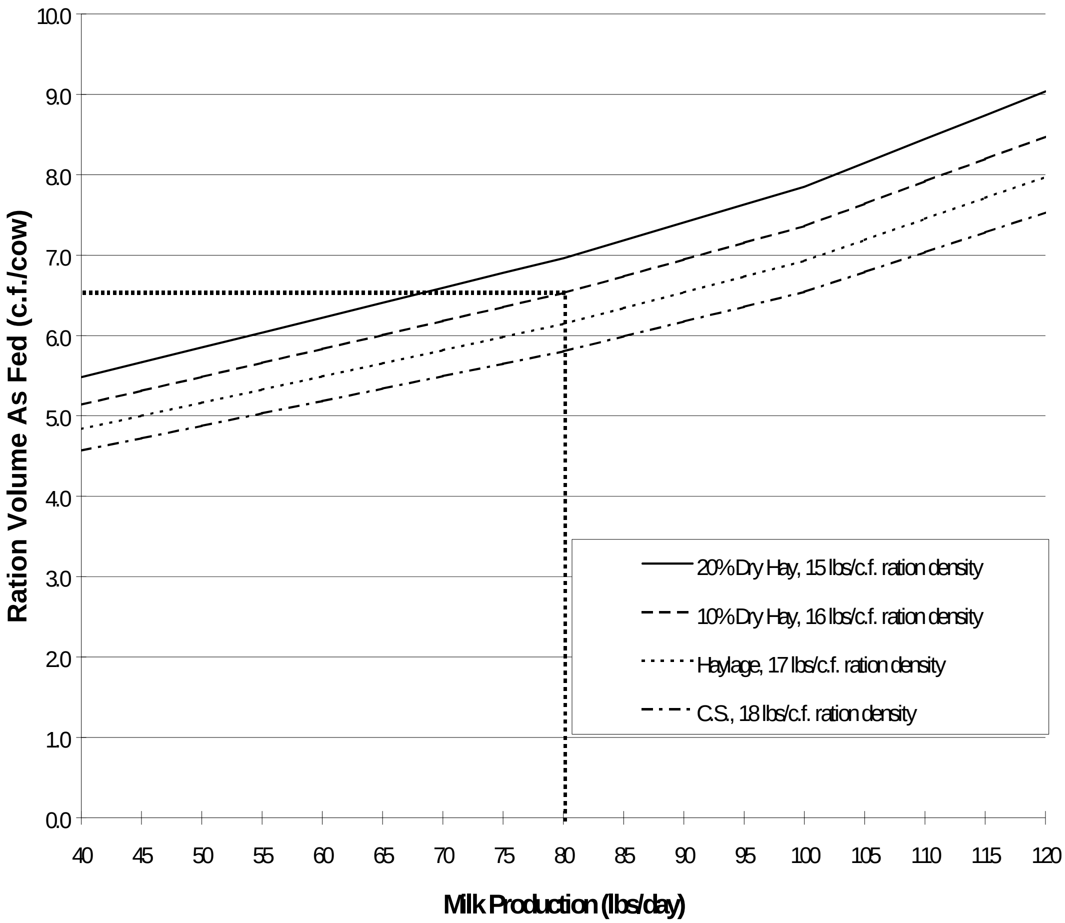

Figure 1. TMR volume for a dairy cow (cf = cubic feet).

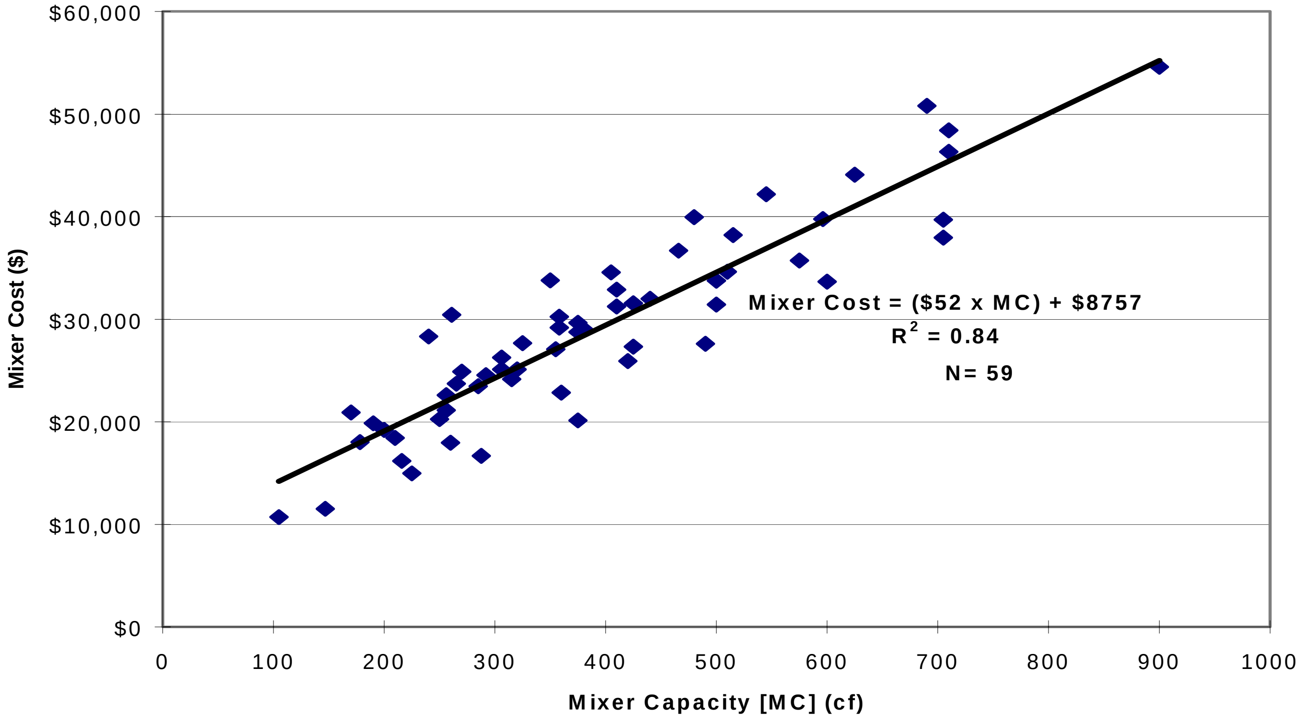

Figure 2. Suggested retail price for TMR mixers based on a survey distributed to mixer Manufacturers (cf = cubic feet).

Now There's Dairy Steers on the Farm: What Do You Feed Them?

Hugh Chester-Jones[1], Alfredo DiCostanzo[2], Tom Peters[3], Herb Rebhan[4], Dan Schaefer[5], and Drew Vermeire[6]

Dairy steers are a familiar byproduct of the dairy farm providing diversity for supporting the primary dairy herd enterprise. The acceptance of the dairy steer as an important niche in the beef market for the consumer in recent years has provided management opportunities for the dairy farmer feeder and a specialized feedlot operator. Distinct market segments for dairy-beef production in the Midwest allows dairy farmers to consider options to integrate into their own operations, provide a calf source for specialized feedlot operators distributed through sale barns, or join with family members or neighbor dairy farmers to form a local alliance for specialized dairy beef production.

This paper will focus on feeding and management options for male Holstein calves. Considerations for Brown Swiss steers will be similar to Holstein steers. The colored breeds such as Jersey, Ayrshire, and Guernsey do have niche markets at lighter finishing weights. The ultimate goal is production of a finished Holstein steer weighing 1150 to 1300 lb finished market weight between 12 and 14 months of age. There are niche markets for lighter (550 to 750 lb) and heavier steers (>1400 lb), but the economic efficiencies need to be evaluated against other options. Specific market options include: calves from 3 to 10 days of age, sold directly off the farm or through sale barn auctions; post-weaned started calves from 175 to 225 lb; feeder steers from 350 to 450 lbs; feeder steers from 500 to 750 lb; heavier feeders 800 to 950 lbs, and finished steers from 1150 to 1300+ lb, depending on previous feeding regimen. Each segment of dairy-beef production is highly specialized. A key consideration is for proper size of calf and uniformity of calf groups that will perform optimally in each selected system. The paper will focus on post weaned calves but will highlight key points to consider pre-weaning.

Feeding and Management Strategies by Production Phase

Ideally, the selection of uniform, healthy calves between 90 and 110 lb is a goal for an efficient dairy-beef production system. A recent profile of birth weights

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from a representative midwest population of male Holstein calves at the University of Minnesota West Central Experiment Station indicated that 4.5% were <70 lb; 70 to 79 lb, 7%; 80 to 89 lb, 20%; 90 to 109 lb, 54%; and >110 lb, 14.5% (D. Johnson, MN West Central Exp. Sta., personal communication, 1998). Dairy-beef producers compete in the market place with large veal growers for >68% of the available calves in the ideal weight range. There is some flexibility for selecting outside the 90 to 110 lb range as calves < 90 lb have been shown to perform as well, if not better than, larger calves to a finished weight with good management. In Wisconsin, for example, some producers take advantage of the $7 to 10/head price for calves <70 lb and use top quality management and feeding programs to successfully compete in the post weaning market place (Rebhan, Domain, Inc., personal communication, 1998). It has been observed that steers from dams selected for high milk protein will have a propensity for high rates of gain (Miller et al., 1986) which is very prevalent for today's dairy industry.

Phase 1. Pre-weaning to 7 to 8 weeks of age.

Optimal calf growth and health during this important phase will be maintained in the later growing and finishing phases.

a. Calf management considerations. Management of calves immediately after birth should be optimal whether calves are sold prior to 10 days of age or retained on the dairy farm. The variability of management after birth has resulted in many calves being immunologically deficient. Variability of immune status of calves retained on dairy farms can also result in higher health costs during the pre- and immediate post weaning periods. Attention to providing good colostral passive immunity transfer within 12 hours after birth and maintaining good sanitation programs for all facilities is critical to minimize health problems and keeping calf death loss at < 5% (home-raised or purchased calves). Preferably, calves should be individually housed (hutches, pens, or raised crates), but some management success and labor saving has been shown for small calf groups in pens with/without access to pasture fed from a nursette or automatic computer liquid feeders.

b. Liquid feeding considerations. A good quality liquid and dry feeding program is essential to enable calves to be weaned as early as possible by encouraging dry feed intake. Estimated energy and protein requirements (NRC, 1989) for a 100 lb pre-weaned Holstein bull calf gaining up to 1.1 lb/day are 4.11 Mcal metabolizable energy (**ME**) and .44 lb crude protein (**CP**). Use of discard whole milk (8 to 10% of calf birth weight) is discouraged if a known case of Johne's *(Mycobacterium paratuberculosis)* disease has been isolated on the dairy farm and if there is the potential of male calves co-mingling with herd replacements (Collins, 1998). Alternatively, use a high quality milk replacer as per manufacturers instructions. In addition to the need of supplying sufficient energy under cold stress conditions, recent research has suggested modified approaches to routinely enhance energy intake from the liquid feeding programs (Chester-Jones and DiCostanzo, 1996; Tomkins et al.,1994; Vermeire, 1998).

c. Dry feeding considerations. Weaning calves early can reduce the high overhead costs. Dry pre-starters based on milk products (22% protein and 12% fat) fed at 0.5 lb/day with regular starter have encouraged starter intake and early weaning (Morrill et al., 1984). Calves should have access to fresh water at all times.

Greenwood et al. (1997) and Vermeire (1998) suggested that calves should be weaned when they are at least 21 days of age, consuming at least 1% of their initial body weight (**BW)** in calf starter, have a cumulative starter intake of 9% of initial BW, and gained at least 12% of their initial BW. Other suggestions have been to wean calves when they have consumed 1 to 1.5 lb of starter for 3 consecutive days (Akayezu et al., 1994).

Calf starters should be coarse textured, providing 1.3 to 1.5 Mcal ME/lb, minimum of 16 to 18% CP, at least 8 to 10% fiber, 2000 IU/lb vitamin A, 200 IU/lb vitamin D, 25 IU/lb vitamin E (supplementation with 125 IU vitamin E/day is beneficial for calves up to 24 weeks of age; Chester-Jones and DiCostanzo, 1996), .7 to .8% Ca, and .45 to .5% P (DM basis). Check the trace mineral specifications in the starter very carefully. Calf starters will contain coccidiostats, such as decoquinate or ionophores. Other feed additives such as probiotics, yeast cultures, sodium bicarbonate, potassium bicarbonate, and potassium chloride have shown positive effects, especially in stressed calves (Chester-Jones and Peters, 1991). Akayezu et al. (1994) evaluated varying protein levels in starter diets (averaged 1.31 Mcal ME/lb) containing corn, oats, and soybean meal (**SBM**) fed from 4 to 56 days of age. They concluded that the recommended NRC (1989) level of 18% CP is adequate for calf growth. They noted that feeding >.15 lb undegraded intake protein (**UIP**) did not improve calf growth. Any post weaning diet changes should be accomplished in the individual housing prior to moving to group pens. A goal is to have a 175-lb calf by 7 to 8 weeks of age (100 lb initial BW). A break-even price for this sized calf would be approximately $0.81/lb with initial calf cost of $75 (Dvorak et al., 1997). In this example, labor and facility costs were $3/week, veterinary costs of $7.50, and death loss of 5%. A total of 25 lb of milk replacer were used, 50 lb starter plus 3 lb protein supplement, and 10 lb corn, and interest of 10%.

<u>Phase 2: Post weaning up to light feeder weight (300 to 450 lb).</u>

Comparative compositional analyses of the main feedstuffs discussed in this paper are shown in Table 1. The choice of diet should be based on economics and the ability to provide a high energy diet (1.4 to 1.5 Mcal ME/lb; .58 to .60 Mcal/lb NEg) to optimize efficient performance until daily dry feed intake is at least 9 to 10 lb/calf (at about 300 lb BW). A number of feed ingredient options and combinations are indicated in examples of steer performance in research studies from weaning to light feeder weight shown in Table 2. Chester-Jones et al. (1991) estimated that calves fed a whole corn diet with a 28% pelleted supplement need 3.77 Mcal ME/lb gain from weaning to 420 lb, BW which concurred with requirements predicted by NRC (1989). In a number of diets shown in Table 2, CP utilization ranged from .42 to .46 lb CP/lb gain. Dry matter intake (**DMI**) is the key to maintan calf growth at lower CP levels and attempts to improve quality of available protein for starter diets have met with mixed results (Chester-Jones and DiCostanzo, 1996; Chester-Jones and Peters, 1991).

Production goals for a high energy program from weaning to light feeder weight are daily DMI of 7.5 to 8, average daily gains (**ADG**) of 2.4 to 2.6 lb, and feed DM/lb gain (F/G) of 3.1 to 3.4 lb. A calf production budget for a high corn program from 8 weeks of age (175 lb goal) to 350 lb based on 70 days on feed (2.5 ADG; 3.0

F/G) suggested by Dvorak et al. (1997) showed consumption of 400 lb of corn ($2.75/bu) and 120 lb supplement ($0.16/lb) for a production budget costs of $210 (2% death loss, $2.25 vet cost; $2.10/week yardage plus 10% interest), and a break even price of $0.60/lb.

In this production phase, critical importance is overcoming the social behavior restrictions of Holstein calves that are slow to adapt to larger groups (Boomer, 1993). At 7 to 8 weeks of age, calves should be moved into small group pens of 12 to 15 calves for two weeks and combined into larger groups of 40 to 50 calves for a minimum of another two weeks (T. Peters, personal communication, 1998). When calves weigh 225 to 275 lb they can be combined into pen sizes of 100+ calves for the larger feed yards (T. Peters, personal communication, 1998). He noted that farmer feeders usually have good success with small pen sizes of under 50 calves, but with larger pens over 80 calves, consistent steer performance is more challenging because of the lack of social adaptation by individual animals which should be identified and culled (5% cull rate in large pens). Confinement housing can be an open-front, naturally ventilated open-ridged barn facing south (may have adjustable curtains on north wall) with a suggested bedding area of 10 to 15 sq ft/steer to 300 lb (15 to 20 sq ft to 500 lb, and 20 to 25 sq ft from 500 lb to market BW) with access to protected outside lots providing 20 to 30 sq ft/head (Chester-Jones and Peters, 1991). Holstein steers are "station" feeders and prefer liberal bunk space. Vermeire (1998) noted that calves up to 450 lb BW perform better if they have to stand on a step (6 to 8 inches) to reach the bunk. He recommended an average of 10 inches of bunk space if steers are fed a total mixed ration (**TMR**) daily.

Alternatively, self-feeders (whole corn and pellet base diet) are used by many farmer feeders. A 2 to 3 ton capacity, double-sided 12 ft self-feeder, for example, has been shown to be adequate for 80 calves (3 to 4 inches of bunk space per steer). Self-feeding takes good daily management and works if feed is always available. It is critical to clean the self-feeders daily, especially removing fines. If digestive problems are indicated that may result from a whole corn:pellet self-fed system, these have been attenuated by some farmer feeders by providing a palatable bedding source, such as corn stalks or free choice long hay. A preferred method of providing roughage rather than a separate bale feeder is to mix ground hay (5 to 10%) with the whole corn and pellet. Daily TMR feeding offers greater control of feed additive intake, greater ability to measure group pen intake swings, and greater ability to integrate alternative feeds. Daily diets should be fed at the same time, and feed in the bunks should be evenly distributed. Whatever the system, steers must have easy access to an adequate water supply.

Phase 3: Feeding and management strategies from light feeder to market weight.

The tight net margins for cattle feeding systems today, in addition to nutrient balance and environmental concerns, requires attention to improvement of feed intake management and utilization. Managed intake, programmed feeding, plateau feeding, and limit/restricted feeding are systems that have been a focus of recent research and field application (Loerch and Fluharty, 1998; Owens et al., 1995; Peters, 1995; Pritchard, 1994). These systems are most prevalent for daily feeding. Maximizing daily DMI may not always return maximum economic benefits, and manipulation of DMI at "optimal" times during the feeding period may be more prevalent than ad libitum intake (Peters, 1995). For consistent effective management, all cattle within a pen must establish consistent behavior (Pritchard, 1994). Owens et al. (1995) suggested that cattle fed high roughage diets must be fed ad libitum to maximize gain and feed efficiency but that cattle fed high concentrate diets have the capacity to eat more feed than they need, especially when grains are poorly processed or if roughage is added to the diet. They noted that yearling Holstein calves are "notorious" for gulping their feed and are inefficient as they chew feed poorly. Peters (1995 and 1998, personal communication) favors programmed intake for Holstein steers which uses predicted intake equations to regulate consistent daily DMI given a known steer BW and allows steers to consume up to a 120% of predicted intake at the top end to remain efficient feed converters.

a. *Overview of nutrient requirements.* The revision of nutrient requirements of beef cattle (NRC, 1996) from NRC (1984) maintains much of the basic premises but allows the user to use prediction equations and computer models to estimate cattle performance under varying nutritional management and environmental scenarios. Holstein steers are particularly sensitive to environmental stresses which affect their DMI and performance, such as high temperatures and humidity, low temperatures with wet hair coat, wind speed with wet hair coat, and muddy conditions. Use of implants can reduce requirements for NEm (Ainslie et al; 1992). Holstein steers that have a propensity for compensatory gain will improve energy utilization for both maintenance and gain (NRC, 1996).

Protein requirements for Holstein steers have been refined with an emphasis on metabolizable protein (**MP**). Higher protein requirements for lean tissue gain with large frame cattle implanted with medium or high potency implants are now suggested (DiCostanzo, 1995; Trenkle, 1993). Strategies for feeding different protein levels are necessary to optimize performance without increasing feed cost of gain. DiCostanzo (Univ. of MN, 1998, personal communication) calculated protein requirements, as CP and MP, for growing-finishing Holstein steers fed high energy diets (implants and ionophores included) by BW within a feeding period using NRC (1996). To verify the results, he incorporated DMI, diet composition, and initial and final weights of various trials at the University of Minnesota and Cornell University using NRC (1996) software. When adjusting for final weights at slight or small marbling score, or microbial efficiency, the projected ADG was within 95% of the observed ADG. Therefore, protein requirements in Table 3 reflect production conditions and performance achievable under these conditions. It is apparent that at faster rates of gain or at a heavier BW, protein requirements (lb/day) increase. As heavier cattle are expected to eat more, the proportion of CP in the diet for a given rate of gain decreases. Degradability of the diet is also of importance when considering protein supplements.

b. System 1 - Continuous high concentrate feeding. Healthy, uniform 300 to 450 lb feeders are very marketable and still maintain excellent potential for rapid growth and efficiency of gains on high energy diets. Regardless of feeding strategy, diets should contain ionophores and cattle should be implanted, the response being cumulative to enhance economic efficiencies. On a continuous 90:10

concentrate to roughage diet, Holstein steers will perform well in the feedlot with peak growth rates between 500 and 700 lb. Expected ADG at 500 lb is 3.50 lbs/day or greater with a F/G of 4.5. Feed intake will continue to increase but daily gain and feed efficiencies will gradually decline. By 1200 lb, ADG declines to 2.25 lb and F/G of 11.0 or greater (Boomer, 1993). Feeding strategies should maintain economic efficiencies for both light and heavy feedlot steers. Schaefer et al. (1986) observed decreased steer growth rate and feed efficiency if amount of corn silage was increased from 10 to 25 or 40% with high moisture corn continuously fed from 430 to 1100 lb market weight. When forage prices are low and corn prices high, the 25% forage diet may command a higher return to the system. Feeding high moisture-corn in high grain diets to long-fed Holstein steers will provide excellent gains from 200 to 600 lb, but dry corn from 600 lbs is often the better source to prevent cumulative subacute acidosis from high moisture corn in later finishing phases that may decrease steer performance (Fox, 1989). Newly received feeders steers, already adapted to high energy diets and to be fed a 90:10 diet in a bunk, can be placed on a diet of 80% corn and supplement plus 20% forage. The forage should be similar to that which was used in the diet prior to arrival.

The whole corn-pellet, no roughage growing finishing program is an alternative continuous concentrate strategy used by farmer feeders, often in a self-feeding (**SF**) system for decreased yardage overheads. In many cases, steers have been on this program since weaning age. With good feedlot management, pen sizes of up to 100 steers/pen have been successfully raised on this program. Feedlot operators purchasing 350 to 400 lb steers adapted to a similar high energy ration can transition to full-feed within 10 days. An example of projections for Holstein steers fed a high-energy no roughage program is summarized from 100 to 1227 lb in Table 4. The market weight end-point depends on producer goals, contractual arrangements, and/or packer preference. A five-year summary from a Minnesota farmer feeder who has raised purchased 442 post weaned calves from 200 lb (average purchase price of $229.14) to market weight of 1292 lb (354 days) on a no-roughage whole corn program indicated an ADG of 3.08 and F/G of 5.1 lbs, as-fed. Feed costs were $337.82 (87 bu corn @ $2.65/bu and 631 lb pelleted supplement @ $0.17/lb from the local elevator) with total costs of production of $648.87/steer (vet costs were $12, yardage at $0.20/day, and death loss of 1% plus 8.5% interest rate). Feed costs of gain were $0.31/lb gain, and the break-even price was $0.53/lb (Rebhan, Domain, Inc., 1998, personal communication). This system provided good profit potential.

Concern has been expressed by commercial operators that continuous high concentrate diets for long-fed Holstein steers result in a "stall-out" that causes inconsistent. Fluctuating intakes may be offset on a whole corn-pellet program by offering palatable roughage daily in the feedlot (not just during transition). Work by Chester-Jones et al. (1993) found that the maximum intake of long grass hay (11.6% CP) fed free-choice to steers from 343 lb to 1134 lb market weight with a whole corn-pelleted diet was 2 lb/day with an average of 1 lb/day over a 259 day feeding period. Feeding hay did reduce DMI variability, did not affect steer performance, but reduced the quality grade average of steers compared to those fed no hay.

Traxler et al. (1992, 1993) further investigated the effect of dietary fiber in high energy long-fed Holstein steers from 375 lb. The study compared growing and finishing programs, varying fiber intake levels using whole/cracked corn with/without built-in roughage pellet or hay crop silage. Built-in roughage levels ranged from 6 to 15%. Steers were implanted initially with a combination of Synovex-S and Finaplex-S and again 112 days later. The continuous whole corn-pellet diet was the most efficiently utilized and the most profitable. Roughage level and grain processing did not improve net margin to the system. Rumen health did deteriorate across all diets fed. The authors recommended for consideration, from a management standpoint, for inclusion of some hay crop silage to reduce potential digestive problems.

c. System 2 - Feeding different forage:concentrate ratios - two phase feeding. A dairy farmer-feeder using a two-phase feeding approach will have more options to use home grown forages or opportunity-priced co-products. Return on equity can be higher with TMR programs, especially if only the cattle are leveraged (Chester-Jones and Peters, 1991). Miller et al. (1986) summarized 20 years of comprehensive research with Holstein steers at the Southern Experiment Station and concurred that a two-phase program from 400 lb to market weight was a good feeding program. It also took advantage of compensatory gains for steers fed high forage diets to 750 lb if followed by high energy finishing diets. Satisfactory steer performance was attained with a 75% alfalfa hay, and 25% corn grain and supplement growing ration followed by a 7 to 10% alfalfa hay and 90 to 93% concentrate finishing ration. Even better performances were shown when steers were fed 3 to 4 parts corn silage:1 part of corn and supplement (as-fed) up to 700 to 800 lb, followed by a finishing diet of equal parts of corn silage and corn grain. In all these studies, urea was the main supplemental nitrogen source.

More recently, Ainslie et al. (1992) fed purchased Holstein bull calves 90% concentrate diets for 20 weeks then switched to 7, 22, or 40%, DM basis, alfalfa silage diets fed with whole corn for a growing period of 98 days, then finished on a 91% concentrate finishing diet (Table 5). Steers were implanted with Ralgro initially then Revalor after 98 days. Diets contained monensin at 14.7 mg/lb of diet and DM. Steers were marketed when marbling via ultrasound indicated a choice grade. The study indicated that Holstein steers can be fed a 40% alfalfa silage diet to 856 lb, then a 90% finishing diet and reach finished BW in a similar number of days as steers fed a continuous high energy diet. Implanted steers grew 15% faster and converted fed 11% more efficiently than non-implanted steers. Siemens (1994) reported similar results with up to 50% alfalfa haylage in growing diets.

d. Programmed feeding growing-finishing diets in the commercial feedlot. Although there is a useful niche for self-fed Holstein steers by the farmer feeder with smaller pen sizes, in larger feedlot pens designed for 250 to 500 head and daily TMR feeding, the self-fed steer does not consume DM as well as those fed some roughage for a period prior to entry into the feedlot or pasture-based ('greener') feeder steers (T. Peters, personal communication, 1998). He noted that the latter will consume 105 to 107% of similar weight colored beef cattle with net efficiencies of feed utilization of 94-95% of colored beef cattle. Performance and economic efficiencies of purchasing (projected from April 1, 1998) pasture raised 625 lb (range 575 to 675 lb) feeder steers placed in a commercial feedlot are shown in Table 6. These steers are initially programmed for 105% of predicted DMI and using a steady consistent intake approach they can be transitioned through a short growing period of 21 to 35 days (.50 to .54 Mcal NEg/lb) to a finishing diet (.63 to .64 Mcal NEg/lb).

Intake will be adjusted upwards to a maximum of 120% of predicted intake. It is critical that each pen is sold on schedule as per prediction. Sorting to sell steers among pens is very costly. These steers will be implanted upon arrival with Ralgro and re-implanted 75 days later with Revalor-S, 100 to 110 days from market. These steers will be expected to grade 65% choice and return $46.91/head after 192 days on feed. The TMR feeding program for these steers is shown in Table 7. The initial diet will include some hay, oats, and a higher percentage of dry feed. A coccidiostat (decoquinate) or aureomycin are included in initial diets. Digestible fiber sources, such as beet pulp, are excellent for these incoming cattle. Ionophores are incorporated later (in this case monensin at 250 to 300 mg/head with tylosin). The importance of these TMR diets is the inclusion of co-product feeds, such as wet gluten feed (**WGF**) up to 25% of the DM, which represents lower soluble starch levels with additional fiber. The estimated protein requirements for these steers over the feeding period would be 2.3 lb CP and 1.54 lb MP (Table 3). The actual average CP intake was 2.66 lb/day. Peters (1998, personal communication) suggested higher levels for the finishing diets of 2.75 to 2.86 lb CP/day, but these were based on programmed DMI up to 25 lb/steer to ensure constant pen intake patterns.

Peters (1998, personal communication) further evaluated the placement of 800 to 950 lb (averaged, 835 lb) Holstein steers in similar sized feedlots that will be pushed to a finishing diet as soon as possible (within 16 days). These steers will be implanted with Ralgro initially then Revalor 50 days later to finish over a 165 day feeding period at 1311 lb market weight. These steers will be programmed-fed and expect 55 to 60% choice grade at market. It is important to market these steers before the DMI curve starts to decline. If these steers were placed on feed April 1, 1998, they would be sold September 10 and expect a return of $32.02/head. Feed intake would average 28.38 lb/day, ADG of 2.89, and F/G of 8.1 lb. Some producers may consider taking these steers to heavier weights to gain market premium of $2/head (T. Peters, 1998, personal communication). When feeding these 835 lb steers 28 days longer to market at 1364 lb, they gained a little in dressing percentage, but F/G declined rapidly and total expenses increased by over $50/steer. Chester-Jones et al. (1992) also found that 612 lb "green" Holstein steers fed a 78:12 high moisture corn:corn silage diet to 1255 lb market weight were more economical than those taken to a 1346 lb terminal weight. Michigan State research (Ritchie and Rust, 1996) fed 410 lb Holstein steers a whole corn:pellet diet to 1000 lb then added 2 lb hay/day until various slaughter BW (100, 1100, 1200, 1300, and 1400 lb) and found that Holstein steers can be fed to heavier BW, but quality grade and dressing percentage were not improved above 1300 lb. Increased slaughter BW decreased ADG and F/G.

e. System 3 - Pasture systems for growing Holstein steers - a controlled study. Pasture-based systems for dairy steers should reflect the land resources of the farm.

Grazing research at the Lancaster Agricultural Research Station during 1995 to 1997 has focused on an evaluation of cattle management options in a system based on Holstein steers grazing slopes typical of those in the unglaciated Upper Mississippi Valley. Information and interpretations gained from this research will be briefly reviewed (D. Schaefer, Univ. of WI, 1998, personal communication).

In each year, 60 Holstein steers were purchased either from a high-grain feeding system (1995) or directly off Southern states pastures (1996 and 1997). Steers were conditioned upon arrival and dewormed initially and again during the first part of the grazing season. Steers were assigned to 3 replicated groups of 20 head and randomly assigned to one of five treatments with 4 head/treament group within replicate. Management options (treatments, Table 8), which were compared singly or in combination, included a control (O); use of an implant/re-implant program in which Synovex-S was administered on days 1 and 84 of the grazing period (S); daily provision of 200 mg lasalocid (Bovatec) in 1 lb of a pelleted wheat middlings formulation (B); and, supplementation of coarsely ground corn up to 1% of BW (C). When steers received the SB combination, the corn supplement and Bovatec pellet equalled 1% of BW. In 1996, the SB treatment was substituted for the C treatment. Within each group of 20 steers, 12 steers across treatments were monitored for supplement intake using Calan gates mounted on a feed bunk which was rotated through the assigned 15 acres of paddocks within replicate group. Steers were weighed upon arrival and at 28-day intervals. Initial and final weights were unshrunk, taken in the morning on two consecutive days.

In each of the grazing seasons, the same 45-acre south slope area was used with paddock sizes from 1 increasing to 1.5 acres in the late season. Paddocks contained grasses (bluegrass, orchardgrass, brome, quack, fescue, and reedcanary grass) and legumes (red and kura clovers). Each replicate group grazed 15 acres of an available pasture. Paddocks were rotated every 2 to 3 days with a complete grazing cycle of 20 (early season) to 45 days (late season). Length of the grazing season and forage availability varied by year due to differences in temperature and precipitation. Crude protein tended to increase from 12 to 15% for early grazing and peaking in the early fall at 20 to 24% (DM basis). In two of the three years, pasture fiber levels (ADF and NDF) tended to increase throughout the grazing period.

Treatment effects are summarized in Table 8. There was incomplete consumption of supplement in all years, especially at the beginning of the grazing trials. Supplement consumption increased during the trial, but was typically only 70 to 80% of the amount offered to the steers. Consumption of corn and the Bovatec pellet is shown for the SCB treatment in 1997 (Figure 1). Although, supplement consumption was still only 50 to 60% of the amount available during May, supplement consumption was less variable (smaller standard deviation) during late July to September among the 12 steers in the SCB as compared to the SC treatment. For steer groups which received only the Bovatec supplement, consumption of this supplement was incomplete during May but nearly complete during the remainder of the grazing season.

Across the five treatments, average daily gains were 1.89 lb/day in 1995, 2.38 lb/day in 1996, and 2.71 lb/day in 1997 (Table 8). This same pattern is evident by comparing the daily gains observed for the control treatment in each of the three years. Based on CP requirements discussed elsewhere in this manuscript, it is unlikely that CP content of the pasture forages limited animal growth. Treatments including C resulted in improved daily gains in all three years, which indicates that energy was the limiting nutrient for growth.

The implications of treatment effects are shown in Table 9. Corn supplementation increased weight gains in all years, but the conversion of corn to weight gain (lb/lb) was relatively inefficient and ranged from 7.7 (SC-S in 1995) to 21.4 (SC-S in 1997). It is very likely that corn consumption substituted for pasture forage consumption. Cost of gain favored corn supplementation in the weather-shortened grazing seasons of 1995 and 1996. Cost of gains for corn tended to be lower when corn was supplemented in combination with an implant or in combination with an implant and an ionophore. Based on these results, it is clear that corn supplementation needs to be employed judiciously. Generally, it seems that corn should be supplemented when pasture forage supply is limited by weather conditions.

The Synovex-S implant improved daily gain numerically in each of the three years but only in a statistically significant manner in 1997 when control average daily gains were 2.38 lb/day. Since implants function by increasing lean growth at the expense of fat deposition, it is only likely that they exert their influence when fat deposition is possible. In Holstein steers with initial weights of 380 to 490 lb, a statistically significant advantage due to implanting and re-implanting with Synovex-S occurred when unimplanted steers gained in excess of 2.3 lb/day. Then this implant strategy resulted in an additional 49 lb of gain over 162 days. If this gain is valued at $.70/lb, the investment of approximately $5 in implanting yielded $34.30.

Bovatec supplementation resulted in significant effects in 1996 only, but then the advantage was achieved very cost effectively. A factor which has not been incorporated into this brief economic analysis is labor required for feeding supplements. It seems that supplementation of small numbers of cattle would be costly. Adverse rainfall or temperature and the economies of scale available with large groups of animals appear to be the most attractive combination for implementation of supplementation strategies.

f. Energy and protein sources for growing-finishing programs. Fox (1989) summarized a series of Cornell studies with growing Holstein steers fed combinations of different energy sources (dry corn, ear corn, and high moisture corn), protein sources (SBM, roasted soybeans, raw soybeans, and urea), forages (corn silage and alfalfa haylage), and co-products (brewers grains and WGF). Growing steers responded to higher protein levels and lower soluble protein sources when fed high corn silage diets but not with high grain diets fed from 12 weeks of age to 700 lb. Chester-Jones et al. (1989) found that there were no differences in feedlot performance when Holstein steers were fed a pelleted supplement containing urea, feathermeal alone, or in a 50:50 combination fed with whole or cracked corn from 460 to 880 lb BW. Lana et al. (1997) found that Holstein steers utilized nitrogen from SBM more efficiently than urea in 90% concentrate growing diets. Opportunities to accurately balance diets for optimal amino acid profiles using higher ruminal bypass protein sources are available (NRC, 1996).

The use of co-products in TMR for Holstein steers is becoming more prevalent as research indicates the value of these as alternatives to corn. For example, Stock and Klopfenstein (1996) observed that both dry and wet distillers grains (**WDG**) fed up to 50% replacement for corn will provide a higher energy value than corn. They noted that although WDG contributed higher dietary fat value than corn based diets, this did not totally account for the increased energy value, and they suggested that replacing the corn starch with high digestible fiber sources (WDG) alleviated many of the problems of sub-acute acidosis suspected in high corn diets. Richards et al. (1996) also found that WGF provided a higher energy value than corn in growing-finishing cattle diets. Dried gluten feed had about 91% the energy value of corn for growing Holstein steers (DiCostanzo et al., 1990). Recent Nebraska work (Lodge et al., 1997) found that a composite of WGF, condensed distillers solubles, corn gluten meal, and tallow improved feed utilization when fed to cattle compared to dry rolled corn and WGF.

g. Ionophore and implant considerations. Ionophores approved for beef cattle include laidlomycin propionate sodium potassium (30 to 150 mg/day; Cattlyst), monensin sodium (50 to 360 mg/day; Rumensin), lasalocid sodium (100 to 360 mg/day; Bovatec), and bambermycins (10 to 20 mg/day; GainPro). Tylosin (60 to 90 mg/day) with or without monensin is approved for reducing liver abscesses (DiCostanzo, 1996). Ionophores also have a sparing effect on amino acids (Lana et al., 1997) and some macro minerals (Grainier et al., 1989). The combination of ionophores and implants provide cumulative responses for improved cattle performance.

Implant strategy should work back from a projected market date. Selection of implants should sequentially increase the potency for re-implant programs (Pritchard, 1993). Trenbolone acetate (**TBA**) and estradiol (**E**) combination have the higher potency levels. Longer lasting implants include Compudose (150 to 200 days) and a newer implant Encore (up to 400 days). Implants can result in 5 to 15% increased growth rate and improvement in feed efficiency (Siemens, 1996). This author suggested that a most effective program for Holstein steers would be to implant with estrogen at 200 to 300 lb, again with estrogen at 500 to 600 lb, and with TBA + E at 95 to 100 days before market. It was also noted that Holstein steers on high silage diets do not respond to TBA + E but do respond very well on high grain diets. Estrogen implants should be used in high forage diets. Chester-Jones et al. (1996) observed a 19% response to Compudose when used as the only implant from 600 lb to 1270 lb market BW for Holstein steers. It is suggested that Encore may be a good choice for Holstein calves > 45 days of age as a single implant (Rebhan, Domain, Inc., 1998, personal communication).

Conclusion

Dairy farmer feeders have a number of options for raising dairy steers for beef production. A number of options for raising Holstein steers have been presented. It is recommended that prior to deciding to specialize in feeding dairy steers, a dairy farm family should establish distinct objectives and goals that will realize a net return to the operation based on opportunities that fit available feed resources, labor, facilities, and market options.

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Table 1. Comparative nutrient composition examples of the main feeds referenced in text and tables (DM basis)[1,2]

	DM	CP	TDN	ME	NE_m	NE_g	Fat	NDF	ADF	Ca	P	K
	%			Mcal/lb			%					
Dry corn	89	9.8	88	1.50	.96	.65	4.3	9	3	.03	.29	.37
H.M. corn	77	10.0	89	1.58	.99	.62	4.3	9	3	.02	.32	.37
Wet brewers grains	21	25.4	66	1.13	.69	.41	6.5	46	24	.33	.55	.09
Dry brewers grains	92	25.4	66	1.13	.69	.41	6.5	42	23	.33	.55	.09
Wet gluten feed	44	25.6	83	1.41	.90	.61	2.4	25	13	.10	.90	.90
Dry gluten feed	90	25.6	81	1.37	.87	.59	2.4	25	13	.10	.90	.90
Dry distillers grains	91	30.4	88	1.45	.99	.68	9.8	44	18	.15	.71	.44
Wet distillers grains	25	29.7	90	1.48	1.02	.71	9.8	44	18	.15	.71	.44
Oats	89	13.3	77	1.36	.86	.56	5.4	32	16	.07	.38	.44
Dehyd. alfalfa	92	19.0	61	1.03	.61	.35	3.0	45	35	1.52	.25	2.60
Alfalfa hay-med	90	17.0	58	.97	.56	.31	2.6	46	35	1.41	.24	1.71
Grass hay	89	15.0	65	1.11	.67	.40	2.8	61	34	.27	.34	2.91
Soyhulls	91	12.1	77	1.36	.85	.56	2.1	67	50	.49	.21	1.27
Soybean meal	89	50.0	84	1.50	.94	.64	1.5	-	10	.30	.68	1.98
Gluten meal	90	67.2	89	1.60	1.00	.69	2.4	14	5	.08	.54	.21
Beet pulp	92	10.1	78	1.37	.86	.56	2.1	44	25	.61	.10	1.78
Whole soybeans	92	42.8	91	1.64	1.03	.71	18.1	-	10	.49	.21	1.27
Haylage	52	21.0	63	1.17	.64	.38	2.5	45	33	1.48	.30	2.01
Corn silage	35	8.1	70	1.21	.74	.47	3.1	51	28	.23	.22	.96

[1]Adapted from NRC (1989); NRC (1996).
[2]DM = dry matter, CP = crude protein, TDN = total digestible nutrients, ME = metabolizable energy, NE = net energy, NDF = neutral detergent fiber, and ADF = acid detergent fiber.

Table 2. Holstein steer performance at the Southern Experiment Station when fed various complete diets from weaning at 4 to 5 wk up to 440 lb body weight[1].

Diet examples		Final BW	CP	DMI	ADG	F/G
		(lb)	(% of DM)	- - - - - - - lb	- - - - - - - -	
1.	3 pt corn:1 pt 28% CP suppl pellet					
	Rolled corn (RC)	405	14.4	7.19	2.32[a]	3.11
	Whole corn (WC)	425	14.4	7.50	2.46[b]	3.05
	RC switched to WC	421	14.4	7.59	2.42[ab]	3.14
2.	4 pt corn:1 pt 25% CP pellet adjusted with corn gluten meal for protein %[c]					
	85% NRC Protein level	430	15.1	8.10	2.39	3.39[a]
	100% NRC Protein level	440	16.8	8.14	2.47	3.30[ab]
	115% NRC Protein level	426	18.8	7.46	2.36	3.16[b]
3.	Beet pulp (BP) for corn[d]					
	0% BP	341	15.2	6.78[ab]	2.31[a]	2.92
	15% BP	337	14.9	7.02[a]	2.27[a]	3.10
	30% BP	339	15.1	6.29[b]	2.05[b]	3.08
4.	Pelleted corn gluten feed (CGF) for corn and SBM[e]					
	0% CGF	385	16.8	7.24[a]	2.16	3.36[a]
	21% CGF	400	16.6	7.99[ab]	2.27	3.52[ab]
	44% CGF	403	18.0	8.18[b]	2.31	3.54[b]
5.	Different N sources[f]					
	Urea (U)	396	15.6	6.89	2.20[a]	3.13[a]
	SBM	392	14.9	6.97	2.40[b]	2.91[b]
	Raw soybeans	396	15.2	6.34	2.13[a]	2.97[ab]
	Extruded beans	394	14.9	6.78	2.38[b]	2.85[b]
	Extruded beans + U	394	14.9	7.25	2.46[b]	2.90[b]
6.	Soyhulls for corn; LSBM for SBM[g]					
	SBM	373	17.0	6.93	2.36	2.94[a]
	LSBM	394	17.0	6.08	2.49	2.76[a]
	LSBMSH	375	17.0	7.20	2.33	3.09[b]

[ab] Means in the same column within diet with unlike superscripts differ ($P < .05$).
[c] Diets adjusted biweekly for protein level based on NRC (1984) estimates.
[d] All diets included 12% alfalfa pellets, 10% soybean meal (SBM), .22% urea, DM basis, with varying levels of corn and beet pulp.
[e] All diets included 26% rolled oats, DM basis, with varying levels of corn and SBM.
[f] All diets included 10% alfalfa hay, DM basis, with varying levels of rolled corn and N sources.
[g] Calcium-ligno-sulfate treated SBM (LSBM) replaced SBM with/without soyhulls (SH replacing 75% of corn grain in LSBM diet). Soyhulls replaced corn in a pellet that contained protein sources, vitamins, and minerals. Pellet fed 1:1 with non-pellet of corn, oats, and molasses.
[1]BW = body weight, CP = crude protein, DMI = dry matter intake, ADG = average daily gain, F/G = feed-to-gain efficiency, and pt = point.

Table 3. Predicted protein requirements for Holstein steers by growth rate and average feeding period body weights.[a]

Feeding period BW, lb		Average daily gain, lb				
		2.5	2.7	2.9	3.1	3.3
650	DMI, lb/day	16.5	16.4	16.3	16.1	16.0
	CP, % of DM	12.12	12.71	13.30	13.97	14.57
	CP, lb/day	2.00	2.09	2.17	2.25	2.33
	MP, lb/day	1.34	1.40	1.45	1.51	1.56
750	DMI, lb/day	18.6	18.5	18.4	18.2	18.1
	CP, % of DM	11.34	11.89	12.39	13.0	13.48
	CP, lb/day	2.11	2.20	2.28	2.36	2.44
	MP, lb/day	1.42	1.47	1.53	1.58	1.64
850	DMI, lb/day	20.8	20.6	20.5	20.3	20.2
	CP, % of DM	10.32	10.81	11.23	11.73	12.16
	CP, lb/day	2.15	2.23	2.30	2.38	2.46
	MP, lb/day	1.44	1.49	1.54	1.60	1.65
950	DMI, lb/day	21.9	21.7	21.5	21.4	21.2
	CP, % of DM	9.91	10.32	10.74	11.12	11.56
	CP, lb/day	2.17	2.21	2.31	2.38	2.45
	MP, lb/day	1.45	1.50	1.55	1.60	1.64
1050	DMI, lb/day	22.9	22.7	22.5	22.4	22.2
	CP, % of DM	9.52	9.88	10.25	10.57	10.95
	CP, lb/day	2.18	2.24	2.31	2.37	2.43
	MP, lb/day	1.46	1.50	1.55	1.59	1.63

[a] NRC (1996) verified with various Holstein studies at the University of Minnesota and Correll University. DMI = dry matter intake, NRC (1996); CP crude protein computed from metabolizable protein (MP) as discussed in NRC (1996).

Table 4. Performance projections of Holstein steers by monthly body weight changes when fed a high energy, no roughage program.[a]

Days on feed	Starting weight	Ending weight	Daily gain	Feed/lb gain, as fed	Cost of gain, $/lb at corn prices/bushel		
					$2.25	$2.50	$2.75
	- - - - - - - - - - - lb	- - - - - - - - -					
0 to 30	100	130	1.0	2.5	0.98	0.98	0.98
61	130	189	1.9	2.7	0.22	0.23	0.24
91	189	264	2.5	3.0	0.24	0.25	0.26
122	264	346[b]	2.7	3.8	0.29	0.30	0.31
152	346	441	3.1	3.8	0.24	0.25	0.25
182	441	542	3.3	4.2	0.25	0.27	0.28
213	541	654	3.7	4.4	0.25	0.26	0.28
243	654	766	3.7	4.8	0.26	0.28	0.30
274	766	872	3.5	5.2	0.29	0.31	0.33
304	872	975	3.4	5.6	0.30	0.33	0.35
334	975	1070	3.1	6.4	0.34	0.37	0.39
365	1070	1154	2.8	7.2	0.39	0.42	0.44
395	1154	1227	2.4	8.8	0.46	0.50	0.53
426	1227	1297	2.3	9.1	0.48	0.52	0.56
456	1297	1364	2.2	9.5	0.50	0.54	0.58
486	1364	1428	2.1	10.0	0.53	0.57	0.61

[a] Based on research with a whole corn pellet, no roughage program conducted by Domain, Tend-R-Leen, and the University of Minnesota Southern Experiment Station, Chester-Jones et al., 1996.
[b] Rumensin (180 mg/steer daily) and Tylan (90 mg/steer daily) included in the pellet for the remainder of the feeding period.

Table 5. Performance of Holstein steers fed 90% concentrate starter and finishing diets with different alfalfa silage levels in the grower period, with or without implants.[ab]

	Alfalfa silage %, DM basis			Implant	
Item	40	22	7	Yes[c]	No
	- - - - - - - - - - - - - grower period - - - - - - - - - - - - -				
Initial wt, lb	345	343	340	342	342
Days on feed	98	98	98	98	98
Final wt, lb	592	614	639	626	603
Daily gain, lb	2.52	2.77	3.05	2.90	2.66
Feed DM/lb gain	5.09	4.72	4.45	4.60	4.95
	- - - - - - - - - - - - - finishing period - - - - - - - - - - - -				
Final wt, lb[d]	1143	1134	1155	1126	1162
Daily gain, lb	2.89	2.95	2.62	3.05	2.58
Feed DM/lb gain	6.83	6.47	7.77	6.40	7.24
	- - - - - - - - grower and finishing periods - - - - - - - -				
Daily gain, lb	2.75	2.79	2.80	2.98	2.57
Feed DM/lb gain	6.22	5.87	6.02	5.70	6.37

[a] Adapted from Ainslie et al. (1992).
[b] Steers fed 90% corn concentrate diets to 20 wk of age; switched to alfalfa silage (17% CP) diets with whole corn, soybean meal, and Rumensin supplements for 98 days (implanted with Ralgro at the switch); fed 91% concentrate and 9% alfalfa silage during the diet finishing diet period (implanted with Revalor after the grower period.
[c] Implant effect in each period for all parameters.
[d] Adjusted to a common dressing percentage (60.4); overall average of 78% choice.

Table 6. Performance and close-out projections for finishing Holstein steers in commercial feedlots from 625 to 1178 lb market weight[a].

	Data	Per Head	Per Lot
Purchase Information:			
Date purchased	04/01/98		
No. purchased	100		
Pay weight, lb	625	625	62,500
Purchase cost/wt	$65.00	$406.25	$40,625
Lot charges:			
Yardage/head/day	$0.30	$57.60	$5,760
Vet and medicine/hd	$11.75	$11.75	$1,175
Interest - cattle	8.50%	$18.16	$1,816
Interest - feed	4.25%	$4.78	$478
Death loss	1.55%	$6.30	$630
Feed		$213.72	$21,372
Total lot charges		$312.30	$31,230
Total Expense		$718.55	$71,855
Economic Analysis:			
Feed Cost of gain (COG)/cwt	$38.87		
Feed & Yardage COG/cwt	$49.09		
Total COG (w/o Int.)/cwt	$52.38		
Total COG (with Int.)/cwt	$56.31		
Breakeven (live)/cwt	$61.02		
Breakeven (carcass)/cwt	$102.55	59.5 Dressing percentage	
Projected Income:			
Date sold	10/10/98		
Estimated market price	$65.00/cwt	$765.46	$76,546
Profit	$3.98/cwt	$46.91	$4,691
Annual return on assets		19.09%	
Annual return on equity		31.50%	
Performance summary:			
Selling weight, lb		1178	115,938
Days fed	192		
Gain, lb/day	2.88	553	54,407
Feed/gain (DM)	7.12		
Average feed intake (DM)	20.49		

[a] Adapted from T. Peters, 1998, personal communication.

Table 7. Example of feeding and cost projections for feedlot Holstein steers from 625 to 1178 lb market weight.[a]

	Transition to Grower			Grower	Transition to Finisher			Finisher
Days on diet	3	3	3	21	5	5	7	145
	Composition of diet, % of DM							
Ingredients								
Corn-dry	18.8	13.3	-	-	-	-	1.0	-
HM corn	-	10.0	27.6	29.7	40.2	47.5	53.9	63.0
Starter 24 % CP	22.5	15.0	12.9	-	-	-	-	-
Gr Suppl. 10% CP	-	-	-	5.3	-	-	-	-
Finisher 36% CP	-	-	-	-	4.8	4.5	4.1	4.0
Wet gluten feed	20.0	25.0	25.0	27.5	30.0	30.0	27.5	25.0
Corn silage	17.5	10.0	16.0	37.5	25.0	18.0	13.5	8.0
Oats	12.5	12.5	12.5	-	-	-	-	-
Hay	21.2	14.2	6.0	-	-	-	-	-
Daily DMI/hd, lb	8	12	14	17	18	20	22	22.5
CP, % of DM	17.1	15.8	14.8	12.2	13.7	13.6	13.1	12.7
Daily CP/hd, lbs	1.37	1.90	2.07	2.07	2.47	2.72	2.88	2.86
NDF, % of DM	30.1	29.7	29.1	31.7	26.2	21.3	18.3	14.7
ADF, % of DM	18.1	18.2	17.2	18.3	13.8	11.9	10.0	8.1
NE_m Mcal/lb	.78	.81	.84	.84	.88	.90	.92	.95
NE_g Mcal/lb	.48	.52	.54	.54	.57	.59	.61	.63
Cost/hd daily, $	0.53	0.72	0.81	0.83	0.94	1.05	1.18	1.23

[a] Adapted from Peters (1998) personal communication. Projection for 625 lb steers purchased April 1st and sold October 10, 1998. Total feed usage/head: 18 lb dry corn; 2,237 lb high moisture (HM) corn; 1,014 lb wet gluten; 1,512 lb corn silage; 62 lbs oats; 21 lb hay; and 199 lb supplements.

Table 8. Summary of treatment effects on growth rate of grazed Holstein steers.

Treatment	Abbrev.[1]	Initial Wt. (lb)	Final Wt. (lb)	Gain (lb)	ADG[1] (lb/day)
June 16 to September 15, 1995 (91 days)					
Control	0	385	527	142	1.55[a]
Implant	S	410	561	151	1.66[b]
Supplement	C	428	604	176	1.92[b]
Implant & Supplement	SC	403	599	196	2.14[c]
Implant, Supplement & Ionophore	SCB	418	617	199	2.19[c]
May 22 to September 24, 1996 (125 days)					
Control	O	394	653	259	2.05[a]
Implant	S	383	662	279	2.21[a]
Implant & Supplement	SC	418	730	307	2.44[b]
Implant and Ionophore	SB	416	728	312	2.48[b]
Implant, Supplement & Ionophore	SCB	436	781	345	2.74[c]
May 13 to October 22, 1997 (162 days)					
Control	O	484	867	385	2.38[a]
Implant	S	491	925	434	2.68[b]
Implant and Supplement	SC	511	983	472	2.92[c]
Implant and Ionophore	SB	508	925	417	2.57[ab]
Implant, Supplement & Ionophore	SCB	498	983	485	2.99[c]

[abc] Means within the same trial with different superscripts are different ($P < .05$).
[1] S = Synovex – S on days 1 and 84 of grazing period, B = 200 mg/day of lasalocid in 1.0 lb of pelleted wheat middlings, C = coarsely ground corn up to 1% of BW, and ADG = average daily gain.

Table 9. Implications of performance results[a] presented in Table 8.

Treatment Variable	Comparison[1]	Outcome Variable	1995	1996	1997
			Year		
Corn	C-O	Weight gain, lb	34	-	-
		Net corn intake, lb	355	-	-
		Cost of gain[b]	$.51	-	-
	SC-S	Weight gain, lb	45	28	38
		Net corn intake, lb	346	451	8115
		Cost of gain[b]	$.38	$.79	$1.05
	SCB-SB	Weight gain, lbs	-	33	68
		Net corn intake, lb	-	417	707
		Cost of gain[bd]	-	$.62	$.51
Synovex-S	S-O	Weight gain, lb	NS[c]	NS	49
		Cost of gain[e]	-	-	$.10
Bovatec	SB-S	Weight gain, lb	-	33	NS
		Net supplement intake, lb	-	102	-
		Cost of gain[e]	-	$.13	-
		Net supplement intake, lb	-	68	-
		Cost of gain[e]	-	$.08	-

[a] Implications are presented for only those comparisons in which differences were detected ($P < .05$).
[b] Corn was valued at $.049/lb ($2.75/bu).
[c] No significant difference was detected for this comparison.
[d] Cost of implant treatment ($5.00) was based on two implants ($3.00) and two implant sessions ($2.00).
[e] Cost of supplement ($.043/lb) was based on ingredient costs of $60/ton of wheat middlings and $.065/g of Bovatec 68.
[1]C = coarsely ground corn up to 1% of BW, O = control, S = Synovex-S on days 1 and 84 of grazing period, and B = 200 mg/day of lasalocid in 1.0 lb of pelleted wheat middlings.

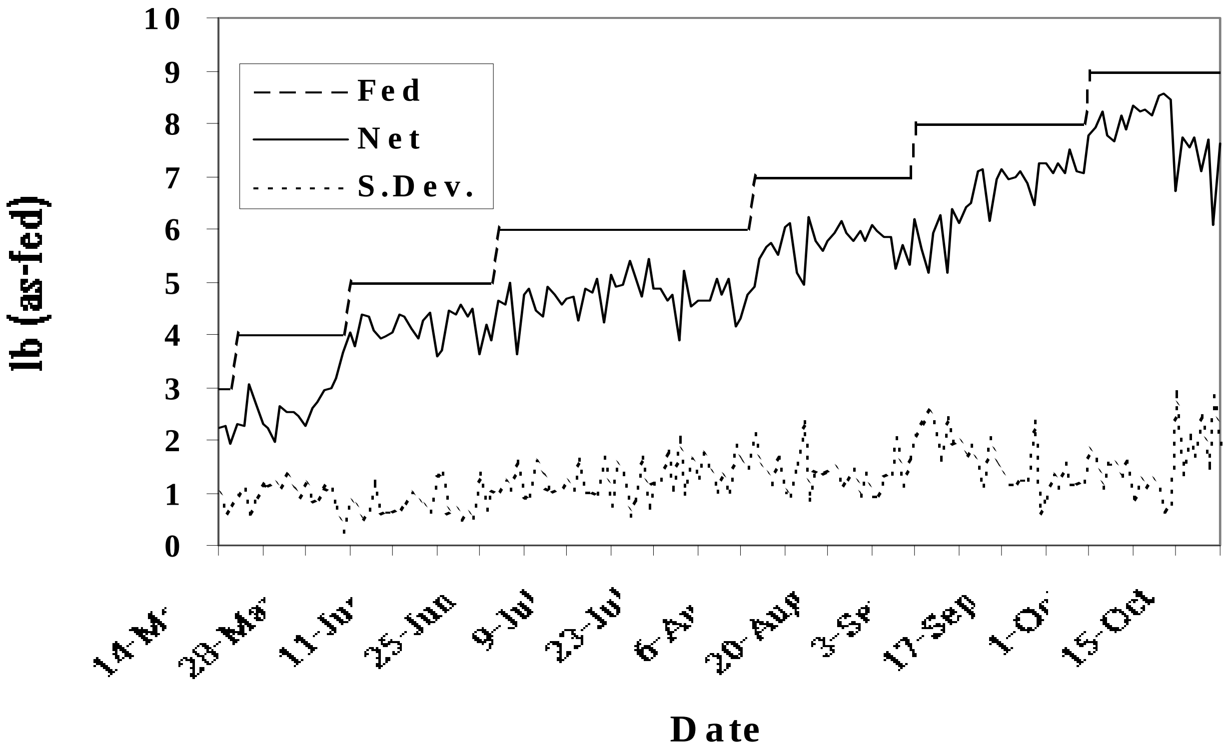

Figure 1. Supplement offered and consumed for SCB treatment (see Table 9 for description of treatment.

Accelerated Heifer Growth: Truth or Consequences

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Introduction

The cost of raising Holstein heifers to first calving at 24 months is about $1200, which is about 15 to 20% of the total costs for a dairy enterprise consisting of cows and replacement heifers (Heinrichs, 1993). Many consultants have focused on trying to decrease the cost of raising heifers as a means to increase farm profitability. One way to decrease these costs is "accelerate" the growth and breeding of heifers so they calve earlier; in fact, some suggestions for age at first calving are as early as 20 months. However, decreased heifer costs will only increase lifetime profits if profitability after calving is not compromised. Thus, just like in the old TV/radio program, we must examine the facts regarding "accelerated heifer growth". Will faster growth result in the prize of increased profitability? Or will it result in dire consequences?

Level of milk production is a major determinant of profitability of lactating cows (VandeHaar, 1998). Thus, breeding heifers for earlier calving must not significantly compromise subsequent milk production. Level of milk production of a cow is determined by the: 1) the ability of the mammary gland to produce milk, 2) the ability of the cow to provide the mammary gland with nutrients, and 3) the ability of the farmer to manage and care for the cow. The ability of the mammary gland to produce milk is largely dependent on its content of milk-secreting cells, which are found in the mammary "parenchymal" tissue (Tucker, 1987). The number of milk-secreting cells is determined by genetics and by the environment during mammary development, especially during the rapid mammary growth that occurs before and during the time of puberty, between 3 and 10 months of age (Sinha and Tucker, 1969). A good heifer rearing program is critical to produce animals at first calving that have well-developed mammary glands capable of producing to the animal's genetic potential and that have good body size and body condition capable of high feed intake and delivery of nutrients to the mammary gland. However, calving heifers as early as 20 months requires a body growth rate faster than 2 lb/day or body size at calving below 1250 lb. Both rapid gains and small size at calving can decrease subsequent milk production (Hoffman, 1997; Sejrsen and Purup, 1997). Thus, the decreased heifer-rearing costs associated with early calving must be weighed against the potential losses in milk income during the life of the cow. The goals of this paper are to review the effects of nutrition on heifer growth and future milk production and to make recommendations for feeding heifers from weaning to calving for maximum lifetime profitability.

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Desired body weight and body condition score at calving

The effects of body weight and body condition at calving on subsequent productivity have never been determined definitively in a "cause and effect" study. Most studies examining this relationship have done so using correlations; therefore, our current recommendations must be viewed with a healthy bit of skepticism. So what is the desired body weight? In high-yielding Holstein herds (>22,000 lb milk year), heifers typically conceive at 16 months of age weighing 910 lb and calve at 25 months, weighing at least 1360 lb before calving (Hoffman and Funk, 1992). Hoffman (1997) exhorts that, in most management situations, the optimal body weight for heifers just before calving is 1310 to 1420 lb, which results in postcalving weights of 1180 to 1280 lb. Field correlations suggest optimal body weight is 1200 to 1300 lb after calving and that lighter body weights result in lower milk production (Heinrichs and Hargrove, 1987; Keown and Everett, 1986;). Van Amburgh et al. (1998b) found that heifers weighing ~1260 lb after first calving produced 700 lb more milk in the first lactation than those weighing ~1150 lb. The potential problem with their data is that prepubertal body weight gain was confounded with calving body weight, and the reason that lighter weight heifers produced less milk might be that they grew too fast before puberty. The data of Van Amburgh et al. (1998b) also suggests that postcalving weights above 1300 lb for Holstein heifers actually decreased milk production. This may partly be due to heavy heifers having excess body fat. Animals with excess body fat before calving tend to eat less and probably mobilize more body fat before calving, which is associated with a greater incidence of dystocia, ketosis, and mastitis in the first month after calving (Dyk et al., 1995). Thus, we will assume that optimal body weight after calving is ~1250 lb for Holsteins (about 90% of mature body weight for other breeds) and optimal body condition score is 3.0 to 3.5. Optimal body length is 66 to 68 inches and withers height should 54 to 56 inches (Hoffman, 1997).

Effect of nutrition on growth, mammary development, and milk yield

To achieve a body weight of 1250 lb after calving, heifers must weigh ~1400 lb before calving, and they must gain an average of 1.8 lb/day if they are to calve at 24 months. Because daily gains are slower in the first 3 months of life, gains thereafter must approach 2.0 lb/day. If calving at 20 months is desired, then gains at peak growth must approach 2.4 lb/day. High energy diets and rapid gains after breeding have little effect on subsequent milk production if calving occurs at optimal body size (Grummer et al., 1995; Hoffman et al., 1996; Sejrsen et al., 1982; Valentine et al., 1987). Thus, this review will focus on the period of growth before puberty.

The period between 3 and 10 months of age is a critical time in mammary development. During this time, mammary growth is rapid and "allometric"; in other words, mammary tissues are growing at a faster rate than that of most other body tissues (Figure 1). The mammary parenchyma extends into the mammary fat pad in a "broccoli-like" fashion and forms the daughter cells which are the foundation for later mammary development. The number of parenchymal cells present at puberty partly dictates the number of milk-secreting cells that will be present during lactation. The best method to assess the number of mammary cells is by measuring the amount of parenchymal DNA.

Growth of the mammary gland once again becomes isometric (same growth rate as other body tissues) shortly after puberty, about the 2nd or 3rd estrous cycle. When heifers are grown rapidly in the first year of life, puberty is attained 1 to 2 months earlier, and the allometric mammary growth phase likely is shortened. Rapidly-grown heifers have less mammary parenchymal DNA around the time of puberty, indicating impaired mammary development. For example, Sejrsen et al. (1982) fed heifers at high or low intake of an energy-dense diet to gain 2.8 or 1.4 lb/day from 7 months of age to 700 lb body weight and found that heifers fed high energy had 32% less mammary parenchymal DNA than those grown slowly.

However, the responses to diets which promote rapid body gains varies considerably, from decreases in parenchymal DNA as much as 50% in some studies to no decrease in others. Some of the variation might be explained by differences in the laboratory techniques used to quantify mammary development or in differences in the actual rates of “rapid” gains, the genetic makeup of the animals, the ages of the heifers during treatment, or the dietary methods employed for achieving rapid gains. For example, Capuco (1995) observed a 48% impairment in mammary development when rapid gains were achieved from high intake of a corn silage-based diet but no impairment from high intake of an alfalfa-based diet. More recently, we conducted a study using the same laboratory techniques as Sejrsen et al. (1982), but using diets much higher in total protein and in rumen-undegraded protein (Radcliff et al., 1997). Diets were fed from 4 months of age to 2.3 months after puberty, when the heifers were killed. Compared to control heifers, heifers fed a high energy, high protein diet gained 2.7 lb/day, had more carcass and mammary fat, and reached puberty and were killed 1.6 months earlier, but, surprisingly, mammary development was not impaired (Table 1).

Other studies have examined effects of prepubertal nutrition on milk production in the first lactation. Decreases in milk production have occurred in almost all studies in which heifers gained weight more rapidly than 2.0 lb/day before puberty, but the magnitude of the response has varied from 5 to 50%. Furthermore, decreased milk yields are not clearly related to impaired mammary development before puberty. For example, in a study by Little and Kay (1979), high gain heifers grew more slowly after puberty and thus calved at lighter body weight; therefore, they devoted more energy to growth during their first lactation than control heifers. In later lactations, however, body weight was similar between groups, and rapidly-grown cows still produced 30% less milk and had 40% less mammary secretory tissue than control animals. In contrast, Capuco et al. (1995) found that rapidly-grown heifers fed a corn silage-based diet had 48% less mammary parenchymal DNA at puberty, but subsequent milk production was only reduced 5%.

The relationship of prepubertal growth and mammary development is further complicated by the interplay of genetics and management. Rapid growth rates are associated with decreased mammary development if the increased growth rate is caused by improved feeding and management, but perhaps this is not the case if the faster growth rate is caused by genetics. Van Amburgh et al. (1998b) found that rapid prepubertal growth (2.1 lb/day) significantly decreased milk yield but that many other factors affected milk yield as well. Thus, they found that the correlation between prepubertal growth rate and first lactation milk yield among 270 heifers was very low (r = 0.2). The genetic component of milk production masked the treatment effects in the correlation. Thus, within a feeding and management system, heifers that naturally grow faster may not have the lowest production. In fact, it seems possible that heifers that naturally grow faster may be the heifers with the highest growth hormone concentrations, the greatest appetites, or the best immune systems, and these same heifers may give more milk as cows. I have heard the comment, "Our heifers grow fast and calve at 20 months, and they produce 20,000 lb of milk in their first lactation. They obviously don't have impaired mammary development." The problem with this logic is that these same heifers might have produced 22,000 lb if they had been managed to grow a little slower and calve a little later.

Our current understanding of mammary development is that heifers that are grown more rapidly than 2.0 lb/day are at great risk for decreased milk yield in first lactation. The fact that decreased mammary development and subsequent milk yield are not always observed indicates that specific feeding and management practices might reduce this risk. But, exactly what these practices might be is not clear.

Thus, although the relationship between mammary development before puberty and subsequent milk production apparently can be overridden, our current understanding of mammary development is that heifers that are grown more rapidly than 2.0 lb/day are at great risk for decreased milk yield in the first lactation. The fact that decreased mammary development and subsequent milk yield are not always observed indicates that specific feeding and management practices might reduce this risk.

Does dietary protein make a difference?

One factor that may explain some of the variation in effects of prepubertal diet on mammary development in heifers is the ratio of protein to energy in the diet. Although we commonly evaluate diets based on protein as a percentage of dry matter, animals actually need a specific percentage of dietary calories to come from protein. So if the energy concentration of a diet is increased, the protein concentration also should be increased. According to the 1978 Dairy NRC, prepubertal heifers should be fed diets with 54 g of crude protein (**CP**) per Mcal of metabolizable energy (**ME**). The 1989 NRC increased the recommended CP:ME ratio to 60 g/Mcal for heifers from 3 to 6 months of age and dropped the ratio to 50 g/Mcal for heifers from 6 to 12 months of age.

To determine if differences in dietary protein would account for some of the variation in mammary responses to high energy diets and rapid gains, the relationship between mammary development or milk yield and the dietary protein to energy ratio was analyzed from published studies in which rapid gains exceeded 2.0 lb/day and in which diets were adequately described (VandeHaar, 1997). Groups of heifers from 11 studies were examined (Capuco et al., 1995; Gardner et al., 1977; Gardner et al., 1988; Little and Kay, 1979; Peri et al., 1993; Petitclerc et al., 1984; Radcliff et al., 1997; Radcliff et al., 1998; Sejrsen et al., 1982; Valentine et al., 1987; Van Amburgh et al., 1998b). Estimated CP:ME ratio was based on reported nutrient values and ingredient concentrations and varied considerably among the studies, from 43 to 83 g/Mcal. Mammary development was calculated as amount of parenchymal DNA or yield of milk in rapidly grown heifers as a percentage of that of control heifers in each study.

Across the studies, mammary development of rapidly-grown heifers relative to their controls was positively correlated with the CP:ME ratio of the diets they were fed. Furthermore, CP:ME accounted for 51% of the variation in mammary parenchyma responses and 78% of the variation in milk yield responses to rapid growth rate (Figure 2). This analysis suggests that inadequate protein might have been responsible for the impaired mammary development of heifers grown more rapidly than 2.0 lb/day in several published studies. One problem with this analysis is that increases in dietary CP do not always result in increased protein for absorption. Estimates of absorbed protein (**AP**) were made using an equation for microbial protein yield with an intercept forced through 0 (to be discussed later). Absorbed protein accounted for 36% of the variation in milk yield responses and 88% of the variation in parenchymal DNA responses.

Dietary protein is only one among several potential confounding factors that may explain the variation in mammary responses in the literature. Potential sources of variation, for responses in milk yield of 11 groups of rapidly-grown heifers were examined in a multiple regression analysis. Three factors were most important in explaining the variation and a simple model with all three factors was highly significant ($P < 0.01$; Table 2). The average gain of controls in the studies was 1.6 lb/day. The implications of this model are discussed below. If a heifer gains 2.0 lb/day and is fed a diet with AP:ME similar to NRC recommendations (~14% CP), the model predicts that milk yield would be 81% of that of control heifers. If the heifers are fed high protein (~20% CP), the model predicts that milk yield would increase to 96% of controls. If the heifers grow at 2.4 lb/day before breeding, milk yield would drop to 77% of controls even if they were fed a high protein diet. Finally, the model predicts that milk yield would drop another 7% if the rapidly-grown heifers weighed 50 lb less than controls at first calving. This analysis gives indirect evidence that increasing the dietary protein of prepubertal diets may allow growth as rapid as 2.2 lb/day with mammary development that is essentially normal.

Very few studies have been designed specifically to examine the effects of dietary protein on mammary development. Interestingly, in the study of Capuco et al. (1995), high rates of gain did not impair mammary development when the diet was alfalfa-based and contained 83 g CP / Mcal ME but did when the diet was corn silage-based and contained only 54 g/Mcal. Although the authors speculated that the different responses were caused by the different bulk densities of the two diets, the low protein of the corn silage diet seems a more likely explanation. In a study with Italian Friesians, Pirlo et al. (1997) fed diets that were low or high in energy and low or high in protein relative to NRC suggestions. Age, body weight, and body condition score were similar for the groups. Heifers fed the low energy and protein diet grew at 1.3 lb/day before puberty and produced the most milk fat and protein. Heifers fed the high energy but low protein diet grew 1.7 lb/day and produced 10% less fat-corrected milk and 15% less protein than the controls. But when heifers were fed high energy with high protein, they grew 1.9 lb/day and produced 5% less fat-corrected milk and nearly as much protein as the low controls. Certainly more work is needed to determine the effect of dietary protein on mammary growth and to determine the specific ratio of protein to energy to feed growing heifers for optimal mammary growth.

The amount of protein that should be fed to young heifers is not clear, but based on the data of Figure 1, NRC (1989) standards for CP:ME ratio may not be adequate when heifers are grown at rates faster than those suggested by the NRC tables. Mammary impairment can be severe even when heifers are fed CP:ME ratios around 54 g/Mcal. Recommendations for protein in NRC seem adequate for good carcass growth and composition at body gains as rapid as 2.2 lb/day (Bagg et al., 1985; Kertz et al., 1987). However, studies examining the protein requirements of heifers have not directly measured effects of protein on mammary development. Such studies, although expensive, are necessary if early calving is to be practiced commonly on farms.

One caution against high dietary protein is that it may decrease fertility. Heifers fed diets high in degradable protein with 81 g CP/Mcal ME had first-service conception rates of 60% compared to 80% for heifers fed standard diets with 57 g CP/Mcal (Elrod and Butler, 1993). Thus, the optimal CP:ME ratio for prepubertal heifers may be ~65 g/Mcal, and this could be dropped 1 to 2 months before breeding occurs.

The analysis shown in Figure 2, however, indicates that NRC (1989) standards for CP:ME ratio may be inadequate, especially if gains are more rapid than suggested by NRC. Two important points about NRC protein recommendations are: 1) they were not designed with gains as rapid as 2.0 to 2.2 lb/day and 2) NRC standards are based on optimal diets for body growth, not mammary development.

Based on an analysis of the literature, the following conclusions and recommendations are offered:

1. Heifers grown faster than 1.8 lb/day will likely produce less milk as cows if they are fed diets with protein at or below NRC recommendations. This is most commonly a problem when heifers are fed diets high in corn silage with inadequate protein supplementation.

2. Feeding high protein (~65 g CP/Mcal ME) can reduce the impact of rapid gains on mammary development and subsequent milk yield and may enable gains as rapid as 2.1 lb/day with very little decrease in subsequent milk production.

3. Even with high protein, feeding heifers for gains faster than 2.1 lb/day will likely decrease milk yield and is not recommended.

4. Rapidly-grown heifers often grow slower than expected after breeding. Unless they are fed and managed to maintain high rates of gain, they will likely calve at lighter weights than control heifers and produce even less milk during lactation.

5. Accelerated growth programs, with a goal of calving at 22 months, require excellent reproductive management. Delayed breeding may cause overfattening in too many heifers.

Effect of heifer feeding program on lifetime profitability

Although the cost of raising a heifer to first calving is not trivial, it is substantially less than the gross income generated from subsequent milk sales.

Thus, in developing a cost-effective heifer rearing program, one must weigh the costs of heifer rearing versus the potential impact on net income of the animal after calving. Early calving may decrease heifer costs, but if mammary development or body size at calving is decreased, early calving may be an expensive mistake.

Some dairy management experts have attempted to examine the economics of early calving with a simple formula. First, they assume that milk production will not be impaired so that the only consideration becomes costs of heifer rearing. Then they assume that if raising a heifer to first calving costs $1200, heifer costs are $50 per month. With this simple model, lifetime profit is increased $200 if calving is expedited from 24 to 20 months. However, this logic fails to consider that early calving does not decrease many types of heifer-rearing costs, such as the initial calf value, the costs of bottle-feeding calves, vaccination costs, and breeding costs. Furthermore, some costs will most likely increase, such as daily feed costs. Perhaps even some nonfeed costs will increase. Better housing and ventilation may be needed, health costs may be greater if heifers are fed more grain, and heifers may require more bedding as they eat more and defecate more. Regarding feed costs, not only will heifers require more calories per day to grow faster, but the feed will likely cost more per calorie as more nutrient-dense feedstuffs are used.

Possible economic outcomes (Table 3) for raising heifers were examined in a model that breaks costs into one-time fixed costs (cost of calf, bottle-feeding costs, vaccinations, and breeding), feed costs (dependent on daily ME intake and cost per Mcal ME), and daily non-feed costs (housing, bedding, labor, utilities, taxes, etc.). Profitability after calving in the model is dependent on level of milk production, amount of feed required for milk and growth, and fixed costs (VandeHaar, 1998). As Table 3 illustrates, feeding for higher rates of gain to calve at heavier body weights is expected to increase profits by $1700 per 100 cows in a dairy enterprise consisting of cows and all replacement heifers (compare programs 1 and 2) if the increased body weight increases milk yield 1000 lb in the first lactation. The net return to heavier calving would decrease if the cost of grains and protein supplements increased relative to forages and byproduct feeds and would increase as milk price increased relative to feed costs. Feeding for higher rates of gain to calve at 22 months instead of 24 months also can increase profits. For example, compared to program 1, program 3 is expected to decrease total heifer costs by $41 and increase profits by $1500 per year per 100 cows.

Combining heavier body weights and earlier calving may also be beneficial, and calving even earlier than 22 months may increase profits further. For example, calving at the optimal body weight of 1250 lb at 20 instead of 24 months may increase farm profits $2500 per 100 cows (compare program 2 with 6a). However, decreasing calving age does have risks -- to date, all studies in which heifers gained faster than 2.0 lb/day have reported at least a 5% reduction in milk yield. If milk yield was impaired in the first lactation alone by 10%, calving at 20 months would decrease profits $3900 per 100 cows (compare program 2 with 6b). Of course, more severe first-lactation impairment or impairment into later lactations would decrease profits even further. In addition, these assumptions were based on a milk price of $12 per 100 lb; the loss in profits would be more than $5000 if milk price was $14.

Perhaps high protein diets before puberty can overcome this impairment, but more studies are needed before we can be confident that feeding high protein will eliminate the risk of impaired mammary development. Feeding more protein before puberty would cost ~$15 per heifer. At the present time, this $15 cost seems a reasonable investment given that even prepubertal gains of 2.0 lb/day have impaired mammary development at protein levels commonly used on farms.

Finally, if heifers are grown at the same average daily gain, lifetime profit would be about the same whether they calved at 22 months weighing 1150 lb or at 24 months weighing 1250 lb (compare programs 2 and 3). Thus, the decision on whether to breed heifers for earlier calving should be based on availability of space to house heifers relative to availability of space to house lactating cows. If heifer space is in short supply, perhaps earlier breeding even at lighter body weight should be considered.

One other purported benefit of early calving is more calves born per year. However, this benefit is only a short term one because space for lactating cows generally limits the number of animals on most farms. Therefore, more calves will be born during the time that management is switched to earlier calving, but in the long-run, calves born per year depends on number of lactating cows on the farm (Figure 3) and should not be used in the decision to move toward earlier calving.

For most well-managed, intensive-feeding operations, the most profitable age for first calving is likely 22 to 24 months. First calving at greater than 24 months will likely reduce profitability, unless feed or fixed costs are unusually low, as may be the case for heifers grown on pasture. Pasture generally has a very low cost per Mcal of ME. Even in pasture systems, however, gains of 1.8 lb/day are attainable through intensive-grazing or grain supplementation, and 22 to 24 months may be most profitable. Decreasing the age at first calving to less than 22 months may increase profits further if milk production is not impaired, but impaired milk production is certainly a risk. To date, this risk is not worth taking.

Goals for Heifer Growth

Previous recommendations to calve heifers at 22 to 24 months of age at a body weight of 1200 to 1300 lb after calving seem reasonable (Hoffman, 1996). Thus, targets for heifer rearing in intensive management conditions are:

- Age at first calving = 22 to 24 months,
- Body weight after calving = 1250 lb,
- Height at calving = 56 inches at the withers,
- Body condition score at calving = 3.0 to 3.5, and
- Growth rate from 3 to 10 months of age = 1.7 to 2.0 lb/day.

To achieve these goals for calving, heifers should be compared to the recommended weights and heights of Figures 4 and 5, and bred at 13 to 15 months, standing 51 inches at the withers and weighing 850 lb.

Feeding heifers to achieve these goals

Nutrition models are needed in evaluating diets to determine if the supply of nutrients from the diet matches the nutrient requirements of the animal. So how good are our models of heifer nutrition? The simple answer is not very good.

In the study of Radcliff et al. (1997), we fed heifers diets with 75% grain or 90%

forage ad libitum for rapid or standard gains. Ad libitum feed intake is shown in Figure 6 and compared to several predictions. The 1989 Dairy NRC is not included because it does not attempt to predict ad libitum intake. Heifers fed a high grain TMR ate 20% more than predicted by the 1984 Beef NRC, and slightly more than predicted by the 1996 Beef NRC, Spartan Dairy Ration program (VandeHaar et al., 1992), or equations developed at Virginia Polytechnic Institute (Hubbert, 1991; Quigley et al., 1986). Heifers fed a high forage TMR ate less than predicted by the 1984 or 1996 Beef NRC models or the equation of Quigley et al. (1986) and about the same amount as predicted by Spartan Dairy (VandeHaar et al., 1992) or Hubbert (1991). Overall, the recent equation from VPI was reasonably accurate under the feeding conditions of our heifers.

More importantly, however, heifers fed the high forage TMR gained more than twice as much as predicted by the 1989 Dairy NRC (Figure 7). Predictions for gain were close to actual gains for heifers fed the high grain TMR. Van Amburgh et al. (1998a) recently published observed versus expected gains for 270 heifers based on actual energy intake and found similar results. The 1989 Dairy NRC underpredicted gains of heifers grown at 1.3 lb/day by half but was reasonably accurate for heifers gaining 1.8 lb/day. The Cornell Net Carbohydrate and Protein System (CNCPS), a much more mechanistic model than the 1989 Dairy NRC, was no better. So why do these models underpredict gains? The most likely explanation is that modern Holstein heifers fed high forage TMR grow with more lean gain and less fat gain than expected and thus more total gain per unit of feed energy input. Another possibility is that dietary forage is retained in the digestive tract longer than expected in heifers so that digestibility and consequently gains are greater than expected as well.

Van Amburgh et al. (1998a) also compared the expected gains based on protein intake with actual gains. They found that the 1989 Dairy NRC underpredicted gains based on protein supply for heifers at the slower gain rates, but that the Cornell Net Carbohydrate and Protein System (**CNCPS**) predicted that protein supply was usually in excess for heifers regardless of actual rate of gain. The most likely reason for this difference is that the NRC uses an equation with a negative intercept to estimate microbial protein yield and thus underpredicts it for young heifers. Hence, in the young heifer (less than 6 months), NRC requires unreasonably high levels of rumen-undegraded protein to counter the apparent lack of microbial protein production. In the Spartan Dairy program, we used an equation proposed by Erdman and Komaragiri (1991) that uses a positive intercept to predict microbial yield (Figure 8). Interestingly, this equation predicts a microbial yield nearly identical to that of the CNCPS for prepubertal heifers. However, the CNCPS overpredicts microbial yield for prepubertal heifers, as mentioned by Van Amburgh et al. (1988a) and clearly seen in the paper describing the model (O'Connor et al., 1993). A much simpler model for predicting microbial yield for prepubertal heifers would be one based on ME intake alone and forced through zero (no intercept). One possible equation would be: microbial protein (g/day) = 38 $\times$ ME intake (Mcal/day). Assuming that ME is converted to NE with 62% efficiency, the equation could also be written as 61 $\times$ NE_m intake. This equation would be very easy to implement and likely more accurate for prepubertal heifers than either the 1989 Dairy NRC or the more mechanistic and complex CNCPS. This equation was used in estimating absorbed protein for analyzing the effect of dietary protein on mammary development earlier in this paper.

In fact, just using the CP system likely works just fine for growing heifers, if it is used with a bit of common sense. In other words, heifers should be fed mostly true protein sources (such as soybean meal) as the CP supplements, but a little urea or other form of non-protein nitrogen is okay in certain diets. In a comparison of the 1984 and 1996 version of the Beef NRC for actual versus predicted duodenal flow of true protein, Zinn and Shen (1997) found that, while the 1984 version (using only crude protein) accounted for 59% of the variation in observed duodenal flows, the 1996 version (using the CNCPS model) accounted for only 65% of the variation. This is hardly an improvement considering the difference in complexity of the two systems, indicating that there is a lot we do not yet understand about ruminal protein metabolism.

In the study of Van Amburgh et al (1998a), the average gain of all heifers was 1.80 lb/day. Predicted gain based on the most limiting nutrient for the 1989 Dairy NRC was 1.50 lb/day, and the CNCPS was only slightly better at 1.56 lb/day.

Thus, regarding our ability to feed heifers to meet growth targets, the following conclusions are made:

1. Dairy heifers fed high forage TMRs ad libitum are more efficient in using consumed energy than current models predict.

2. In addition, current models are often inaccurate at predicting feed intake.

3. Under good environmental conditions and management, dairy heifers usually will grow considerably faster than expected when fed a TMR for ad libitum intake. In other words, if you balance a diet for 1.8 lb/day, the heifers may very likely grow 2.3 lb/day.

4. Under poor environmental conditions, heifers may grow considerably slower than predicted. Some models, such as the CNCPS, do try to account for such conditions and likely work better than the 1989 Dairy NRC for formulating diets when conditions are poor. However, environmental conditions are often difficult to accurately define, so accuracy of the model may still be a problem.

5. Therefore, don't assume any computer program will accurately predict gains in Holstein heifers. Let the heifers be the judge of any feeding program. If weights cannot be measured, use heights and body condition.

6. For prepubertal heifers, complicated models for formulating diets for heifers usually are no better than simple ones. For protein, the CP model as found in 1989 Dairy NRC can work well if most protein comes from true protein sources of average rumen undegradability. Diets should contain 60 to 65 g of CP per Mcal of ME or ~100 g CP per Mcal NE_m with rumen undegradable protein at 25 to 35% of the total protein.

Recommended daily gains and dietary energy and protein concentrations are given in Table 4. These recommendations assume feed will be offered as a TMR for ad libitum intake. Although NRC works well when heifers are fed at restricted intake (Bortone et al., 1994), NRC tables were not developed for ad libitum feeding. Ad libitum feeding may be desirable in group-feeding situations. Thus, these recommendations for dietary energy concentration are lower than those of NRC (1989) to achieve target gains of 1.8 lb/day. Instead the recommendations are based on data from the study of Radcliff et al. (1997; unpublished data), in which heifers were group-housed in a comfortable yet confined environment, were kept healthy, had water and feed available all day with plenty of bunk space, and were fed their diet as a TMR. In some situations, higher energy diets may be needed to meet the target gains. The recommendations for protein are higher than recommended by NRC or by many computer programs, including Spartan Dairy 2.0 (VandeHaar et al., 1992).

Summary

A good heifer rearing program is critical to produce animals at first calving that have well-developed mammary glands capable of producing to the animal's genetic potential and that have good body size and body condition capable of high feed intake and delivery of nutrients to the mammary gland. Weight gains more rapid than 2.0 lb/day before puberty generally decrease development of the mammary gland and subsequent milk production. However, in many of the reported studies, heifers were fed diets with marginal protein content. Feeding more protein when heifers are grown rapidly will reduce the risk for impaired mammary development and is probably worth the added expense when trying to achieve postpartum body weights of ~1250 lb and calving at 22 to 24 months. Although calving earlier than 22 months may decrease the costs of raising heifers further, heifers fed high energy diets for rapid gains before puberty are at risk for impaired mammary development and such practices are not recommended. Heifer-rearing is not just an expense but an investment, and when done wisely, it can yield great dividends!

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Table 1. A high energy, high protein diet promoted normal mammary development (Radcliff et al, 1997).

	Control	**Rapid gain**	*P*
Daily gain, lb/day	**1.7**	**2.7**	0.01
Age at puberty, mo.	**10.3**	**8.7**	0.01
Body weight at slaughter, lb	740	870	0.01
Body condition score	2.9	3.9	0.01
Carcass fat, lb	62	123	0.01
Carcass protein, lb	65	80	0.01
Mammary total fat, g	580	1,130	0.01
Mammary lean parenchyma, g	213	232	
Mammary parenchymal DNA, mg	**1,470**	**1,820**	0.05
Mammary parenchymal DNA, mg/ lb carcass protein	**22**	**23**	

Table 2. Multiple regression analysis of factors affecting fat-corrected milk yield (expressed as a percentage of controls)of rapidly-grown heifers[1].

Parameter	**Estimate**	**SEM**	**P**
Intercept	-45	49	0.4
Prepubertal weight gain, % of control	-0.46	0.12	0.01
Dietary absorbed protein, g / Mcal ME	+1.4	0.4	0.01
Calving body weight, % of controls	+1.5	0.4	0.01

[1]SEM = standard error of mean and ME = metabolizable energy.

Table 3. Possible impacts of heifer-rearing program on lifetime income and expenses.

Rearing program:	1	2	3	4	5	6a	6b
Calving age, month	24	24	22	22	20	20	20
Weight after calving, lb	1150	1250	1150	1250	1150	1250	1250
Weight gain from 3 to 10 months, lb/day	1.8	2.0	2.0	2.2	2.2	2.4	2.4
First lactation milk yield, lb	18,500	19,500	18,500	19,500	18,500	19,500	17,550
Total heifer costs[1], $	1184	1246	1143	1211	1107	1174	1174
Net income as a cow[2], $	2586	2694	2586	2694	2586	2694	2513
Annual farm profit per 100 cows[3], $	49,400	51,100	50,900	52,300	52,200	53,600	47,200

[1] Feed costs from birth to calving for programs 1 to 6 are assumed to be 4.4, 4.5, 4.5, 4.7, 4.7, and 4.9 cents / Mcal ME, respectively, which results in average daily feed costs of 66, 73, 71, 79, 77, and 86 cents. Costs other than feed are considered to be $200 plus daily nonfeed costs of 69, 71, 71, 72, 72, and 74 cents for programs 1 to 6, respectively.

[2] Income minus expenses as a cow, assuming cow will be sold at end of third lactation, so life consists of three 305-day lactations and two 60-day dry periods. Income is from sales of milk at $12/100 lb, three calves at $100 each, and final sale of cow at $500. Milk yield during second and later lactations is assumed to be 22,000 lb. Milk yield for column 6b is decreased 10% in the first lactation but not in subsequent lactations. Feed costs for cows are calculated using energy requirements based on NRC (1989) and an average cost of 8 cents/Mcal NE_L during the lactation and dry periods. Total non-feed costs as a cow are assumed to be $120 per calving plus $3.00/day of lactation and $1.50/day during dry period.

[3] Profitability on a per cow per year basis of a dairy enterprise including cows and heifers. This was calculated as lifetime profit per animal divided by the 2.83 years spent as a cow times 100 cows.

Table 4. Growth goals and recommendations for feeding Holstein heifers ad libitum.[1]

Age (months)	Weight (lb)	Gain (lb/day)	Height (inches)[2]	ME[3] (Mcal/lb)	NE_m [4] (Mcal /lb)	CP[5] (% of DM)	CP:ME g/Mcal[6]
2	167	1.76	34.1	1.33	0.80	19.3	66
4	279	1.96	37.6	1.27	0.76	18.4	66
6	398	2.00	40.8	1.18	0.71	17.1	66
8	517	1.97	43.9	1.12	0.67	15.5	63
10	634	1.93	46.7	1.12	0.67	15.5	63
12	748	1.89	48.7	1.08	0.65	14.3	60
14	860	1.84	50.4	1.08	0.65	14.3	60
16	970	1.81	51.7	1.08	0.65	13.3	56
18	1,077	1.79	52.8	1.08	0.65	13.3	56
20	1,184	1.76	53.8	1.08	0.65	13.3	56
22	1,290	1.76	54.8	1.08	0.65	13.3	56
23	1,343	1.76	55.2	1.08	0.65	13.3	56
24 precalf	1,400		55.6	1.20	0.72	15.8	60
24 postcalf	1,250		55.6	1.30	0.78	18.0	63

[1] Targets for other breeds could be calculated using these weights as references with the goal of attaining 90% of mature body weight at 24 months.
[2] Height at the withers.
[3] Concentration of metabolizable energy in diets. ME is approximately NE_m divided by 0.6.
[4] Concentration of net energy for maintenance in diets. NE_{gain} is approximately 0.66 times NE_m.
[5] Concentration of crude protein in diets. Special protein sources high in undegraded protein likely are not needed in most heifer diets. Most of the supplemental CP should come from true protein sources, such as legume forages and soybean meal. Urea should not be used as the CP supplement.
[6] Recommended ratio of CP to ME in heifer diets. To calculate this ratio, multiply Mcal ME / lb by 2.2 to give Mcal ME / kg. Then multiply CP (% of DM) by 10 and divide by Mcal ME / kg. At 66 g/Mcal, about 26% of the dietary calories are from protein.

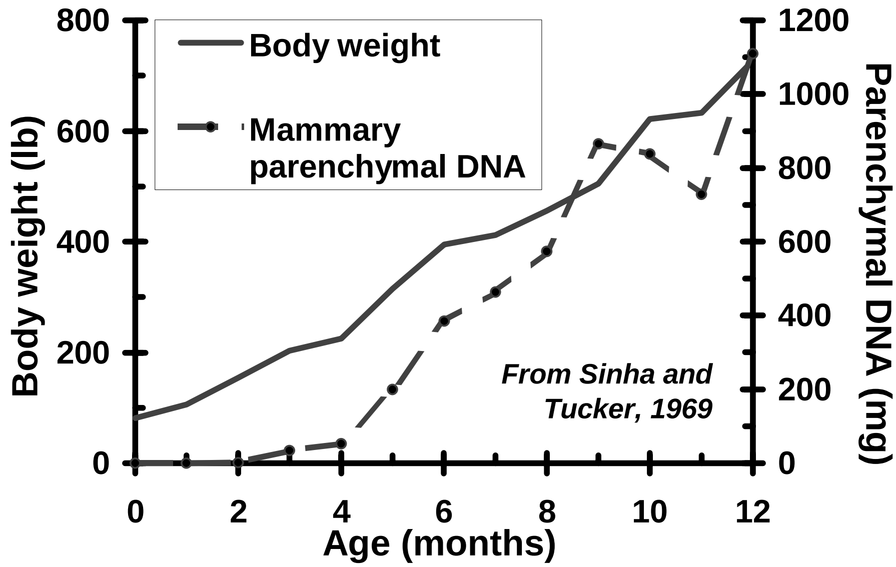

Figure 1. From 3 to 10 months of age is a time of rapid mammary development.

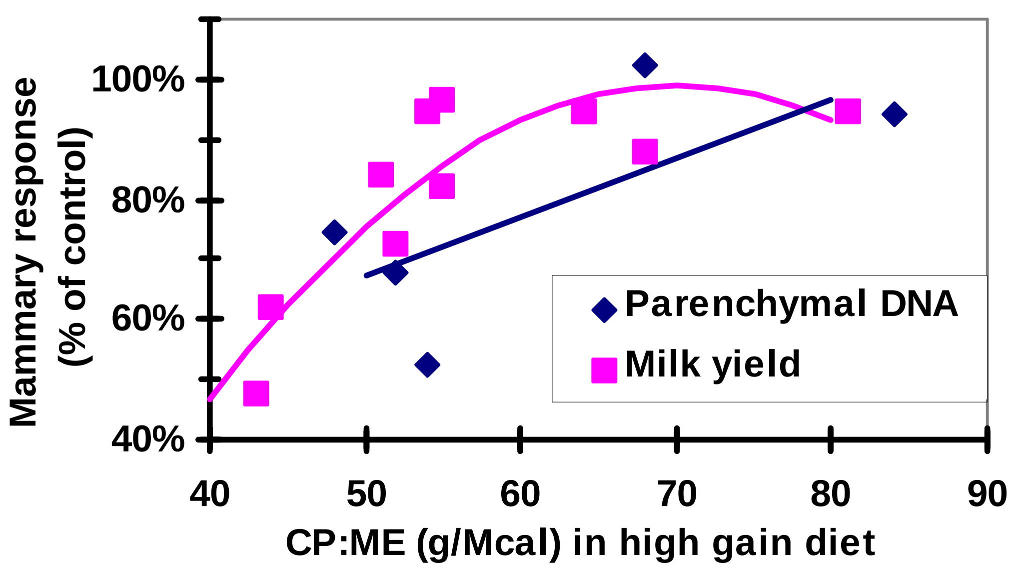

Figure 2. Dietary protein and mammary development across several studies. The response of mammary development or milk yield of heifers grown faster than 2.0 lb/day, relative to their respective controls, was regressed against the protein to energy ratio of their diets. Only studies in which diets were adequately described were included in the analysis. Data are from Capuco et al., 1995; Gardner et al., 1977; Gardner et al., 1988; Little and Kay, 1979; Peri et al., 1993; Petitclerc et al., 1984; Radcliff et al., 1997; Radcliff et al., 1998; Sejrsen et al., 1982; Valentine et al., 1987; and Van Amburgh et al., 1998b. Across the studies, mammary development of rapidly-grown heifers relative to controls was positively correlated with CP:metabolizable energy (ME), and CP:ME accounted for 51% of the variation in mammary parenchyma responses and 78% of the variation in milk yield responses to rapid growth rate.

Figure 3. Heifers calving per 2 month period in a herd of 100 cows after making a switch to breed all heifers by 11 months of age instead of 15 months of age. The number of cows calving per 2 months is assumed to be 16.7.

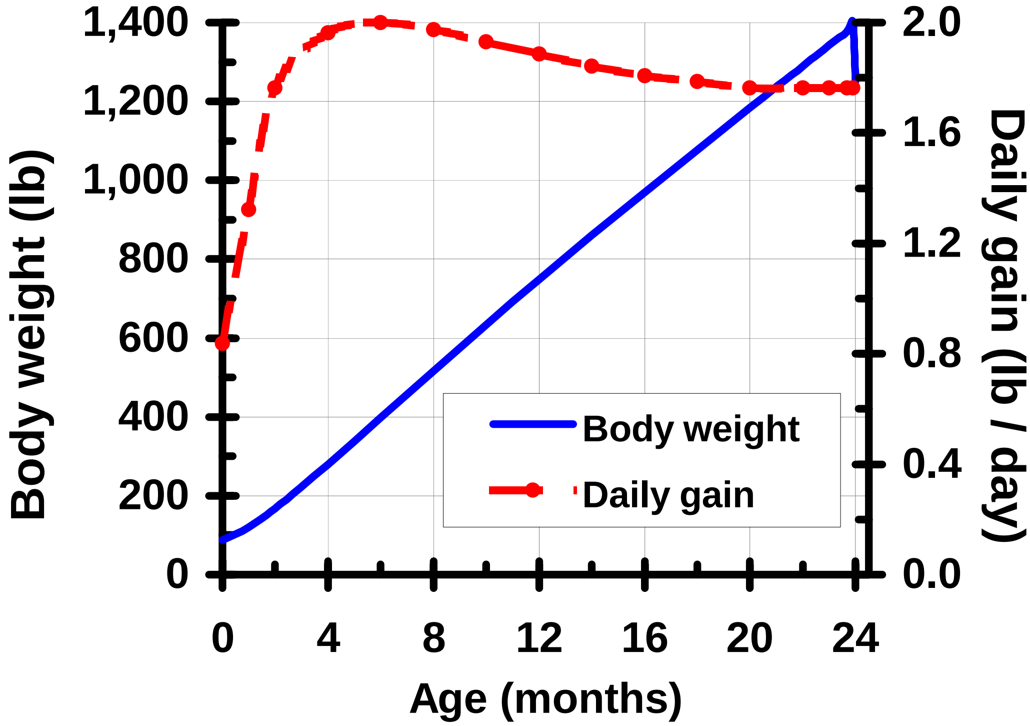

Figure 4. Recommended body weights for Holstein heifers with calving at 24 months.

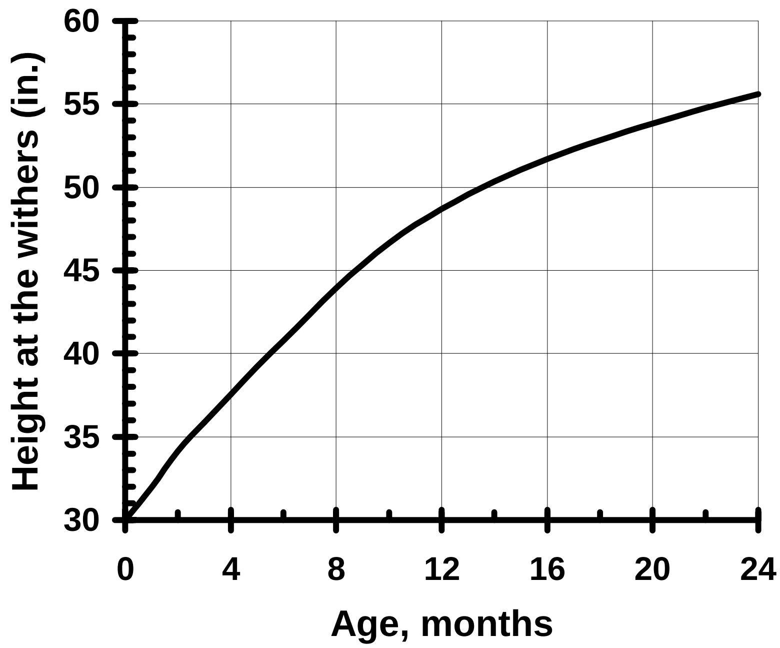

Figure 5. Recommended heights for Holstein heifers with calving at 24 months.

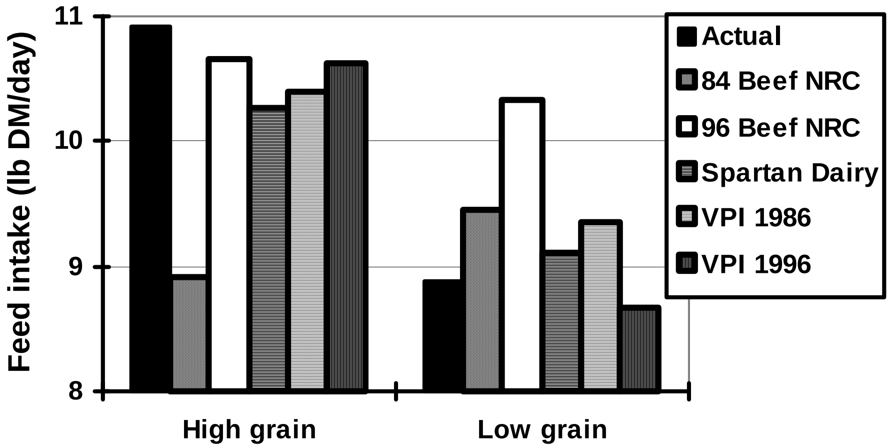

Figure 6. Actual feed intake of heifers from 4 to 6 months of age compared to predictions based on several models. Prediction equations are:

- 1984 Beef NRC: $BW^{0.75} \times (0.1462 \times NE - 0.0517 \times NE^2 - 0.0074)$
- 1996 Beef NRC: $SBW^{0.75} \times (0.2435 - 0.0466 \times NE - 0.1128/NE) \times 1.08$
- Spartan Dairy: $0.02 \times BW + 1.0 \times Gain$
- VPI 1986 (Quigley et al. 1986): $-29.86 - 0.0000154 \times BW^2 + 0.157 \times BW^{.75} + 2.09 \times Gain - 0.118 \times Gain^2 + 73 \times TDN - 48.2 \times TDN^2 - 0.00136 \times BW \times Gain - 1.91 \times TDN \times Gain$
- VPI 1996 (Hubbert, 1991): $-1.71 + 0.0429 \times BW - 0.0000246 \times BW^2 - 0.023 \times BW \times ADF + 3.2 \times ADF - 6.8 \times ADF^2$

where DMI is dry matter intake in kg, BW is body weight in kg, NE is net energy for maintenance in Mcal / kg of feed, SBW is shrunk BW which was considered to be 97% of BW, gain is in kg/day, TDN is total digestible nutrients as a fraction of DMI, and ADF is acid-detergent fiber as a fraction of DMI.

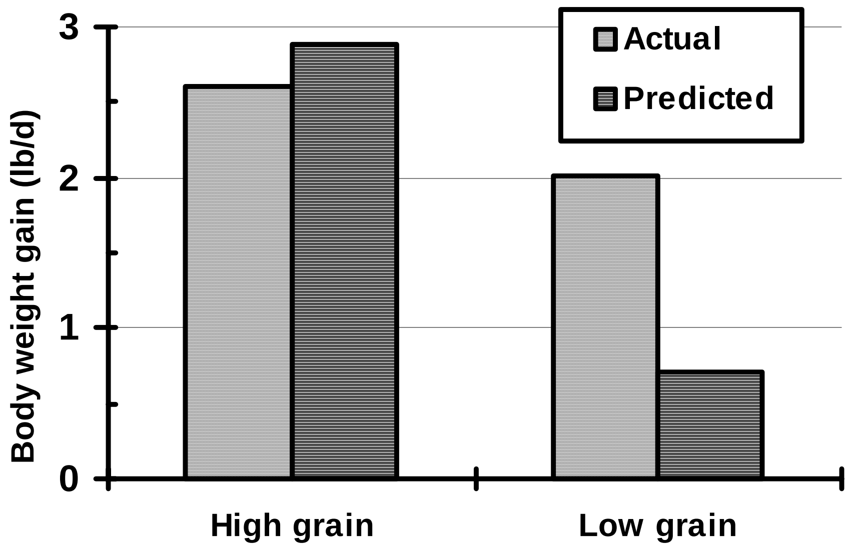

Figure 7. Actual daily body weight gain of heifers from 4 to 6 months of age compared to predictions based on the 1989 Dairy NRC. Data are from the study of Radcliff et al. (1997).

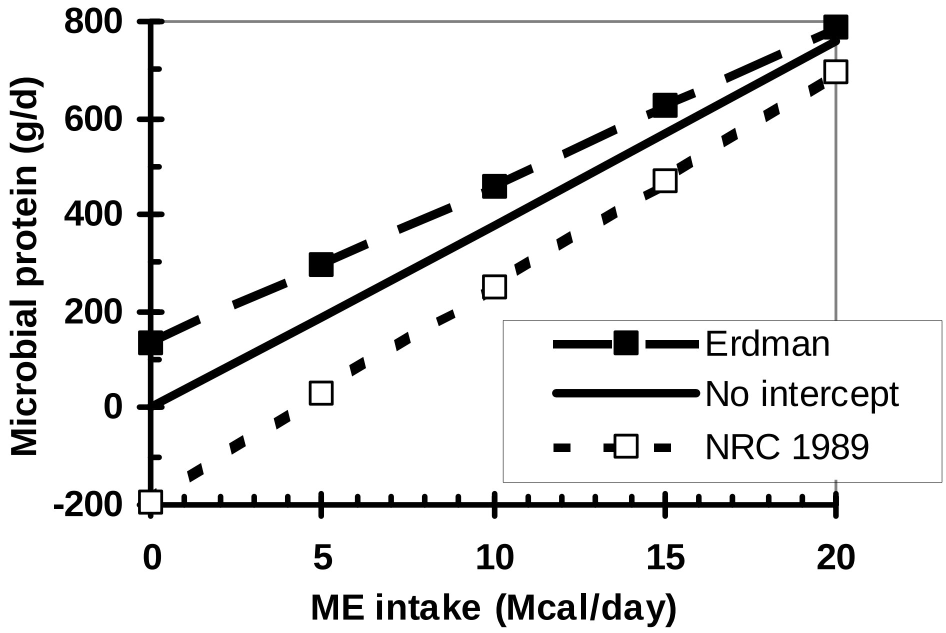

Figure 8. Equations for predicting microbial protein yield in heifers. The equations are:

- NRC Dairy (1989): microbial protein (g/d) = -193 + 44 x ME intake (Mcal/day)
- Erdman and Komaragiri (1991): microbial protein (g/day) = 135 + 32 x ME intake (Mcal/day)
- No intercept proposal: Microbial protein = 38 x ME intake (Mcal/day)

Experiences With Teams on Dairy Farms

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At the Tri-State Dairy Nutrition Conference in 1993, Dr. Rob Davis defined some of the ways in which farm service professionals need to change in order that they may better serve the dairy producer. In this discussion he remarked that "we all need to take a close look at how we interact not only with our clients but with each other", recognizing the limits of traditionally compartmentalized professional roles in dealing with the complex management issues on progressive dairy farms.

We operate a dairy farm referral practice for a university based extension service, and it has been interesting to explore how the professional interactions referred to by Dr. Davis can play out on the farm to the benefit of the producer. In many cases, a professional nutritionist, industry feed representative, veterinarian, county extension educator, facilities consultant, or the farmer, have recognized the opportunities in bringing together and integrating expertise in the solution of herd health and production problems. In most situations, this team approach utilizes the existing group of farm professionals by the simple expedient of getting them on the farm at the same time. This can be done with a little planning, and routine meetings of this sort may already form part of the management strategy of the successful dairy farm.

Teams are not the answer to every problem. In many situations, a disease problem falls within the expertise of the veterinarian, a feed issue is squarely in the bailiwick of the nutritionist, and financial advice may fall within the province of the county extension educator, banker, or other financial officer. The value of the team is in addressing problems which encompass different areas of expertise, either as health or production problems, or in the planning and decision making process in such areas as herd expansion. Teams are also essential where it is not clear where the problem lies. In these cases, the team is especially useful in deciding whether the observed symptoms are a primary or secondary manifestation of the problem.

Team Troubleshooting

In this discussion, with teams are addressed for the purpose of problem solving health and production problems, but the team approach is even more essential in planning new facilities or in making herd expansion decisions or other major management changes.

Structuring the Team

The team may consist of two or more people and the nature of the team reflects the nature of the problem. The problem is

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frequently not well defined but often consists of a combination of health problems or deaths and production failures. One of the team members needs to take the responsibility for managing the process. Good communication among the team members is essential. Nutrition has an impact on almost all aspects of health and production. With the exception of mastitis, the majority of health problems in adult dairy cattle have a metabolic basis. Because of the centrality of their skills to the success of the dairy operation, nutritionists (especially feed sales representatives who operate in a highly competitive environment) are vulnerable to arbitrary dismissal from the farm. It is important that the problem-solving process does not undermine the position of the nutritionist or feed sales person on the farm. Their role as advisers is critical, and the time taken to replace them and for the new incumbent to develop a perspective on the farm operation is substantial.

Structuring the Investigation

When a group of people work together to solve problems on the farm, it is essential that it be done in a systematic manner. It is important to initially share the history to see if there is a common version of the problems the farm is facing. Veterinarians and nutritionists may have different views of what is occurring, and the farmer often has concerns that have not been clearly expressed in routine contacts with farm advisers. At this time, it is also important to establish by observation, measurement, or testing, the parameters that are going to define the problem and form the basis for diagnosing it and solving it. We have adopted the approach of having an initial phase of data collection, which may involve some or all of the team members, followed by the preparation of an initial report which includes the agenda for a farm meeting (Kenyon et al., 1996). At this meeting, the data and the observations of the various team members are reviewed. Problems can then be prioritized, and a consensus reached as to the favored options. This open review and discussion process is particularly important, because it is at this time that the producer takes the lead in the decision making process with the support of the other team members. The leader of the advisory group is now responsible for writing a final report which summarizes the issues, captures the points of discussion, and sets out the agreed conclusions and plan of action. This report forms the basis for future review and is a benchmark by which progress can be charted. It is at this stage that a method of monitoring progress needs to be established so that the effectiveness of the interventions can be measured and the approach tuned or, if necessary, changed.

Data Collection

The process of data collection for the troubleshooting of nutritional problems was addressed by Lundquist (1994). The taking of a proper history of the problem, examination of herd records, including DHIA records but also breeding records, health events, and culling records may be useful. The DHIA records rarely provide solutions to problems, but they do help to define some of the questions that need to be asked and may occasionally point to other problems which need to be addressed more urgently than the presenting complaint. Records of health events may be the most difficult to obtain since on many farms these are not kept systematically. In many cases, there may have been substantial death losses or cows have been shipped for salvage without a diagnosis being made.

At the time of the investigation, there should be a walk through of the premises by the team with attention paid to the facilities and cow condition. Most herds do not have previous records of body condition scores (**BCS)**. Where they are available, they are invaluable. Body condition scoring of the herd and the plotting of BCS by lactation and against days in milk is almost always informative. Although this provides a "snapshot" of the herd rather than the dynamic view that a BCS record keeping system provides, it delivers important diagnostic information and a baseline from which to monitor changes. At this time, it is also convenient to observe manure consistency, rumination, cow behavior, freestall use, and foot and leg problems. It is frequently necessary to examine individual cows, particularly in order to diagnose the nature of hoof and foot problems, gastric disturbances, reproductive failures, etc. Although many of the problems that the team will deal with are predominantly nutritional, these conditions also exist within the overall context of herd health with respect to such infectious conditions as Johne's disease, bovine leukosis, hairy heel warts, and contagious or environmental mastitis. In many cases, these diseases interface with nutritional management through overall levels of hygiene, contamination of feed with fecal material, and cow behavior in holding pens and on exit from the milking parlor, as well as in freestall use.

Even though there may be recent proximate analysis of forages, a fresh sample is almost always worthwhile as it provides a current basis for ration re-formulation or trouble shooting. Fiber length analysis of the TMR by use of a forage separator is useful because it provides information on effective fiber which cannot be obtained from the proximate analysis (Heinrichs, 1997). An analysis of the TMR by chemical methods is warranted, despite the inherent difficulties of obtaining a representative sample, as a check on ration preparation and mixing.

Information Sharing

The material obtained during the initial farm visit and data analysis need to be organized into an initial report that then sets the agenda for a farm meeting. The team leader usually does this. Graphical representations are used in the report to clarify changes in herd performance which may not be readily apparent from examination of numerical data and may be particularly useful for showing relationships between different parameters. However, an excess of graphs simply confuses everybody. Data should only be presented in this form if there is a point to be made. In our practice, we often summarize the initial report into a bullet list of items for discussion.

The Farm Meeting

In many ways, the farm meeting is the focus of the team's work as it is at this point that the data are on the table, the observations have been made, and an open discussion of the issues can occur. The selection of a suitable meeting place should not be overlooked. A meeting held at the windy end of a row of silos on an Indiana, February afternoon may have the advantage of encouraging brevity but hampers constructive discussion. Effective meetings may be held in the milk house, farm office, farm house, or even at a local restaurant. The team leader's responsibility is to keep the discussion focussed and to make every effort to help the team arrive at a consensus. It is especially important that the producer is encouraged to participate in an active way in this discussion. The other members of the team may provide a diagnosis of the problem, but without the producer's acceptance of the diagnosis and active engagement in prioritization of issues as far as the farm is concerned, then the whole event has been a pointless exercise. One of the most difficult issues to get producers to address are those which deal with cow behavior. For instance, often the farmer's interpretation of cow behavior at the feed bunk is that if the cows are not fighting to get to the bunk, then there is no problem. In fact, the true picture may be that less aggressive cows are not attempting to get to the bunk because they are avoiding confrontation with dominant cows. The central tasks that need to be accomplished are to rank the problems that have been identified and to identify those that have to be addressed with the most urgency and those that may be tackled at another time. It may be that the most important problem is not the one that brought the team together in the first place. If that is the case, it shows the value of being able to assess the priorities at the level of the farm operation rather than having the agenda dominated by the discipline specific interest of individual team members.

The final report summarizes the discussion and lists the decisions made at the farm meeting. It may also specify responsibility for other tasks, such as reviewing the literature on a topic, pricing feed supplements, or setting up a vaccination schedule. This report also specifies how the changes in management agreed to at the meeting are to be monitored. This may include rechecking BCS or identifying key items in the DHIA records that are to be followed.

Some of the changes agreed upon might have production and health effects which are very rapidly apparent, particularly if there are major problems in the feeding program of, for instance, transition cows. Decreases in the incidence of clinical ketosis, summit milk production, milk fat:protein ratios, and dry matter intake may be evident in days to weeks. Changes aimed at improving body condition in cows at calving will not usually be measurable for a number of weeks to months. For this reason it is important that, through the team's discussions, the producer has a realistic expectation of what changes are likely to occur and how long they will take to become apparent. Without this information, the producer will be less inclined to persevere with the program and to try and find quick fixes from other sources.

Conclusion

The team approach to solving animal health and productivity problems provides a powerful management tool, which is available to all members of the farm advisory team. It may be initiated by any member of the professional team and provides a means of dealing with problems which cross the discipline barriers of nutrition, health and disease, design and utilization of the cow environment, and management of financial and other resources. The essential features of a successful team effort are good communication, good documentation of data and issues, sharing of information, a farm meeting with an agenda, a final report, and a system of monitoring changes. When the team approach works well there is a point at which a transformation of the relationships within the team occurs. At this time, the producer takes charge of the process and there is a transition from a problem solving team led by a farm adviser to an implementation team led by the producer.

Additionally, the opportunity for farm advisers to work in professional teams strengthens their own skills, consolidates the position of the participants in the farm advisory group, and provides a powerful tool for producer education. Perhaps most importantly, it helps to create the professional and producer networks on which a successful industry depends.

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Formulating Rations Based on Changes in Markets

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Introduction

The progressive withdrawal of the U.S. Federal Government from programs aimed at supporting grain and milk prices has resulted in a substantial increase in volatility of input and output prices in dairy production. It can be anticipated that charges brought about by the 1996 Federal Agricultural Improvement and Reform Act (FAIR) will simultaneously increase risks inherent in the physical production of milk, risks involved in the purchasing of nutritional inputs, and risks associated with the marketing and pricing of milk.

A consequence of stagnant milk prices during the last 15 years has been the progressive decline in marginal profits per unit of milk produced (Knoblaugh, 1996). Feed costs represent approximately 50% of the total cost of producing milk on a typical U.S. dairy enterprise. Logically, control of feed costs in rapidly changing markets should become an ever increasing function of farm management. Additional pressure will be put on nutrition advisors to optimize the animal/feed production system. In general, these advisors are poorly prepared to meet this economic challenge as exemplified by the wide perception that profits are maximized when feed costs per hundredweights are minimized. VandeHaar (1995) made a brave attempt to dispel this myth but numerous examples that appeared in the popular press over the last year demonstrate that the basic concepts are still poorly understood.

The objectives of this paper are:

1. To explain the basic mechanisms of economic input-output optimization,

2. To expose the current limitations of input-output optimization when applied to milk production, and

3. To present a new method of determining nutrient values (and therefore feed ingredient values) from market prices of a large array of feed ingredients.

Economics of Production

The range of concepts and methods for agricultural response or production function research is substantial (Woodworth, 1977). The reader is referred to Ritson (1977) for a comprehensive expose of classical production economics. We will concentrate on those concepts essential for the understanding of how nutritional management should adjust with changing markets. We will proceed from the simple case of production with one variable input to the more complex case of two or more variable inputs, all other inputs being considered fixed. This classification of resources is dependent on the production

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period. In the short run, the time period is of such length that at least one resource is varied while other resources are fixed. In the long run, the time period is of such length that all resources can be varied.

Production with one variable input

Suppose that we are interested in the relationship between daily milk production (lb/day) and the amount of grain fed (lb/day), all other factors being assumed constant. The mathematical representation of this input/output relationship is called a production function (also called response function). Symbolically, we have:

$$Y = f(X_1/X_2,\ldots,X_n),$$

Where:

Y = lb of milk/day
X_1 = lb of grain fed
$X_2,\ldots,X_n$ = other factors (e.g. genetic potential) held constant
f = signifies "function", or form of the relationship that transforms inputs into output

An example of such a relationship is presented in Figure 1 and Table 1. This example is fiction, but it displays all the characteristics of the *classical* production function. The production function in Table 1 and Figure 1 can be expressed algebraically. Its equation is:

$$Y = X + .2X^2 - .004\,X^3,$$

where: Y is the units (lb/day) of milk resulting from the use of some number of units (lb/day) of grain. The output Y is often called *total physical product* (**TPP**).

Two measures of efficiency of inputs in production are: 1) *marginal physical product* (**MPP**) and 2) *average physical product* (**APP**). The APP is obtained by dividing the total amount of the output, Y, by the total amount of the variable input, X. It measures the average rate at which an input is transformed into a product. The APP equation for our example can be derived from the equation for the production function:

$$APP = \frac{Y}{X} = \frac{X + .2X^2 - .004X^3}{X} = 1 + .2X - .004X^2$$

The APP represents the physical efficiency of a production process. In our example, the feeding of grain reaches a maximum physical efficiency at a level of 25 lb/day. At this level of grain fed, we expect 87.5 lb of milk production, for an APP (efficiency) of 3.5 lb of milk/lb of grain. As we shall see later, <u>this point of maximum physical efficiency is rarely the point of maximum economic efficiency</u>.

The MPP is defined as the change in output level when an additional unit of input in question is applied, while holding all other inputs at fixed levels. It is evaluated as the first derivative of the production function with respect to the input. Geometrically, MPP represents the slope of the production function. It is derived in our example as follows:

$$MPP = \frac{dY}{DX} = 1 + 0.4X - 0.012X^2$$

We have now defined all the essential characteristics of the physical process. We must now turn our attention to costs in order to comprehend the process of optimization.

Costs are the expenses incurred in organizing and carrying out the production process. Recall that a resource or input is called a fixed resource if its quantity is not varied during the production period. A resource is a variable resource if its quantity is varied at the start of or during the production period. In general, costs of fixed inputs are called fixed costs, while costs of variable inputs are called variable costs. Fixed costs do not change as the amount of output changes and are incurred even when production is not undertaken. In dairy, cash fixed costs include land taxes, principal, and interest on land payments, insurance premiums, and similar costs. Noncash fixed costs include building depreciation, machinery and equipment depreciation, interest on capital investment, and charges for family labor and management.

In our example, *total fixed costs* (**TFC**) are shown in the third column of Table 2. These costs are the same for all output levels and are assumed at $4.00/cow/day.

Total variable costs (**TVC**) are computed by multiplying the amount of variable input used by the price per unit of input. In symbolic notation:

$$TVC = P_x X,$$

where:

P_x = price per unit of input.

In our example, we assumed the price of grain at $0.10/lb.

Total costs (**TC**) are simply the sum of total variable costs and total fixed costs. In symbolic notation:

$$TC = TFC + TVC = TFC + P_x X$$

Average fixed costs (**AFC**) are computed by dividing total fixed costs by the amount of output. As output increases, AFC decreases. Thus, when economists refer to increasing output as a method of "spreading fixed costs", they mean increasing production to divide fixed costs among an increased number of units of output, therefore reducing the cost per unit.

*Average variable costs (***AVC**) are computed by dividing total variable costs by the amount of output. The shape of the AVC curve depends upon the shape of the production function.

Average total costs (**ATC**) can be computed two ways. First, total costs can be divided by output. Second, AFC and AVC can be added. Both methods yield the same results.

Marginal cost (**MC**) is defined as the change in total cost per unit increase in output. In essence, it is the cost of producing an additional unit of output. The MC is computed by dividing the change in total costs, ΔTC, by the corresponding change in output, ΔY. Geometrically, MC is the slope of the TC and TVC curve. Algebraically, MC is derived as follows:

$$MC = \frac{\Delta TC}{\Delta Y} = \frac{\Delta TVC}{\Delta Y} = \frac{P_x\,(\Delta X)}{(\Delta Y)} = \frac{P_x}{MPP}$$

One last measure of importance in the production process is the total value product (**TVP**), the total dollar value of the production. In symbols,

$$TVP = P_y \# Y,$$

where: P_y = price per unit of ouput.

The TVP for our example was assuming a milk price of $13/cwt. The TFC, TVC, TC, AFC, AVC, ATC, MC, and TVP were calculated in Table 2 and graphed in Figure 2.

We can now optimize the production in economic terms. That is, we can determine the most profitable point of operation for an enterprise in the short run. We will assume that the objective is to maximize net returns or profits. This can be done by determining the most profitable level of input or the most profitable level of output. If we are consistent, either method results ultimately in the same answer.

Because our objective is profit maximization, it is essential that we define profit. In simple terms, profit is expressed algebraically as:

$$\text{Profit} = TVP - TC = TVP - TVC - TFC$$
$$= P_y Y - P_x X - TFC$$
$$= P_y \# f(X) - P_x X - TFC$$

This equation expresses profit as being equal to the value of product minus total variable and total fixed costs.

As mentioned previously, there are two approaches to profit maximization. The first one uses an input approach as it determines the optimum amount of input that results in the largest profit. To maximize the profit function with respect to the variable input, the first derivative would be set to zero as follows:

$$\frac{d\,\text{Profit}}{dX} = P_y \frac{dY}{dX} - P_x = 0$$

$$= P_y\, MPP - P_x = 0, \text{ or}$$

$$P_y \# MPP = P_x, \text{ or}$$

$$\boxed{MPP = \frac{P_x}{P_y}}$$

The optimum level of input is where the MPP (the slope of the production curve, the measure of how much additional output results from one additional unit of input) is equal to the ratio of input price to output price. This optimum point is presented in Figure 3. In our example, profits are maximized when 33.8 lbs of grain are fed. This level of grain results in a profit of:

$$\text{Profit} = (107.8 \# \$0.13) - (33.8 \# \$0.10) - \$4.00 = 14.02 - 3.38 - 4.00 = \$6.64/\text{cow/day}$$

The second approach to profit maximization determines the optimum level of output to be produced. The marginal conditions for the maximization of profit as a function of output can be derived from the profit function. The variables in the equation must be regarded as functions of output.

$$\text{Profit} = TVP - TC$$
$$= P_y \# Y - P_x \# X - TFC$$
$$= P_y \# Y - P_x f^{-1}(Y) - TFC$$

where the concept of the inverse production function must be used to express X as a function of Y. Taking the derivative of profit with respect to Y yields:

$$\frac{d\,\text{Profit}}{dY} = P_y - P_x \frac{dX}{dY} = 0$$
$$= P_y - \frac{P_x}{MPP} = 0$$
$$= P_y - MC = 0, \text{ or}$$

$$\boxed{P_y = MC}$$

Therefore, P_y is equal to MC (change in total cost per unit increase in output) at the optimum. Expressed differently, profit is maximized when marginal revenues are equal to MC. This optimum point is presented graphically in Figure 2.

All this derivation yields important results:

- <u>The optimum is not a function of fixed costs</u>. They do not appear in either the input or output criteria of optimization. Therefore, the optimal ration adjustments due to changes in market prices of grains are not dependent on fixed costs (building, machinery and equipment depreciation, etc.).

- The optimum is not at the point of minimum average total cost or minimum average variable cost. That is, the optimum feeding program is not at a point of minimum cost per cwt of milk or minimum feed costs per cwt of milk.

- The optimum is not at the point of maximum production unless feeds are free or the price of milk is infinity (two unlikely events!).

- The optimum is not at the point of maximum input efficiency. That is, the optimum amount of grain is not at the point of maximum milk per pound of grain.

Production with two or more variable inputs

When two or more inputs are variable, a given amount of output may be produced in more than one way. Substitution possibilities among inputs or factors of production create what is called the factor-factor relationship. To simplify the analysis, the special case of one output (milk, lb/day) resulting from two variable inputs (grain and hay intake, both in lb/day) will be used. We agree that the example used is "biologically impaired", but it is characteristic of the traditional view held by economists of an animal production system. Issues of relevance will be discussed later.

The production function for two variable inputs does not differ conceptually from that for one variable input. Each combination of the two inputs produces a unique amount of output. In symbolic notation, the production function for two variable inputs is written:

$$Y = f(X_1, X_2),$$

where: Y is the amount of product and X_1 and X_2 are amounts of the two variable inputs. As an example, we will use a production function where Y is the amount of milk in lb/day, X_1 will be replaced symbolically by G, the amount of grain in lb/day, and X_2 will be replaced by H, the amount of hay in lb/day. The production function is:

$$Y = -45 + 5.75\,G - 2.50\,H - .08\,G^2 - .02\,H^2 - .055\,GH$$

This function is presented graphically in Figure 4. Recall from Figure 3 that the optimum use of one input was at the tangent point between the TPP curve and the price ratio line. In the two inputs case, the optimum is geometrically located at the tangent point between the TPP surface and the price ratio plane. Analytically, several methods of determining the optimal combination are available. The profit function is:

$$\text{Profit} = P_yY - (P_{x1} \# X_1) - (P_{x2} \# X_{x2}) - \text{TFC},$$

where $Y = f(X_1, X_2)$.

Maximizing this function with respect to X_1 and X_2 gives two equations in two unknowns:

$$1)\qquad \frac{\delta\, \text{Profit}}{\delta X_1} = Py\frac{\delta Y}{\delta X_1} - Px_1 = 0$$

$$2)\qquad \frac{\delta\, \text{Profit}}{\delta X_2} = Py\frac{\delta Y}{\delta X_2} - Px_2 = 0$$

The unknowns are X_1 and X_2, the amounts of the two inputs that maximize profits. Let us apply this derivation to our two inputs, grain and hay intake, for our milk production function.

We have:

$$\frac{\delta Y}{\delta G} = 5.75 - .16\,G - .055\,H$$

$$\frac{\delta Y}{\delta H} = 2.50 - .055\,G - .04\,H$$

Under the market conditions where P_y = \$.13, P_G = \$.10, and P_H = \$.05, the equations for the optimum are:

1) $.13(5.75 - .16\,G - .055\,H) - .10 = 0$

2) $.13(2.50 - .055\,G - .04\,H) - .05 = 0$

Solving for G and H, we get the optimum of 19.1 lb of hay, 24.6 lb of grain, with an output of 62.6 lb of milk.

We are now in a position to evaluate the effect of changes in input or output prices. In Table 3, we report the effect of a 20% increase or decrease in the price of milk, grain, and hay on the optimum allocation of inputs and the optimum level of output. Two mechanisms are operating: **substitution and expansion**. When the price of milk drops by 20%, from \$13/cwt to \$10.40/cwt, the optimum level of output drops by 1.2 lb/day, from 62.6 to 61.4 lb/day. This is the expansion effect (in this case, a negative expansion). The level of both inputs also changes under optimization. However, the level of hay falls more than the level of grain (-1.43 lb/day vs. – 0.71 lb/day). This is the substitution effect. This effect is more obvious when we compare the case of normal milk price (\$13/cwt), high grain price (\$0.12/lb), and normal hay price (\$0.05/lb) to the case of normal milk price, normal grain price (\$0.10/lb), and high hay price (\$0.06/lb). In both instances, the optimum output is at 62.0 lbs/day. In the first case, this is optimally done by feeding 22.7 lb of grain and 21.6 lb of hay. In the second case, the optimum strategy is to feed 25.8 lb of grain and 15.5 lb of hay. If the markets were to move from the second situation to the first, the optimum level of production would not change but substantial adjustments in levels of inputs would have to be made. If not, the income over feed costs (**IOFC**) would drop from \$4.56 to \$4.19/day, an additional drop of \$0.07/day. This trade-off in optimum levels of inputs is the substitution effect.

In general, optimization with more than two inputs is algebraically messy. Conceptually speaking, however, it is a straightforward extension to the case of two variable inputs. Each marginal physical product must be equal to the ratio of input price to output price.

Depending on their discipline of expertise, scientists have use of radically different views of the animal feed/production system to be optimized.

The economist approach

The concept of production function is very well known among economists. However, these specialists tend to lack a sufficient understanding of the biological processes underlying the transformation of feeds into milk. Figure 5 presents a characteristic view of the process to be optimized according to an economist. Numerous studies based on this conceptualization have been published over the years (Dillon, 1968; Heady and Bhide, 1983; Heady and Dillon, 1961; Heady et al., 1956; Heady et al., 1964; Madden, 1962; Sjo, 1976). The work summarized by Heady and Bhide (1983) will be used to demonstrate the severe limitations of such an approach.

Using data from nutritional experiments conducted in the 1950's, the authors derived the following response function linking weekly milk production to weekly intakes of hay and grain.

$$M = -340.1 + 1.544\ H + 2.974\ G$$
$$= .001192\ G^2 - .00388\ H^2 - .001056\ HG,$$

where:

M = milk production (lb/week)
H = hay intake (lb/week)
G = grain intake (lb/week)

This functional form is in direct line with the review we conducted in the previous section. Limitations of this approach are severe:

1. The production factors (inputs) are not uniform and are poorly defined. What is grain? What is hay? Because of the wide variety of grain ingredients available and the considerable variation in nutritional value of hay types used on farms, this production function has a very restricted inference range. It can be used to predict the performance of those specific cows used in those specific trials when fed grain mixtures and hay of identical composition and qualities as those used. In short, the function may explain the results observed 50 years ago, but it has little other value.

2. Although other factors (e.g., body weight, coefficient of inbreeding, temperature, etc.) can be incorporated into the function, the estimation of their direct effects and their interaction effects leads to models where the number of parameters grows exponentially with the number of factors. In short, the function quickly becomes untractable.

Therefore, it is no surprise that this approach has seen little development efforts in the last 25 years.

The nutritionist approach

Historically, nutritionists have viewed the system as one of nutrient requirements (e.g., NRC, 1989). Under this approach (Figure 6), the level of output is pre-determined and is one of the independent variables. The level of nutrient to be fed is invariant to changes in market prices.

With the concept of nutrient requirements, levels of nutrients are dependent variables (Figure 7a). Algebraically, the relationship can be inverted to yield a linear response function of milk to nutrient intake. A maximum production ability, representing genetic potential can be added to the model, with the resulting response curve shown in Figure 7b. This abrupt threshold and plateau model has some severe limitations:

1. It assumes linear biology, whereas the kinetics of metabolic processes are highly nonlinear.

2. It yields only two possible milk production optima (points A and B in Figure 7b).

3. When expanded to two variables, this model implies perfect complement inputs, without any substitution. In beef, we have clearly

demonstrated the hypothesis of complementary inputs to be invalid (St-Pierre et al., 1987). It is likely that the same conclusion would be drawn in milk production, but this has not been proven yet.

An integrated approach

In view of the severe limitations of the previous two approaches, we have initiated work on an optimization model that would adequately represent the underlying production process while allowing valid economic analysis. The underlying schematic model is shown in Figure 8. Feeds are no longer primary inputs to the animal but serve as sources of nutrients. Nutrients are no longer "required", but serve as inputs to the "animal machinery". The animal responds to nutrient intake by varying the level of output of multiple products. Some products (e.g. milk) have a positive market value; others (e.g. manure) have a negative value.

There is evidence in the literature that this is a valid approach. Roffler et al. (1986) published production responses in early lactation as functions of crude protein in the ration (Figure 9). Although these functions have rather limited inference ranges, they demonstrate eloquently the curvilinear response function of milking cows to diet composition. This curvilinear relationship between nutrient intake and milk production is present even when nutrients are quantified using complex net systems. Verité and Peyraud (1988) summaried results from 17 experiments on the French PDI protein system (Figure 10). The law of diminishing returns appears to be operating even in French!

The response to intake of energy leads to interesting modeling problems. Although the laws of thermodynamics must apply, the partitioning of energy is dependent on numerous factors, including genetics. Results of an experiment by Broster et al. (1969) demonstrate this very well. Table 4 reports the performance of two individual cows which were offered and ate the same amount of rations of identical specifications during the first 67 days postpartum. Clearly, a given level of input can be associated with a variety of outcomes depending on the energy partitioning by the animal.

Work done in California (Bath and Bennett, 1980) produced response functions of milk to energy intake (Figure 11). The user, however, must make an arbitrary selection of which curve is most appropriate to a given group of cows. In essence, this is an overparameterized model. A posteriori, a curve can always be found to perfectly predict the response.

Although the specific shape and parameterization of response functions as illustrated in Figure 8 are still undetermined, we have made much progress in developing methods to assess the unit cost of nutrients to be used in the optimization. The method outlined in the next section has an interesting by-product. It can estimate the value of feed ingredients.

As of now, the specific shape and parameterization of response functions as illustrated in Figure 8 are still undetermined. The practicing nutritionist cannot evaluate quantitatively the optimum nutrient substitution and output expansion to follow when markets change. However, much economic gain can be achieved by the identification of the most economical sources of nutrients. Feed substitution should be made if: 1) the relative prices of feed ingredient changes, or 2) a new, better priced feed ingredient enters the market. Optimum feed substitution requires the knowledge of nutrient values (costs) which themselves determine feed values.

From nutrient unit cost to feed ingredient values

Corn and soybean meal have long been used as estimators of unit costs of energy and crude protein (Morrison, 1956). This method is still widely used to assess the value of feed ingredients and to determine if a given commodity is a "good buy" (see, e.g., Dairy Reference Manual 1995. This method is of questionable merit when used to assess the value of feed ingredients for dairy cows.

1. Crude protein is not a uniform nutrient in ruminants because of the rumen partitioning of protein into degradable (**RDP**) and undegradable (**RUP**) fractions. Logically, RUP should be priced differently than RDP.

2. The total demand for corn and soybean meal by the U.S. dairy industry represents a small portion of the total demand. For example, of the 250,000,000 tons of corn produced annually in the U.S., less than 10% is used by the dairy industry. Therefore, corn and soybean meal may not be good barometer feeds for dairy, that is, their prices might not be reflective of their real intrinsic values in dairy rations.

Our method for deriving nutrient costs, and therefore value of feedstuffs, is based on a regression approach. For each and every feed available in a given market, we set an equation where the content of each nutrient is multiplied by its unknown nutrient value to be estimated. This means that the price of any given feed is equal to the value of its nutrients plus a certain error. Algebraically, the model is as follows:

$$Y_i = B_o + B_j X_{ij} + E_I,$$

where: Y_i = price per ton of ingredient *i*, *i* = 1,…,*n*

B_o = intercept

B_j = regression coefficients (unit costs) of nutrient *j*, *j* = 1,…,*m*

X_{ij} = composition of ingredient *i* in nutrient *j*

E_i = error term

A solution to this set of *n* equations is obtained by the method of least-squares which determines the unit value of each nutrient that minimizes the sum of all E_i squared. If the E_i are normally and independently distributed, the least-square estimates are also maximum likelihood estimates.

The appropriate set of nutrients to include in the evaluation is situation dependent. We present here three different sets to illustrate the impact that nutrient selection has on the estimation of the value of feed ingredients.

Nutrient Set 1

Nutrients: NE_L and crude protein

Using all 19 ingredients with prices and composition from Table 5, the best estimates are:

$\$NE_L$ = \$0.049/Mcal

\$CP = \$0.227/lb

(Note: Estimates of $\$NE_L$ and \$CP are dependent on the prices of all 19 ingredients; $\$NE_L$ and \$CP would change even if only one price changed.)

Table 6 reports the value of all 19 ingredients calculated using this method. Based on the prevailing prices in July, 1997, canola meal, distillers dried grains, feather meal, corn gluten feed, hominy, soybean meal - (48% CP), and wheat middlings were underpriced by at least 20%. Blood meal, fish meal, molasses, and tallow were overpriced by at least 20%.

Nutrient Set 2

Nutrients: NE_L, RDP, and RUP

Using July prices, we get the following estimates:

$\$NE_L$ = \$0.055/Mcal
\$RUP = \$0.300/lb of RUP
\$RDP = \$0.093/lb of RDP

Using these estimates, we calculated the value of all 19 feed ingredients (Table 6). By separating the CP into RDP and RUP, the value of some feedstuffs changed considerably. Blood meal is no longer on the list of overpriced feeds, whereas brewers dried grains and shelled corn are now considered underpriced feeds.

It can be argued that the quality (amino acids contribution) of the RUP should be considered when valuing feedstuffs. Also, one should probably account for the filling effect of each feed in the digestive tract. The next method accounts for the positive value of methionine (**MET**) and lysine (**LYS**) and the negative value of neutral detergent fiber (**NDF**).

Nutrient Set 3

Nutrients: NE_L, NDF, RUP, RDP, and the MET and LYS from RUP.

Again, using July prices, we obtained the following estimates:

$\$NE_L$ = \$0.065/Mcal of NE_L
\$NDF = -\$0.060/lb of NDF
\$RUP = \$0.000/lb of RUP
\$RDP = \$0.128/lb of RDP
\$MET = \$9.764/lb of undegradable MET
\$LYS = \$2.73/lb of undegradable LYS

One should note that undegradable protein no longer carries any value once the undegradable methionine and lysine (part of the RUP) are used in the estimation.

Estimates of values for all 19 feedstuffs are reported in Table 6. Only five feeds remain on the list of underpriced feedstuffs: canola meal, shelled corn, corn gluten feed, hominy, and wheat middlings. Three feeds are still overpriced: beet pulp, dried brewers grains, and whole cottonseed.

Care must be taken that the feed library does not include outliers that would bias estimates. Our procedure includes an automatic detection of outliers and leveraged points. Although the complete procedure could be programmed in a modern spreadsheet, compatibility and portability could become an issue. For these reasons, we opted to write a stand-alone software in FORTRAN, for which compilers are available for all widely used operating systems. This program named

"FEEDCOST" is currently being beta-tested and should be available soon for general release.

The program allows for a rapid and accurate estimation of nutrient values. These estimates are used to calculate feed ingredient values. The program can be used:

1. By a supplier of a new feed ingredient to estimate its market aggregate value (e.g., How much is a new bypass lysine product worth?),

2. By practicing nutritionists to determine which set of commodities are best priced, and

3. By producers to calculate benchmark feeding costs based on herd structure and productivity.

Conclusions

The optimal allocation of nutritional resources in dairy production is still quantitatively ill-defined. This is the result of economists thinking in terms of feeds (grains versus forage) as opposed to nutrient inputs, and nutritionists thinking in terms of nutritional requirements as opposed to nutrient responses. The practicing nutritionist can apply quantitative economic principles to ration formulation. The exact application will remain somewhat an art in the foreseeable future. Our method of nutrient valuation can be applied to rapidly determine the value of a new feed ingredient. The estimated nutrient costs can also be used as budgeting benchmarks.

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Table 1. Example of a one input production function.

Grain input X (lb/day)	Milk Output Y (lb/day)	Average Physical Product (APP)	Marginal Physical Product (MPP)
0	0.0	0.0	1.0
5	9.5	1.9	2.7
10	26.0	2.6	3.8
15	46.5	3.1	4.3
20	68.0	3.4	4.2
25	87.5	3.5	3.5
30	102.0	3.4	2.2
35	108.5	3.1	0.3
40	104.0	2.6	-2.2
45	85.5	1.9	-5.3
50	50.0	1.0	-9.0

Table 2. Example of costs derived from the one input production function[1].

X	Y	TFC	TVC	TC	AFC	AVC	ATC	MC	TVP	Profit
0.0	0.0	$4.00	$0.00	$4.00	-	-	-	-	$0.00	-$4.00
2.5	3.7	$4.00	$0.25	$4.25	$1.085	$0.068	$1.153	$0.052	$0.48	-$3.77
5.0	9.5	$4.00	$0.50	$4.50	$0.421	$0.053	$0.474	$0.037	$1.24	-$3.27
7.5	17.1	$4.00	$0.75	$4.75	$0.234	$0.044	$0.278	$0.030	$2.22	-$2.53
10.0	26.0	$4.00	$1.00	$5.00	$0.154	$0.038	$0.192	$0.026	$3.38	-$1.62
12.5	35.9	$4.00	$1.25	$5.25	$0.111	$0.035	$0.146	$0.024	44.67	-$0.58
15.0	46.5	$4.00	$1.50	$5.50	$0.086	$0.032	$0.118	$0.023	$6.05	$0.55
17.5	57.3	$4.00	$1.75	$5.75	$0.070	$0.031	$0.100	$0.023	$7.45	$1.70
20.0	68.0	$4.00	$2.00	$6.00	$0.059	$0.029	$0.088	$0.024	$8.84	$2.84
22.5	78.2	$4.00	$2.25	$6.25	$0.051	$0.029	$0.080	$0.025	$10.16	$3.91
25.0	87.5	$4.00	$2.50	$6.50	$0.046	$0.029	$0.074	$0.029	$11.38	$4.88
27.5	95.6	$4.00	$2.75	$6.75	$0.042	$0.029	$0.071	$0.034	$12.42	$5.67
30.0	102.0	$4.00	$3.00	$7.00	$0.039	$0.029	$0.069	$0.045	$13.26	$6.26
32.5	106.4	$4.00	$3.25	$7.25	$0.038	$0.031	$0.068	$0.075	$13.84	$6.59
33.8	107.8	$4.00	$3.38	$7.38	$0.037	$0.031	$0.068	$0.123	$14.02	$6.64
35.0	108.5	$4.00	$3.50	$7.50	$0.037	$0.032	$0.069	$0.333	$14.11	$6.61
37.5	107.8	$4.00	$3.75	$7.75	$0.037	$0.035	$0.072	-	$14.02	$6.27
40.0	104.0	$4.00	$4.00	$8.00	$0.038	$0.038	$0.077	-	$13.52	$5.52
42.5	96.7	$4.00	$4.25	$8.25	$0.041	$0.044	$0.085	-	$12.57	$4.32
45.0	85.5	$4.00	$4.50	$8.50	$0.047	$0.053	$0.099	-	$11.12	$2.62
47.5	70.1	$4.00	$4.75	$8.75	$0.057	$0.068	$0.125	-	$9.11	$0.36
50.0	50.0	$4.00	$5.00	$9.00	$0.080	$0.100	$0.180	-	$6.50	-$2.50

[1]X = grain input (lb/day), Y = milk output (lb/day), TFC = total fixed costs ($/cow/day), TVC = total variable costs ($/cow/day), TC = total costs ($/cow/day), AFC = average fixed Costs ($/lb of milk), AVC = average variable costs($/lb of milk), ATC = average total costs ($/lb of milk), MC = marginal costs ($/lb of milk), and TVP = total value product ($/cow/day).

Table 3. Optimum allocation of grain and hay as a function of market prices[1].

P_M ($/lb)	P_G ($/lb)	P_H ($/lb)	Optimum M (lb/day)	Optimum G (lb/day)	Optimum H (lb/day)	G/H	DM (lb/day)	IOFC ($/cow/day)
0.130	$0.10	$0.05	62.6	24.56	19.12	1.28		$4.73
0.156	$0.10	$0.05	63.3	25.03	20.07	1.25	0.7	$6.37
0.104	$0.10	$0.05	61.4	23.85	17.69	1.35	-1.2	$3.12
0.130	$0.12	$0.05	62.0	22.74	21.62	1.05	-0.6	$4.26
0.130	$0.08	$0.05	62.9	26.38	16.61	1.59	0.3	$5.24
0.130	$0.10	$0.06	62.0	25.81	15.47	1.67	-0.6	$4.56
0.130	$0.10	$0.04	62.9	23.30	22.76	1.02	0.3	$4.94

[1]P_M = unit price of milk ($/lb), P_G = unit price of grain, P_H = unit price of hay, M = optimum amount of milk output, G = optimum amount of grain input, H = optimum amount of forage input, dM = change in optimum amount of milk output from change in market prices, and IOFC = income over feed costs.

Table 4. Performance of two cows eating the same amounts of rations of identical specification[1].

	Cow 1	Cow 2
Initial weight (lb)	1140	1144
Weight change (lb)	+86.2	-114.2
Mean milk yield (lb/day)	27.1	58.0

[1]Adapted from Broster et al. (1969).

Table 5. Composition and prices of 19 feed ingredients[1].

Feed No.		Origin[2]	$/Ton	% DM	CP (% of DM)	NE_L (Mcal/lb of DM)	NDF (% of DM)	RUP (% of CP)	RUP MET (% of RUP)	RUP LYS (% of RUP)
1	Beet pulp	C	125	91	9.7	.81	54	58.3	0.65	3.00
2	Blood meal	MN	605	92	95.6	.68	0	79.1	1.07	9.20
3	Brewers dried grains	C	145	92	25.4	.68	46	68.8	1.48	2.69
4	Canola meal	MN	135	94	37.4	.77	34	40.4	1.40	6.67
5	Corn-shelled	C	100	88	10.0	.89	9	53.6	1.70	1.75
6	Cottonseed meal – 41% CP	C	215	91	45.6	.79	26	43.6	1.11	4.25
7	Cottonseed – whole	MEM	225	92	23.0	1.01	44	30.9	0.88	3.67
8	Distiller's dried grains	C	150	92	25.0	.93	44	70.3	1.81	2.06
9	Feather meal	MN	285	92	86.5	.74	0	74.7	0.49	2.51
10	Fish meal	C	555	92	66.7	.76	0	62.6	2.76	7.20
11	Corn gluten feed	C	80	90	25.6	.87	45	35.0	1.88	1.55
12	Corn gluten meal	C	350	90	67.2	.94	14	69.4	2.28	1.99
13	Hominy	C	78	90	11.5	.91	25	61.3	1.11	3.20
14	Molasses	C	105	75	5.8	.75	0	1.0	0.29	0.59
15	Meat and bone meal	BLT	330	94	54.8	.74	0	52.6	0.89	5.28
16	Soybean meal – 48% CP	C	250	89	55.1	.91	8	35.5	1.10	5.82
17	Soybean meal – 44% CP	C	236	89	49.9	.88	15	34.1	1.07	5.77
18	Tallow	C	340	99	0	2.65	0	0	0	0
19	Wheat middlings	C	60	88	18.4	.71	37	27.2	1.01	3.75

[1]RUP = rumen undegradable protein, MET = methionine, and LYS = lysine.
[2]Origin of markets: C = Chicago; MN = St. Paul, MN; MEM = Memphis, TN; and BLT = Baltimore, MD

Table 6. Calculated value of 19 feed ingredients used in dairy rations ($/ton).

	Nutrient Set		
Ingredient	1	2	3
1 Beet pulp	112	118	61
2 Blood meal	461	514	624
3 Brewers dried grains	167	177	119
4 Canola meal	230	202	200
5 Shelled corn – shelled	116	121	123
6 Cottonseed meal – 41% CP	259	229	206
7 Whole cottonseed – whole	187	167	134
8 Distillers dried grains	188	202	156
9 Feather meal	428	463	279
10 Fish meal	347	346	508
11 Corn gluten feed	181	161	125
12 Corn gluten meal	358	375	375
13 Hominy	127	135	115
14 Molasses	75	70	84
15 Meat and bone meal	302	281	278
16 Soybean meal – 48% CP	302	250	270
17 Soybean meal – 44% CP	278	230	240
18 Tallow	256	287	340
19 Wheat middlings	136	118	91

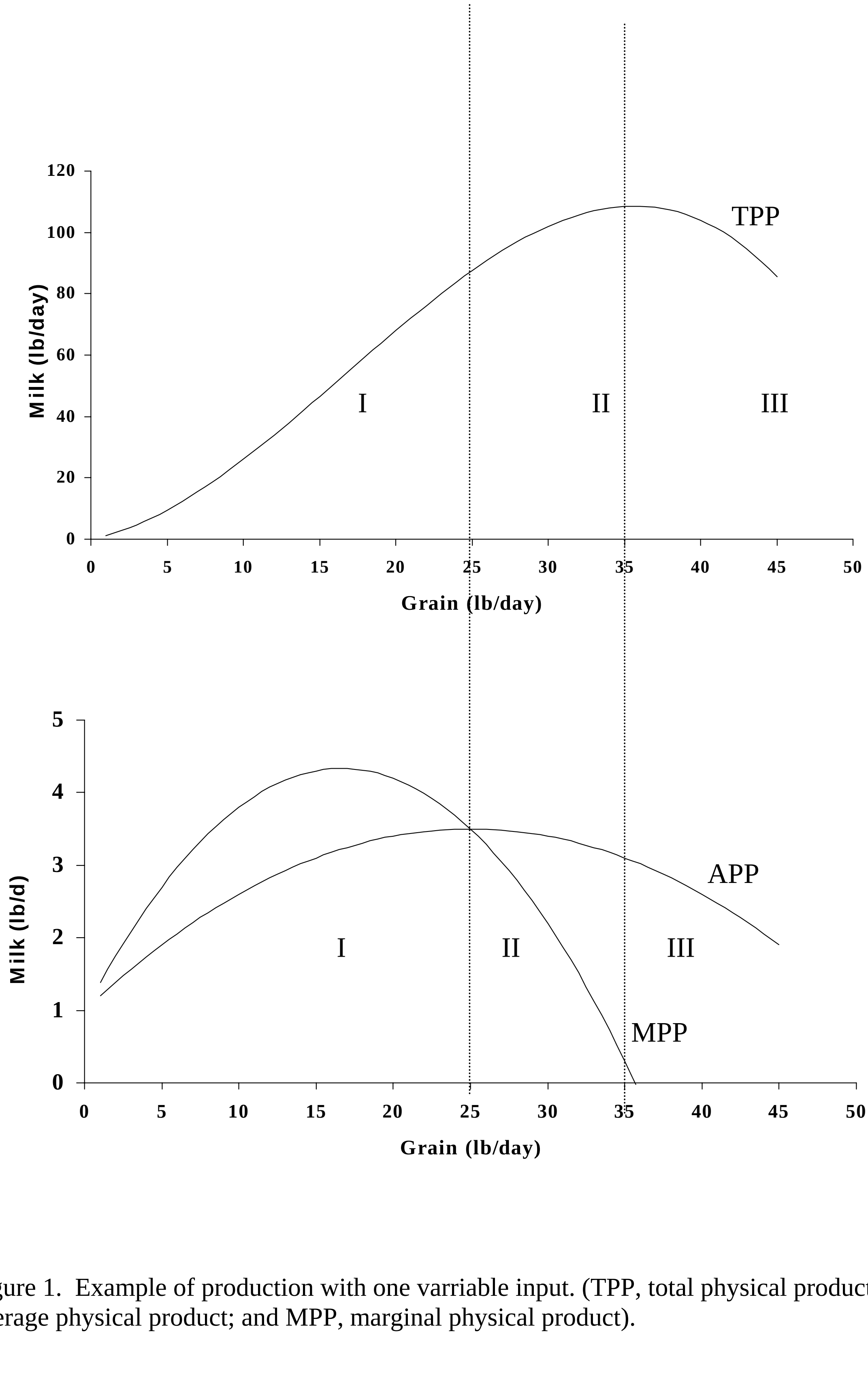

Figure 1. Example of production with one varriable input. (TPP, total physical product; APP, average physical product; and MPP, marginal physical product).

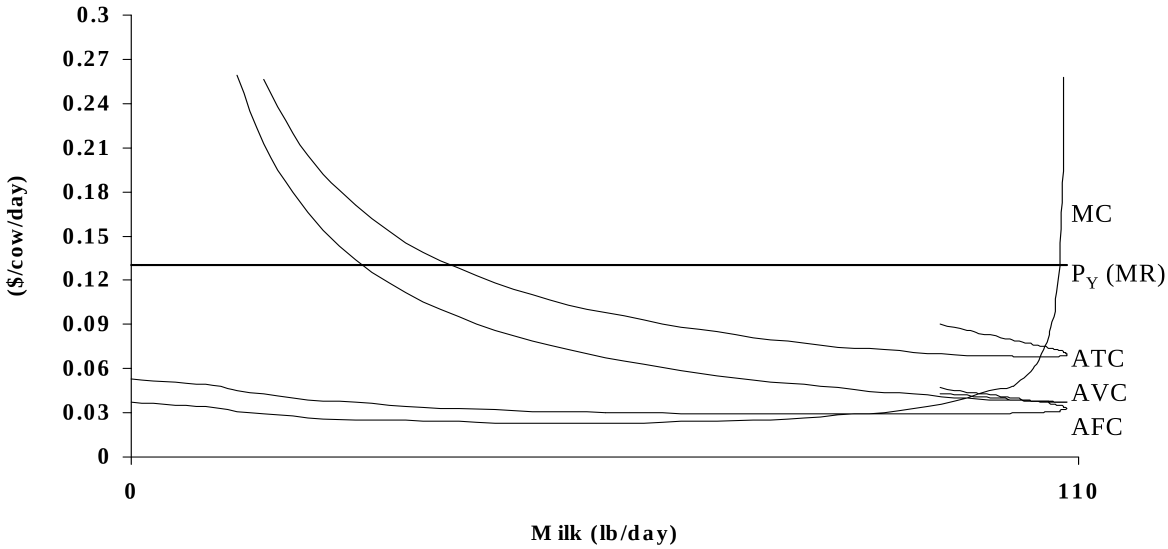

Figure 2. Costs functions: average fixed costs (AFC), average variable costs (AVC), average total costs (ATC), marginal cost (MC), price of output (P), and MR = marginal revenues as a function of output level.

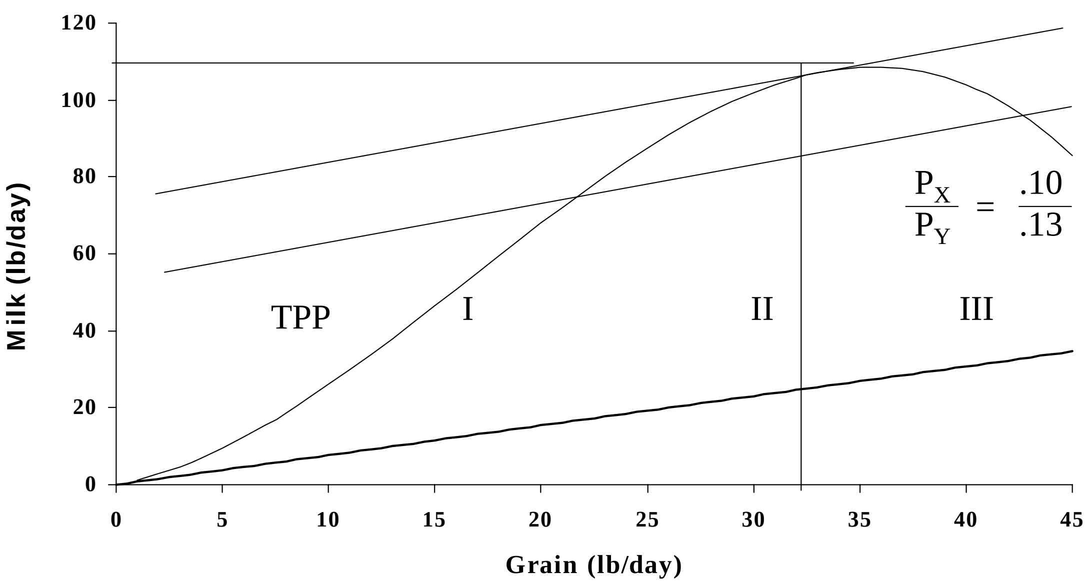

Figure 3. Determining the optimum amount of input using the production function (TPP, total physical product; P_x, price per unit of input; P_4, price per unit of output).

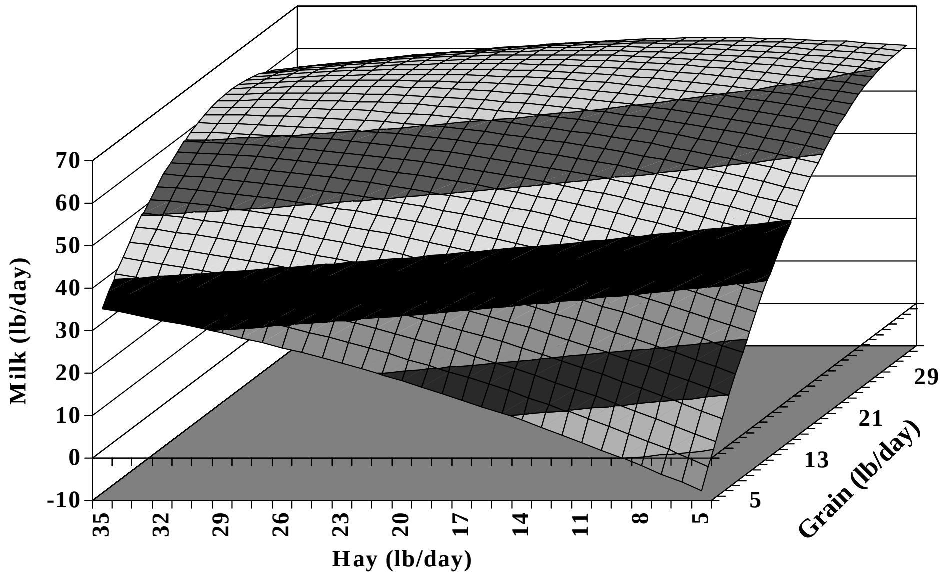

Figure 4. Example of a production function with two variable inputs: milk yield as a function of hay and grain intake.

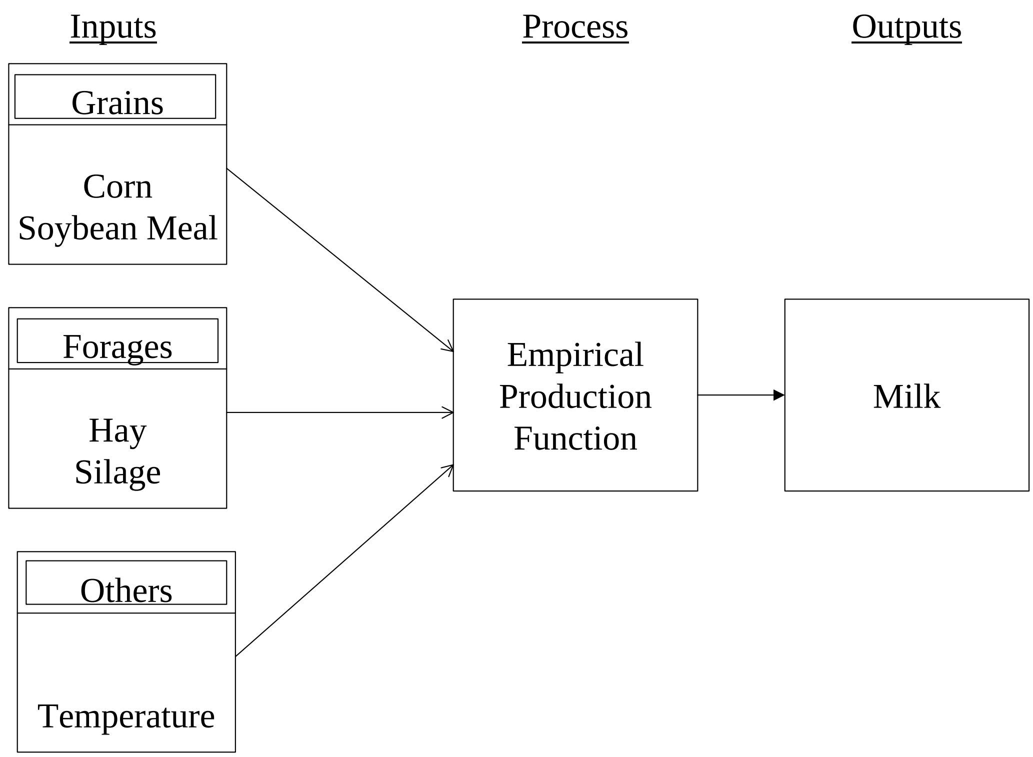

Figure 5. Schematic of an economist's view of the optimization.

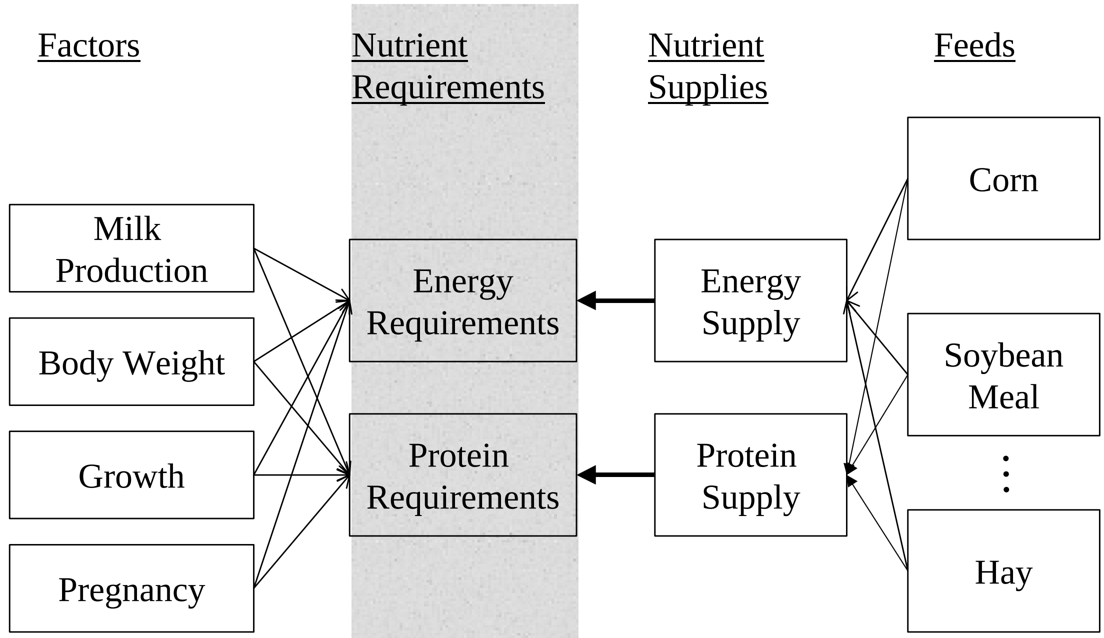

Figure 6. Schematic of a nutritionist's view of the optimization process.

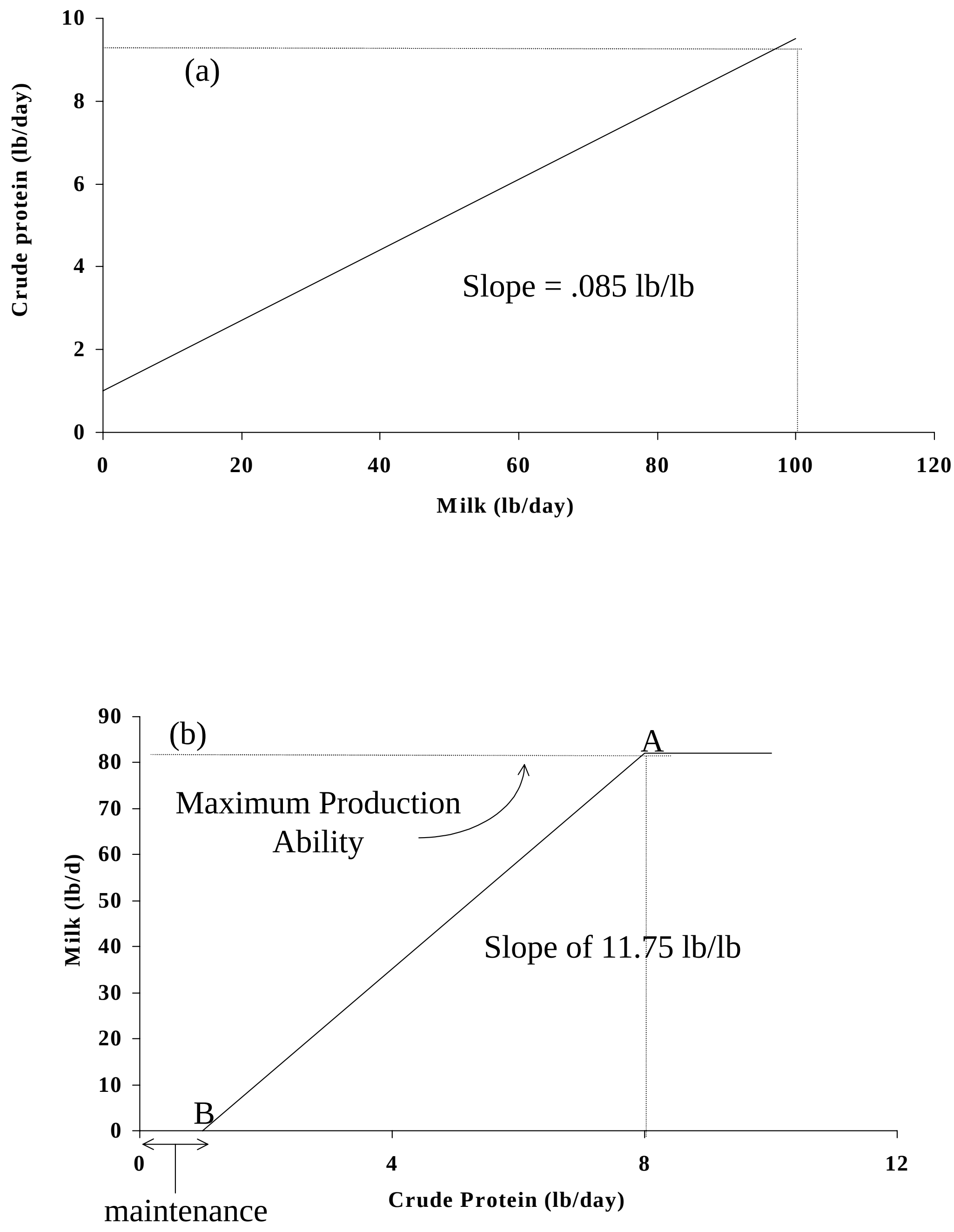

Figure 7. Transformation of a nutrient requirement function into an equivalent nutrient response curve.

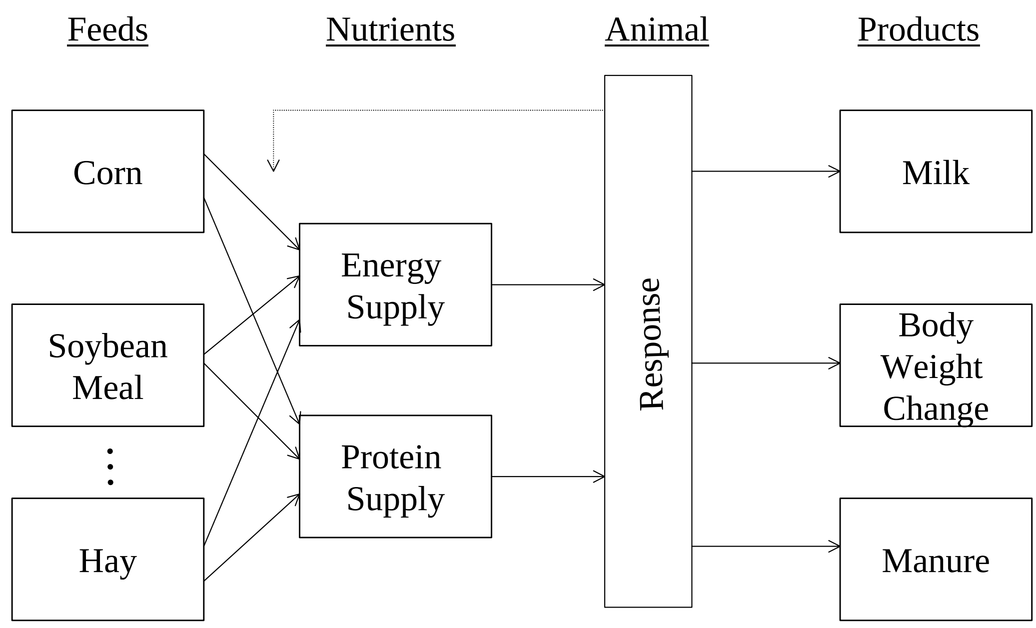

Figure 8. Schematic view of an integrated approach to modeling response functions.

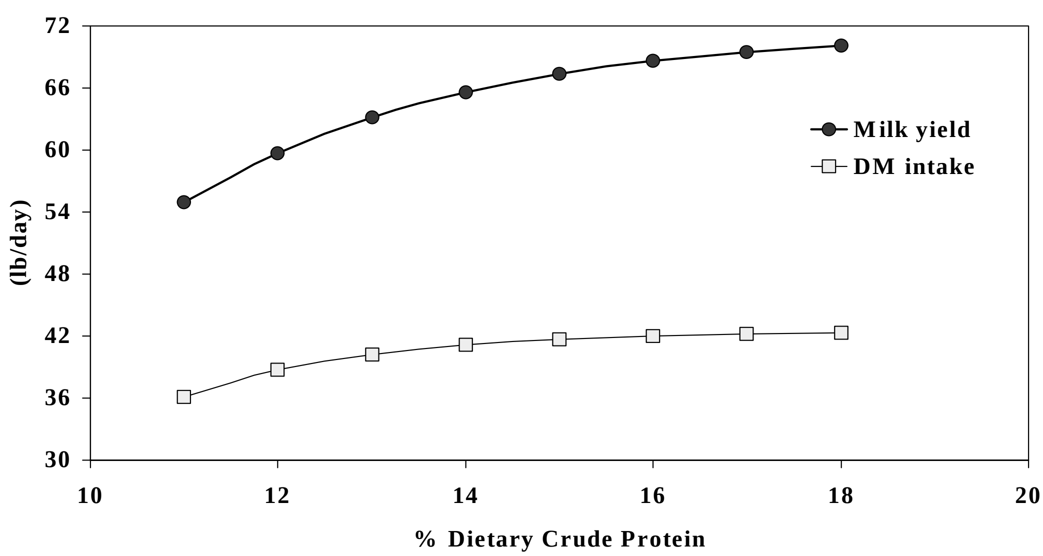

Figure 9. Relationship between concentration of dietary crude protein and predicted yield of milk and intake of dry matter (Roffler et al., 1986).

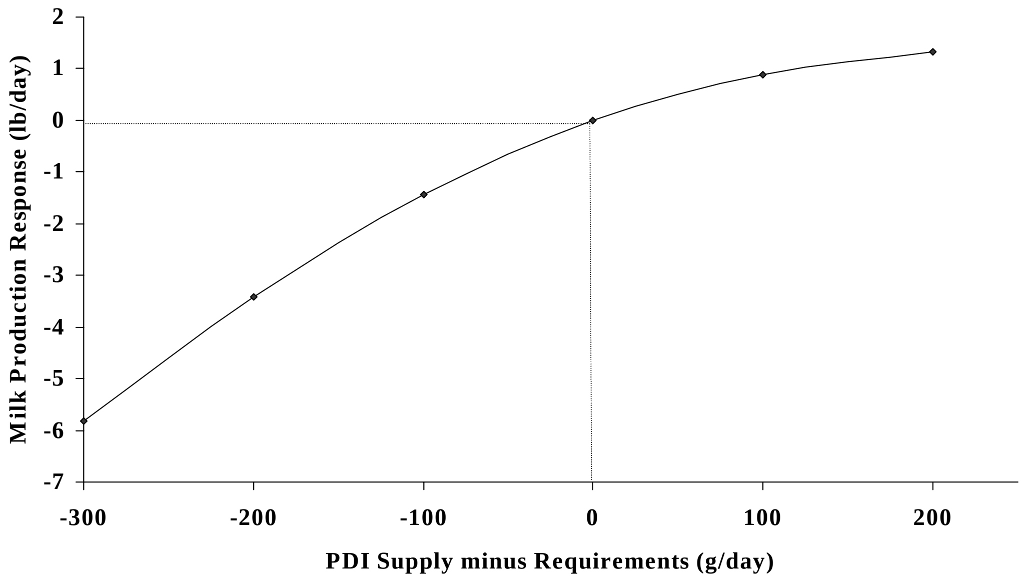

Figure 10. Milk production response (4% fat-corrected milk equivalent) to the net supply of protein based on the French PDI system (protein digestible in the intestine).

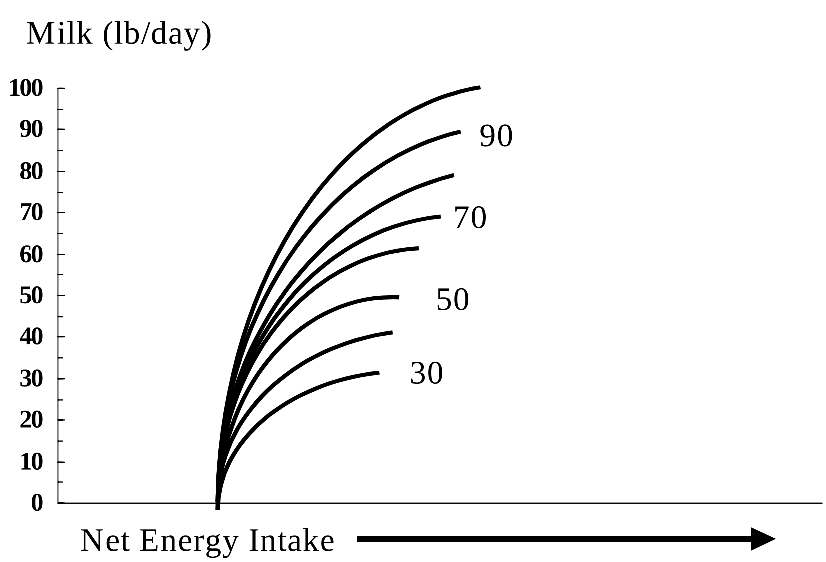

Figure 11. Generalized milk response curves for maximum income above feed cost program. (Beth and Bennett, 1980).

Practical Considerations For Monitoring Milk Urea Nitrogen

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Department of Animal Science
University of Minnesota

Dairy nutritionists are looking for tools or methods to evaluate the efficiency of nutrient metabolism within dairy cows. Milk urea nitrogen (**MUN**) has been proposed as a metabolic monitor for nitrogen and nitrogen-energy metabolism in dairy cows. Some reasons for the interest in optimizing nitrogen utilization in dairy cows are to reduce nitrogen excretion into the environment and increase true milk protein production. In addition, high levels of nitrogen in the diet have been associated with infertility problems (Staples et al., 1993; Tamminga, 1992). In this paper, we will review the origin of MUN, look at several factors that affect MUN values, and provide some suggestions for using MUN to monitor feeding programs.

Origin of MUN

Ammonia is produced from either the degradation of dietary crude protein (**CP**) in the rumen or the deamination of amino acids for glucose production (Figure 1). The release and recapture of ammonia from microbial degradation of CP in the rumen is affected by the balance of carbohydrates and protein in the diet. An inadequate carbohydrate availability relative to high amounts of degradable protein in the rumen will increase rumen ammonia levels. The ammonia not incorporated into microbial protein either flows with the liquid phase from the rumen or diffuses across the rumen wall (Bodeker et al., 1992). Ammonia escaping from the rumen is transformed in the liver and the kidney to urea and either excreted (urine and milk) or recycled through saliva.

Ammonia also is formed when amino acids are metabolized for energy. This occurs when there is a shortage of dietary energy or post-ruminal absorption of amino acids is in excess of requirements. Amino acids leave the rumen as microbial protein and undegraded feed protein.

Because ammonia is toxic to animal tissues, the liver and to a lesser extent the kidney, converts ammonia into urea. Urea is a small nontoxic molecule which is readily absorbed into water and easily diffuses into and out of body tissue spaces. Thus, urea equilibrates rapidly throughout body tissues, including milk, and any changes in blood urea nitrogen (**BUN**) levels are reflected in MUN.

Average MUN Concentrations

Based on several thousand individual cow samples analyzed by Minnesota and Pennsylvania DHIA, the average individual MUN value is 14 milligrams per 100 milliliters (**mg/dl**) with a standard deviation (**SD**) of about 4 mg/dl. This means 66% of the cows tested had MUN values between 10 to 18 mg/dl. Ninety-five percent of all

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cows were between 6 and 22 mg/dl. Cows outside the 95% range, especially on the upper end, should be investigated for feeding or health problems. Values below 6 mg/dl probably reflect an error in analysis rather than a cow feeding or health problem, but this should not be automatically assumed.

Milk samples can be obtained from well mixed bulk tanks to estimate herd MUN levels. A Minnesota survey of 110 bulk tanks found MUN level averaged 16 mg/dl (SD = 4 mg/dl). A bulk tank sample will be less precise than individual cow samples as they will be weighted by milk production level of the cows contributing milk to the bulk tank (Kohn et al., 1997). That is, a higher producing cow influences the MUN level more than a low producing cow. The limitation with bulk tank samples is that it represents all cows contributing milk to the tank and no evaluation of group feeding problems can be made.

The average values listed above provide a reference for interpreting MUN values. They should not be considered the optimum or best MUN value. What the MUN value should be for optimum milk production and health of an animal has not been defined.

Cow Factors Affecting MUN

Breed. Rodriguez et al. (1997a) reported a higher true protein and lower MUN content in milk from Jersey cows compared to Holstein cows (Table 1). On the contrary, Ferguson et al. (1997) found MUN values of 15.8 mg/dl (SD = .16) and 14.0 (SD = .05) mg/dl for Jersey and Holstein cows, respectively.

Parity. The MUN concentrations appear to be unaffected by parity (Ferguson et al., 1997) or slightly decline with increasing parity (Broderick and Clayton, 1997).

Days in milk (DIM). It has been suggested the total nonprotein nitrogen (**NPN**) fraction in milk decreases with DIM until approximately 5 to 10 weeks postpartum and then gradually increases throughout the remainder of the lactation (DePeters and Cant, 1992). Ferguson et al. (1997) reported a negative correlation (r = -.136) between MUN and DIM as did Garcia et al. (1997) (r = -.125). The small and non-significant correlations showed a 2 to 3 mg/dl decline in MUN from freshening to dry-off.

Milk production. Increasing milk production has been associated with increases in MUN. Carlsson and Pehrson (1994) showed as MUN increased from 7.6 to 16.3 mg/dl, herd fat-corrected milk production increased from 13,145 to 15,840 lb per year. A similar association between increased MUN values with higher daily average milk production was found by Garcia et al. (1997). Daily milk production increased about 7 lb per cow per day as MUN increased from < 10 to > 20 mg/dl (Figure 2).

Milk sampling. Recent Iowa State research (Faust et al., 1997) suggested a minimum of 75% of the cows in a group or herd should be sampled to obtain a reliable MUN value. Coefficients of variation for error were 7.9, 4.7, 3.6 and 1.8% when 10, 25, 50, or 75% of the cows in a group were sampled. Previous research at Iowa State (Faust and Kilmer, 1996) recommends always collecting milk samples for MUN comparison from the same milking, always use the same testing laboratory, and exclude cows with a high somatic cell count before beginning to interpret results.

Environmental Factors Affecting MUN

Diurnal variation. Both BUN and MUN concentrations fluctuate considerably over a 24-hour period. Gustafsson and Palmquist (1993) showed MUN levels peaked about 4 hours after feeding. Two studies, (Broderick and Clayton, 1997; Rodriguez et al., 1997b) have shown that MUN peaks approximately 1 hour after plasma urea nitrogen (**PUN**) levels peak, and PUN peaks occur 1 to 2 hours after cows eat. The presence of circadian rhythms for PUN could complicate the interpretation of PUN and MUN results (Bitman et al., 1990). Thus, the number of times a cow eats per day and the time of eating relative to milking will significantly affect MUN concentrations.

Several researchers have shown (Table 2) MUN values differ between AM and PM milkings. The PM milkings tend to be higher in MUN than AM milkings. This probably reflects cows not eating for several hours before the AM milking as feed offerings and push-ups are less likely to be done between midnight and 6 AM. Broderick and Clayton (1997) found lower MUN concentrations in AM than PM samples and indicated switching milk samplings back and forth between AM and PM confounded the interpretation of MUN results.

Seasonal variation. Seasonal variation has to be carefully addressed in order not to confound environment with animal or feed effects. Ferguson et al. (1997) reported means of 14.0, 15.0, 16.3, and 14.2 mg/dl for winter, spring, summer, and fall, respectively, of 1996. The SD of the herd mean MUN by season were as follows: winter '96, 2.88; spring '96, 3.16; summer '96, 3.45; and fall '96, 3.05. A seasonal variation in a study of 17 dairy farms for MUN from July to November of 1997 also was found by Garcia et al. (1997) (Figure 3).

Dietary Factors Affecting MUN

Protein. In the 17-farm study of Garcia et al. (1997), MUN was better correlated with percentage of soluble protein (**SIP**) or CP in the diet than with amount consumed of either protein fraction (Table 3). The better correlation of SIP than CP with MUN suggests the availability of protein to the rumen microbes is a factor affecting MUN concentrations. Others (Broderick and Clayton, 1997; Hof et al., 1997) reported MUN concentration was reflective or correlated to the amount of surplus nitrogen for microbial synthesis in the rumen.

The ratio of rumen degradable to undegradable protein (RDP/RUP) would be expected to affect MUN concentrations if form and availability of protein to the rumen microbes are a factor. High MUN concentrations would be expected when a high ratio of RDP/RUP is fed. Feeding an insufficient amount of rumen fermentable carbohydrates (NFC) along with a high RDP/DUP should accentuate MUN values. Both Elrod (1995) and Roseler et al. (1993) showed PUN increased with changing ratios of RDP/RUP (Table 4). A deviation in RDP or RUP from NRC (1989) guidelines resulted in an increase in PUN.

Energy. Rumen fermentable carbohydrates play an important role in determining MUN concentrations by supplying energy and carbon skeletons for microbial protein synthesis. Rate of protein and carbohydrate fermentation must be similar for efficient incorporation of ammonia into microbial protein. Hoover and Miller (1995) reviewed carbohydrates in the rumen and suggested NFC should be more than 35% of the dietary DM to maximize rumen microbial growth.

In the on-farm MUN study by Garcia et al. (1997), MUN was not correlated directly with either the amount or percentage of NFC in diets but was correlated with the ratio of NFC to CP in the diet. Broderick and Clayton (1997) looked at the reverse relationship, dietary CP per unit of NE_L, and reported a negative relationship with MUN. These relationships further emphasize the importance of balancing diets for both protein and carbohydrates.

Rumen pH could also affect MUN concentrations. At a pH below 7, ammonia (NH_3) is converted to ammonium (NH_4) and is less diffusable from the rumen. Kertz et al. (1983) found that when ruminal contents were acidified with ammonium chloride, concentrations of blood ammonia and BUN tended to be lower as pH decreased below 7.

Although most trials have dealt with rumen fermented organic matter, De Peters et al. (1987) reported an increase in milk NPN content as the dietary fat percentage increased (Table 5). In a recent trial (Rodriguez et al., 1997a), MUN increased by 4.9% in Holstein and Jersey cows fed ruminal inert fat. As fat percentage in the diet increases, ruminal fermentable carbohydrate or grain usually decreases and, thus, the MUN increase may reflect this change in rumen fermentation.

Using MUN as a Diagnostic Tool

Feed, animal, and environmental factors all contribute to the urea pool within the body. To use MUN as a diagnostic tool for evaluating rations on dairy farms, it is important for all factors that can affect MUN be taken into consideration.

A one time MUN analysis of a bulk tank or of cows in a herd is not recommended. Without an established baseline MUN value for the herd, no determination of the impact of nutrition or other factors on MUN can be made. An exception to this will be in extreme cases with individual cows or herds where MUN values are outside of 10 to 18 mg/dl (mean + 1 SD) range. Health problems or abnormal feeding programs may be the cause of MUN values outside this range. In these situations, other signs of health or feeding complications will most likely be apparent.

Based on the information to date, it appears that the best way to use MUN within a herd is to establish a minimum of a 6-month baseline. The DHIA or an independent MUN analysis on all or 75% of the cows in a group should be taken every month. A 6-month period should allow for most milking and feeding factors affecting MUN to be exhibited. Once this baseline is developed, changes in MUN values then can be evaluated with some degree of certainty that a change has occurred.

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Table 1. Effect of breed and rumen undegradable protein (RUP) on milk nitrogen (N) fractions[1].

Milk nitrogen fraction		Dietary RUP (% of CP) 29	41
		g/100 g of total N	
Casein N	Holstein	75.4	75.1
	Jersey	78.2	77.2
MUN	Holstein	4.77	5.24
	Jersey	3.51	3.66

[1]Modified from Rodriguez et al. (1997a).

Table 2. Morning and afternoon variation in MUN concentration.

	Morning	Afternoon
	mg/dl	
Miettinen and Juvonen (1990)	10.92 ± 1.88	15.54 ± 1.71
Robinson et al. (1991)	12.60	14.20
Ferguson (1996)	12.25 ± 2.25	14.35 ± 2.20

Table 3. Correlations between dietary protein fractions or intake and milk urea nitrogen (MUN)[1].

	Crude protein		Soluble protein	
	% of DM	kg/day	% of CP	kg/day
MUN	0.38**	0.23**	0.42**	0.36**

** *P* < *.01*

Garcia et al., 1997.

Table 4. Plasma urea nitrogen as affected by the ratio of rumen undegradable to rumen degradable protein (RUP/RDP).

	RUP/RDP	RUP	RDP
	100% of requirements	125% of requirements	125% of requirements
	---------- mg/dl ----------		
Elrod (1995)	15.7	19.2	22.8
		120% of requirements	
Roseler et al. (1993)	14.8	17.8	

Table 5. Effects of adding yellow grease to the diet on milk nitrogen (N) fractions (DePeters et al., 1987).

Milk N fraction	% fat in dietary DM 0	3.5	7
	---------- % of total N ----------		
Casein N	75.47	75.55	74.53
Whey protein N	18.55	18.07	18.79
Non protein N	5.98	6.39	6.68

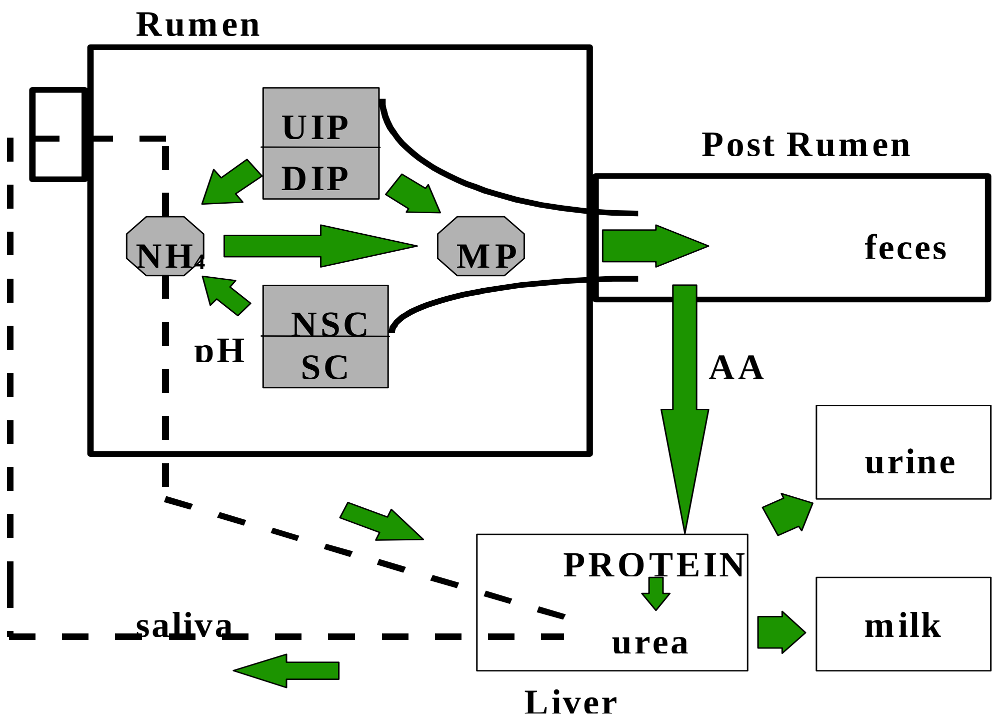

Figure 1. Nitrogen excretion routes.

UIP = undegradable intake protein; DIP = degradable intake protein; MP = microbial protein; NSC = non structural carbohydrates; SC = structural carbohydrates; and AA = amino acids.

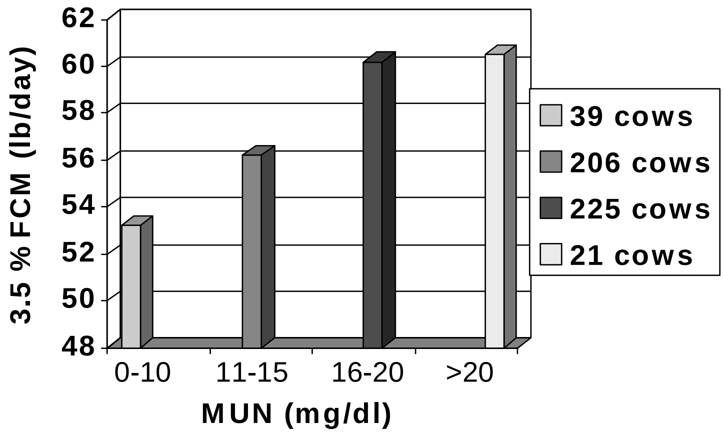

Figure 2. Relationship of MUN concentration with average daily milk (Garcia et al., 1997).

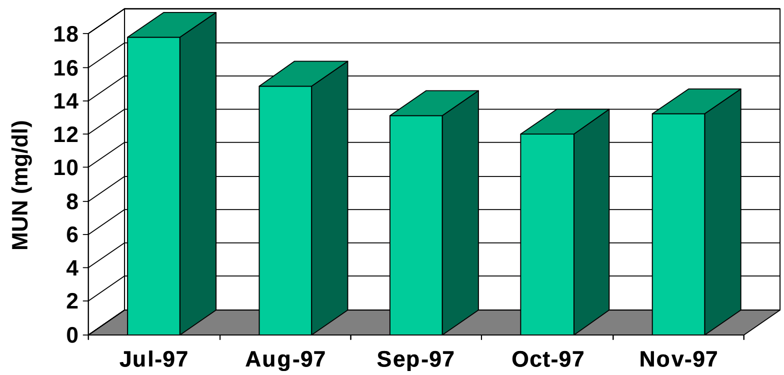

Figure 3. Mean MUN concentrations by month for 17 farms (Garcia et a1., 1997).

Current Research in Dairy Cattle Nutrition at Michigan State, The Ohio State, and Purdue Universities

Listed in this section are brief descriptions of the current dairy cattle nutrition research being conducted at the three universities which co-sponsor the Tri-State Dairy Nutrition Conference. The purpose of these descriptions is to allow people interested in dairy nutrition to be aware of the types of research that are currently being conducted and which will be published in the future. If there is an interest in learning more about a specific area of research, contact the researcher at their respective university.

Michigan State University
Department of Animal Science
2265 Anthony Hall
East Lansing, MI 48824-1225
Dr. Maynard Hogberg, Chair

Researchers: Mike Allen, David Beede, Herb Bucholtz, Tom Herdt, and Mike VandeHaar

Dr. Mike Allen 517-432-1386 msallen@msu.edu

Forage Utilization, Carbohydrate, and Energy Intake - Maximizing Energy Intake in Early Lactation

Graduate students and staff: Richard Longuski, Masahito Oba, Jackie Ying, Frank Xu, Berry Choi, Elisabet Nadeau, Jackson Oliveria, Dave Main, and Richard Longuski

I. Fiber digestibility - Quantifying the importance of fiber digestion

II. Balancing production and removal of rumen fermentation acids
   1. Adaptation of the rumen and rumen papillae
   2. Effective fiber
   3. Ruminal digestibility of carbohydrates - grains and fiber

III. Physical control of feed intake
   1. Rumen fill
   2. Fermentation acids

IV. Predication of alfalfa fiber quality

V. Corn hybrid comparisons for silage

Dr. Dave Beede 517-432-5400 beede@pilot.msu.edu

Graduate students and staff: J. Davidson, D. Mashek, T. Pilbeam, S. Puffenbarger, L. Rodriguez, S. Scheurer, R. Ashley, and R. Kreft.

I. Nutritional physiology of transition cows

A. Ca homeostasis
1. Ca metabolism
2. Comparison of different anion sources in prepartum diets
3. Optimal Ca concentration of prepartum diets with supplemental anions

B. Exercise physiology of pregnant dry cows
1. Influence of programmed exercise on physical and physiological fitness in transition
2. Effects of programmed exercise on energy metabolism of pregnant dry cows through transition.

C. Energy (carbohydrate) nutrition of transition cows
1. Influence of dietary particle size distribution pre- and postpartum on animal health and performance
2. Effects of fermentability of the dietary fiber and other diet/nutrient characteristics on transitional health and performance
3. Influence of length of time (3 vs. 6 wk) of feeding the close-up diet on peripartum health and performance
4. Effects of concentration of non-fiber carbohydrate in the close-up diet on peripartum health and performance

II. Whole-farm nutrient management.

A. Influence/ impact of dietary nutrients (e.g., phosphorus) utilization on whole-farm nutrient management.

Dr. Herb Bucholtz 517-355-8432 bucholtz@pilot.msu.edu

Nutrition and Feeding Management for Michigan Dairy Herds
Location of Research: MSU Upper Peninsula Experiment Station, Chatham, MI
Research Staff: Paul Naasz, Alice Charlebois, and Matt Thompson

I. Effects of feeding management systems and grain supplementation on grazing dairy cattle.

A. Effects of forage species on lactating cow performance grazing alfalfa or birdsfoot trefoil
B. Effect of grain feeding strategies on grazing lactating dairy cows

II. Practical feeding management methods that effect feed intake
   A. Effect of the number of hours feed is available on feed intake and performance
   B. Effect of diet dry matter on feed intake and performance

Dr. Tom Herdt Animal Health Diagnostic Lab, 517-355-8725 herdt@pilot.msu.edu

A. Assessment of nutritional status in animals
   1. Vitamin and mineral status
   2. Energy status

B. Transition cows and metabolic diseases

C. Nutrition-fertility relationships

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A. Understanding the endocrine mechanisms by which energy and protein nutrition alter metabolism and mammary development in dairy cattle

B. Role of nutrition on dry cow health and on mammary development

1. Dry cows: The relationship of prepartum lipid mobilization on farms to disease incidence, fertility, and milk production is being studied. Cows mobilizing fat prepartum are much more likely to contract mastitis in the first 10 days after calving. Because neutrophils are the first line of defense against mastitis, work is underway to examine the effect of energy and protein nutrition on neutrophil function of cattle. Eventually this work will help us make more informed recommendations about feeding high-producing dairy cows in the periparturient period.
2. Mammary development: Previous work at MSU suggests that high protein along with high energy may accelerate mammary development of heifers, but this idea has never been directly tested. Research is being conducted to investigate the effects of protein nutrition on mammary development of dairy heifers grown at 2.4 lb/day before puberty. Insulin-like growth factor (IGF) -1 may be the mechanism by which nutrition alters mammary development. Effects of IGF-1 on mammary cells are complicated by the presence of several binding proteins. Thus, we are studying the role of insulin-like growth factor binding protein-2 on mammary cell proliferation in vitro. Eventually, this work will enable us to improve the growth and mammary development of dairy heifers and to manipulate mammary involution to control the lactation cycle.
3. Nutrition modeling: Dr. VandeHaar is leading the dairy group and working with programmer Bob Kriegel to develop a new Windows version of the Spartan Dairy Ration program, which will enable more efficient management of feeding and nutrition on farms.

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Energy and Forages

Energy values of corn silage. A conventional hybrid and a high-oil hybrid of corn was grown at OARDC and chopped with a conventional silage chopper or a chopper equipped with a kernel processor in the fall of 1997. The four different silages were ensiled in separate tower silos for approximately 100 days. Diets with 65% corn silage (DM basis) were formulated and fed to cows starting at approximately 100 days in milk. Total collection digestion trials are being conducted to determine TDN of the diets. Lactation performance will be measured during an 84 day lactation trial. This study will provide information about the effect of processing and oil content on the available energy content of corn silage. (Weiss)

Role of forage surface characteristics on absorption of fatty acids. Techniques have been developed to measure the quantity of fatty acids adsorbed to forage surfaces. This research may help explain why performance of cows is better when fed fat with alfalfa compared to corn silage. (Palmquist and Yang)

Brewers grains (BG) replacing forage or concentrate. Brewers grains replaced forage from 50 to 37% or reduced nonfiber carbohydrates from 42 to 37% or did both in late lactation cows with ruminal and duodenal cannulas. Dry matter intake was depressed by about 5 lb/cow/day when BG replaced concentrate, apparently because total NDF in the diet increased about 5 percentage units up to almost 35% (DMI was correlated with dietary NDF percentage, $r = -.42$, $P = 0.08$). Because periods were only 2 wk, long-term feeding studies are needed to verify this conclusion. Ruminal pH was not significantly affected by treatment. Although rate of NDF disappearance in situ was decreased for BG when BG replaced forage, no differences in NDF digestibility in the rumen or total tract were detected. Results indicate that NDF from BG can reduce forage NDF from 23 to 17% of DM; however, when BG replaces concentrate, DMI can be decreased due to bulk fill if total NDF reaches 35%. This study tends to support work from Wisconsin that BG are effective at stimulating chewing and can replace forages effectively. (Firkins and Younker)

Level of forage NDF (FNDF) and source of nonstructural carbohydrates in diets for lactating cows. In previous a short-term experiment with Jersey cows, we concluded that FNDF could be reduced to 16%, but not 11%, when sources and concentrations of starch are adequately balanced. To investigate this further in a longer time period, forty-eight Holstein cows were blocked and fed one of four diets: 1) 21% FNDF with corn, 2) 16% FNDF with corn, 3) 16% FNDF with corn and wheat (1:1), and 4) 11% FNDF with whole cottonseed (WCS; 11% of DM) and corn. Fatty acids were 4% of DM, with supplemental fat provided from tallow and WCS. Diets were fed week 10 to 25 of lactation as a TMR. Actual FNDF was slightly lower than expected. The DMI and milk yield were highest for cows fed 11% FNDF with WCS. Milk fat percentage was highest for cows fed 21% and 16% FNDF with corn. Cows fed 16% FNDF with corn and wheat had milk fat-protein inversion. The ruminal acetate:propionate ratio was highest for cows fed 16% FNDF. The most heath problems were with feeding 16% FNDF with corn; four cows had a DA and one had an abomasal ulcer. We concluded that for cows in midlactation, FNDF may be reduced to 9 to 11% when WCS is fed at 11% of the DM and dietary starch is reduced to 30%, and may be reduced to 14 to 16% without WCS when concentration of rumen degradable starch is monitored and starch is at 30% of dietary DM. In another trial, 36 Holstein cows were fed a transition ration containing yeast (Diamond V Mills, Cedar Rapids, IA) and 24 cows fed a transition ration without yeast beginning -21 days prepartum. After parturition, cows are being fed one of four diets: 1) 21% FNDF and yeast, 2) 21% FNDF and no yeast, 3) 17% FNDF and yeast, 4) 17% FNDF and no yeast, and 5) 25% FNDF with yeast for 30 days then switched to Diet 3. Diets are being fed for 140 days of lactation. Project is currently underway. (Eastridge, Harmison, Slater, and Wang)

Effectiveness of whole cottonseed at various levels of substitution for alfalfa with ground versus steam-flaked corn. We will look at ruminal pH, site of digestion (ruminal versus post-ruminal) of starch and NDF, chewing measurements, and ruminal mat consistency. The effectiveness of cottonseed appears to vary with the particle size of the forage that it replaces (Michigan State research) and probably with the concentration of forage in the diet and with starch degradability in the rumen. This study should help quantify these hypotheses. (Firkins and Harvatine)

Brown mid-rib corn versus dent corn for silage. The objective is the research is to determine yield, chemical composition, and animal utilization of corn silage (CS) with and without the brown midrib (BMR) gene. Both hybrids will be incubated in the rumen via in situ to estimate ruminal digestibility of DM, NDF, protein, and starch. Four lactating cows with ruminal and duodenal cannulas will be fed the following diets in a Latin square design: 1) 21 % FNDF from control CS, 2) 21% FNDF from BMR CS, 3) 17% FNDF from control CS, and 4) 17% FNDF from BMR CS. Diets will consist of 16 to 18% CP and 30 to 35% starch. Forage in the diets will consist of 75% corn silage and 25% alfalfa silage. Data to be collected will include DM intake, milk yield, milk protein, milk fat, body weight, ruminal pH, ruminal VFA, and ruminal mat consistency. Two other squares (8 cows) of intact cows will be fed the same diets to further investigate intake and production measures. (Eastridge and Qiu)

Rumen Microbial Protein and Digestibility Markers

Prediction of microbial N flow in duodenally cannulated cattle. Data from 55 trials with 213 treatment means from published literature were used to predict microbial N (multiply x 6.25 to estimate microbial CP) flow to the duodenum empirically from DMI and feed composition data. Microbial N flow (grams/cow/day) can be predicted from NE_L intake or from DMI and NDF % of the diet:

= 6.13 + 7.57 (Mcal/day of NE_L), or

= 16.1 + 22.9 (DMI, kg/day) - .365 (DMI2) - 1.74 (NDF, % of DM)

Estimation of microbial protein flowing to the small intestine is critical in the estimation of bypass protein required in the diet. The NRC equation to predict microbial N flow from NE_L intake underpredicts microbial N at low intakes and overpredicts at higher intakes. The current statistical models above reflect current data much more accurately (many of the data were not available to the previous NRC committee, and more appropriate statistical techniques, e.g., trial effects, were used). Studies in the literature evaluating effects of dietary fat, limitation of ruminally degradable protein, and some other factors were limited in the dataset, so further research is needed to better model these mechanistic factors affecting microbial protein synthesis. (Firkins, Oldick, St-Pierre, and Allen)

A compartmental model to evaluate intra-ruminal microbial protein recycling. Microbial N flows to the duodenum are "net" values from microbial protein synthesis and microbial protein degradation in the rumen. Synthesis and degradation may be affected by separate mechanisms, so understanding recycling (degradation) is critical. Nitrogen-15 was used to develop a compartmental model to quantify microbial non-ammonia nitrogen (estimate of microbial CP) recycling in the rumen in heifers fed dietary fat varying in the degree of saturation. Previously, we have shown that feeding fat increases the efficiency of microbial protein synthesis (higher microbial N reaching the duodenum per unit of organic matter digested in the rumen). This study showed that efficiency of microbial protein synthesis increased by over 20% when fat was fed. This efficiency seems to be correlated negatively with protozoal counts in the rumen (higher concentrations of protozoa may mean more predation of bacteria and more recycling). Recycling of microbial protein decreased linearly (by over 20%) with increasing unsaturation of fat, but recycling was not correlated with protozoal counts or with efficiency of microbial protein synthesis. Apparently, some recycling of microbial protein is through metabolism by microbes that is less energetically wasteful than is protozoal predation and lysis of entire microbial cells. Feeding dietary fat does not increase dramatically the need for more bypass protein because of reduced microbial protein per se (as is often speculated); rather, if fat decreases feed intake, there may be a greater need for bypass protein, or bypass protein may be needed to provide a better balance of amino acids reaching the duodenum to help prevent milk protein depression. (Firkins and Oldick)

Requirements by ruminal microbes for peptides versus ammonia. Peptides and ammonia are lumped into feed systems as "degradable" or "soluble" protein. Many nutritionists are using some version of the Cornell Net Carbohydrate and Protein System (CNCPS), which predicts microbial protein flow to the duodenum based on availability of carbohydrates with peptides or ammonia. A continuous culture system is being used to control these peptide and ammonia levels and to reduce variation resulting from various animal effects (e.g., ruminal passage rate). (Firkins and Griswold)

Markers for measurement of ruminal passage rate. Markers will be evaluated for errors resulting from migration of rare earth markers to unmarked feed or due to the marking process. A potential solution to reduce these errors is being explored. Models such as the CNCPS rely on accurate ruminal passage rates, and many published data appear to overestimate ruminal passage rate because of errors in marker techniques. (Firkins and Winland)

Milk Composition

Contribution of fat source and micronutrients in the cow's diet to development of spontaneous oxidized flavor in milk. The objectives of the research are to determine the role of feeding whole soybeans on increased polyunsaturated fatty acids in milk and the contribution of micronutrients (copper and vitamin E) and breed (Jersey and Holstein) on the development of spontaneous oxidized flavor. (Palmquist, Weiss, and Harper)

Conversion of trans-11 18:1 to conjugated linoleic acid (CLA) in mice. Milk fat contains significant amounts of trans-11 18:1 and up to 50% of trans-11 18:1 fed to mice is converted to CLA before it is stored in tissues. This fatty acid metabolism has important implications for human health and marketing of milk fat. (Palmquist and Santora)

Minerals and Vitamins

Effect of sulfate intake on selenium utilization in lactating cows. Typical lactation diets with 0.1 or 0.3 ppm and 0, 0.15, or 0.30% added sulfur from a mixture of calcium and magnesium sulfate were fed to lactating Holstein cows for approximately 120 days. The basal diet contained 0.18% sulfur. Added sulfur reduced DM intake and linearly reduced milk production. As sulfur concentration in the diet increased, plasma concentrations of Se decreased in cows fed either concentration of Se. Apparent digestibility of Se was lower by cows fed added sulfur than for those fed the control diet This experiment showed that long term intake of sulfur from sulfate above the current NRC recommendation reduces Se absorption and Se status in lactating cows. (Ivancic and Weiss)

Effect of extra vitamin E during the prefresh period on prevalence of mastitis in commercial dairy herds. Three large commercial dairy herds near Wooster OH were used to determine the effects of feeding extra vitamin E during the prefresh period on the prevalence of mastitis and retained fetal membranes. Dry cows and heifers were divided randomly into two groups and fed either approximately 1000 or 5000 IU/day of supplemental vitamin E for the last 16 days of gestation. Aseptic milk samples were collected from all cows within 2 days of parturition for microbiological analysis. Based on NRC recommendations, animals in all 3 herds were fed excess amounts of copper, zinc, vitamin A, and especially selenium. The average prevalence of retained fetal membranes was 8% and was not affected by treatment. In one herd, prevalence of mammary gland infections was reduced by feeding high levels of vitamin E but no effect was observed on the other 2 herds. These data contradict a previous study conducted at OARDC. The main difference between the two studies was the level of supplemental Se. In the OARDC study with positive results from feeding high vitamin E, cows were fed diets with 0.1 ppm of Se, but in this study, cows were fed diets with approximately 1.0 ppm of Se. (Weiss, Hogan, and Smith)

Effect of supplemental biotin on hoof health in first lactation Holstein cows. One hundred first lactation cows in a commercial dairy herd were randomly divided into two groups. Diets were the same for both groups except for the addition of 20 mg/day of supplemental biotin to one diet. Diets were fed for approximately 300 days. Overall, hoof health was good in both groups. Concentrations of biotin increased in milk and serum with biotin supplementation. Cows fed biotin had less white line separation at approximately 100 days in milk than did control cows. This study indicates that supplemental biotin may have some benefit to hoof health, but additional research is needed before routine supplementation is recommended. (Midla, Hoblet, and Weiss)

Dairy Farm Management

Management information systems. *Economic design of control charts for monitoring longitudinal data*: The objective is to develop nonparametric control methods optimized for the relative cost of Type I and Type II errors. The new methods should be more reliable and accurate at detecting changes in processes like milk production, milk composition, and body composition score. We have derived a general methodology to determine optimum sample size, sampling period, and location of boundaries for control charts used to monitor feed production processes. Unbiased methods of estimation of gradient functions: In the animal sciences, measurements are often taken for which the interest is in estimating their rates of change (e.g. weights of animal are taken periodically to estimate their average daily gain). We have proven that all current methods of estimation yield biased estimates. In this project, we want to estimate the magnitude of the bias and develop new methods that would yield unbiased estimates of the gradient. We have derived four alternative cubic splines methods. Two of them yield unbiased parameter estimates under most of the conditions studied for both growth and milk production data. However, the parameter estimates have generally larger variances than traditional (but biased) quadratic equations. So the choice is between unbiased or minimum variance estimates. (St-Pierre)

Optimization methods of agricultural systems. *Development of methods for the maximization of mathematical preference models*: Current ration balancing programs use linear programming (LP) models and algorithms to determine a least-cost ration. An LP model assumes perfect knowledge of ingredient costs, ingredient composition, and animal requirements. None of these are met in practice. As a result, applied nutritionists spend a large amount of time deriving a solution that meets their expert preferences. Such preferences can be quantified and models developed to directly optimize those preferences. We have developed two alternatives for the solution of what we call "Maximum Preference Programming Models". Both will be programmed and tested for their reliability and speed. (St-Pierre and Posner)

Financial strategies for U.S. dairy farms. *Managing risk associated with milk income variance:* The price paid for milk to farmers is expected to show much larger fluctuations through time than what has been customary, a direct consequence to prices being more market driven. New mechanisms, such as milk futures contracts, will emerge as means of price variance reduction. The price received for milk is only one component of the monthly gross income from milk on a dairy farm, the other part being a function of the number of cows being milked, their daily milk production, and the number of days in the month. In this research, we want to evaluate the relative weight of milk price fluctuations versus herd monthly milk shipment fluctuations on monthly milk income variance. We have derived a method for predicting the future performance of a given herd (and its prediction variance) based on historical data, mixed model estimates, and transitional probabilities. The method is currently under evaluation. (St-Pierre, Schnitkey, and Thraen)

Methods of monitoring and improving nitrogen (N) utilization on dairy farms. *Validation of a simple model linking blood urea nitrogen (BUN), milk urea nitrogen (MUN), and urinary nitrogen (UN)*: Kuhn at the University of Maryland proposed a simple model to predict N excretion in dairy cows. The model was developed exclusively with Holstein cows and needs to be validated with other breeds. Jersey cows would serve as good research models due to their high relative N (protein) output. Also, a critical relationship between MUN and urinary N excretion needs to be tested. Four diets differing widely in ruminally degradable protein and ruminally available carbohydrates are being fed to four Holstein and four Jersey cows in a double Latin square design. The relationships between MUN, BUN, and total urinary N excretion are being quantified. (St-Pierre and Kauffman). Improving nitrogen and phosphorus utilization in dairy rations: Environmental concerns are making the issue of improving nitrogen utilization by livestock a more urgent one. We are evaluating: (1) how grouping strategies on dairy farms affect nutrient balance and optimum allocation of nutrient inputs, and (2) how uncertainty in levels of inputs, model structure, and parameter estimates influence the optimum allocation of inputs. Results will be presented at the ADSA-ASAS annual meeting this summer. (St-Pierre)

Ohio Dairy Ration Program. A new version of the software is being developed to incorporate some additional variables for use in ration formulation and evaluation, to provide some new features, and to further user friendliness. The new version should be released in 1998. (Eastridge, Weiss, and Lemon)

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Protein Nutrition of Transition Cows

Researchers: Shawn Donkin and Tim Johnson

Feeding strategies of transition dairy cows contribute to the risk factors associated with metabolic disorders in the next lactation. Protein nutrition for transition cows was investigated in 40 multiparous Holstein cows fed isocaloric rations beginning 28 days prepartum. Prepartum rations were 12% CP (% of DM) and 26% rumen undegradable protein (RUP; % of CP), 16 % CP and 26 % RUP, 16 % CP and 33 % RUP, and 16 % CP and 40 % RUP. All cows received the same postpartum diet 18 % CP and 40 % RUP. Cows fed the 12 % CP: 26% RUP diet during the transition period produced more milk for the first 56 days of lactation ($P < .05$) than cows receiving any of the 16% CP diets. Plasma triglycerides, glucose, calcium, urea nitrogen, and nonesterified fatty acids were not different among treatments. The data indicate carryover effects of prepartum dietary protein on postpartum intake and milk production. A follow up study is in progress which is designed to replicate these treatments and follow cows longer into lactation.

Monitoring of Inter-Ruminal Temperature

Researcher: Shawn Donkin

Inter-ruminal temperature can be used to monitor health status, changes after drinking bouts, and at parturition. Electrical recording with an inter-ruminal device is being tested at the Purdue Dairy Research and Education Center to determine possible benefits to herd management.

Glucose Metabolism in Hepatic Cell Culture

Researcher: Shawn Donkin

Various projects involving liver cell culture, gene expression, and nutrient metabolism of ruminants are underway.

Corn Silage Processing and Theoretical Length of Chop

Researchers: Tim Johnson, Shawn Donkin, and Mike Schultz

Processing of corn silage with mechanical roller mills or corn crackers has been shown to improve starch digestibility and milk production of cows. Theoretical length of chop (TLC) widely recommended for non-processed silage is 3/8 inch. A study is currently underway at Purdue which is designed to answer two questions on how to maximize use of chopper and processor technology. Corn silage was chopped at 9 mm (3/8 inch) TLC and 17 mm (3/4 inch) TLC. These silages are being monitored for actual particle size and chemical composition. In a replicated 3 X 3 Latin square design, 12 cows are being fed these two silages, and the 17 mm silage is being fed at a greater inclusion rate. Milk and milk component production, rumen VFA, and chewing time are being measured to investigate possible benefit to longer chop length with processed silage. Silage from the 1997 crop was from a variety selected for increased fiber digestibility. We are hypothesizing that the greatest benefit to kernel processing and obtaining more effective fiber by increasing TLC could occur when feeding a high starch hybrid. In a continuation of the present study with the 1998 crop, an experiment will be designed to compare chop length and presence or absence of processing with a variety selected for grain yield and starch content.

Composting of Dairy Manure Solid Waste

Researchers: Larry Underwood, Mark Hamilton, and Steve Hawkins

Composting of separated manure solids and fertilizer quality of the resulting digest has been demonstrated on the Purdue Dairy from 1995 to present. Manure is removed from the 200 cow freestall barn by a flushing system. A chopper pump mixes and elevates the waste stream to a manure solids separator with the capacity of 200 to 800 gallons per minute. Separated solids are placed in windrows approximately 5 ft. high, 10 ft wide, and 250 feet long. Solids are maintained at 40 to 65% moisture, 110 to 150o F, and 5 % oxygen. Water is added as needed and windrows turned to maintain these conditions. Compost is utilized on crop land using a crop nutrient management plan designed to meet phosphorus requirements and supplemented with nitrogen fertilizers as suggested by the Tri-State Fertilizer Handbook.

Tail Docking: Effects on Behavior and Animal Health and Well-Being

Researchers: Julie Morrow-Tesch and Susan Pruitt

The USDA ARS Livestock Behavior Lab has completed a tail docking project with primiparous dairy cattle to study acute behavioral and physiological response to a rubber band tail docking procedure. Behavioral response to the presence of flies was studied with these cattle during the summer of 1997. These ARS scientists have also conducted a calf transportation stress study to determine the effects of electrolyte solutions and shipping stress on immune response.

Tri-State Dairy Nutrition Conference