HOW DO FORAGE QUALITY MEASUREMENTS TRANSLATE TO VALUE TO THE DAIRY FARMER?

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ABSTRACT

The economic value of a feed resides in its content of nutrients. In dairy, the economically important nutrients are net energy lactation (**NE_L**), metabolizable protein (**MP**), effective NDF (**eNDF**), and non-effective NDF (**neNDF)**. Unit prices of the important nutrients can be calculated using the composition and prices of all feeds being traded in a given market (i.e., using a method called hedonic pricing). This method is available in a Windows-based software. Alternatively, estimates of unit prices are being published on a monthly basis in a national dairy magazine for all major dairy regions. Hay composition for NE_L, MP, eNDF and neNDF can easily be determined using 11 compositional inputs and equations provided in the appendix of this paper (largely derived from NRC, 2001). Using data from our experimental research station, we do not find a strong association between in vivo total tract NDF digestibility and in vitro NDF digestibility (NDFd). At this point we are still recommending the use of protein-free NDF and lignin to estimate NDF digestibility. For most feeds, the economic value is calculated as the simple sum of the values of their nutrients. With forages, however, one must introduce a correction associated with quality because forages are not entirely substitutable. Dairy cows exhibit a small, but significant response in milk yield when high quality forages are substituted for low quality forage in otherwise equally balanced diets. The values of three levels of quality within alfalfa and grass hay are calculated over the period of January through October 2011. In alfalfa, nearly 65% of the total value is associated with the NE_L content, whereas in grass NE_L content accounts for nearly 75% of hay values. Of the 11 compositional inputs required in the calculation of hay values, NDF, lignin and ash appears to have the greatest importance.

Key Words: alfalfa, grass, hay quality, dairy, economic value

INTRODUCTION

What are feeds used for? Animals do not require feeds; animals require nutrients. Feeds are nothing else than containers, packages of nutrients. The sole value of a feed is in the value of the nutrients that it contains. A feed containing no nutrient has no economic value. No economic value means that it is worthless - ZERO.

What are the nutrients of economic value? The answer to that question depends on two things. First, the nutrients of economic value are dependent on the class of animals under consideration. For example, the nutrients of economic importance are not the same for beef cattle, lactating

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dairy cows, dry cows, and replacement animals. Hence a given feed has a different economic value to lactating dairy cows and replacement heifers.

Second, the nutrients of economic value depend whether one is interested in the strategic value of a feed versus its tactical value. This begs further explanations. A dairy producer feeding 50 lbs/day of a finely chopped corn silage is looking for attributes in purchased hay that are very specific to the narrow conditions in which it is to be fed. The value of a given lot of hay to this producer would be entirely tactical – i.e., determined by how well it fits as a complement to other feed ingredients that are essentially pre-determined. On the other hand, a dairy producer who considers all feed components of his dairy rations to be exchangeable (tradable) would look at a given lot of hay with a strategic view. The hay would no longer be looked at as a complement to other pre-determined feeds, but as a component of the whole diet. To put it differently, tactical is when you have painted yourself in a corner; strategic is when you look at the floor configuration before you start painting.

The economic values calculated in this paper are (1) exclusively for lactating dairy cows, and (2) entirely strategic.

Of the large set of nutrients required by dairy cows, some have large economic values while others have small economic values. The calcium content of feeds is a good example of a nutrient with a small economic value. Calcium can be supplemented very inexpensively in any dairy diets. This is not to say that calcium is not important to dairy cows or that ration balancing should ignore calcium. It just says that the economics of feeding cows have little to do with calcium.

We have extensively studied the major dairy feed markets in the U.S. over a period of 30 years. Across all 3 major markets (Midwest, Northeast, West), two sets of nutrients explain over 98% of the variation in feed prices. These are:

1. Net energy for lactation (NE_L), rumen degradable protein (RDP), digestible rumen undegradable protein (dRUP), effective neutral detergent fiber (eNDF), and non-effective neutral detergent fiber (neNDF), or
2. NE_L, metabolizable protein (MP), eNDF, and neNDF.

The two sets are entirely interchangeable and give very similar results. The protein requirements of dairy cows, however, are best expressed as metabolizable protein. Therefore, nutrient set #2 will be exclusively used in the balance of this paper.

THE UNIT PRICES OF IMPORTANT NUTRIENTS

Calculating nutrient unit prices. Feed markets do exist; there are people selling and buying feeds in all major dairy regions. But there is no market for nutrients. Or is there? Can we calculate the implicit nutrient prices from the market prices of feedstuffs?

The problem of determining the implicit price of attributes (the nutrients) embedded in various products (feedstuffs) is no at all unique to the feed/nutrient complex. Economists have found an elegant way to solve this problem using a method called hedonic pricing. We will not review the details of how this work in this paper. Interested reader can consult St-Pierre and Cobanov

(2000) for further details. In short, prices and nutritional composition of all ingredients traded in a given market are used to back-calculate using statistical methods what the markets are implicitly pricing the nutrients contained in feeds.

Market prices of nutrients in the Midwest for the 80 months between January 2005 and September 2011 are shown in Figure 1. During this period, the cost per unit of NE_L has more than tripled, the cost per unit of MP has doubled, while the cost per unit of eNDF has seen a drastic surge over the last 12 months. The U.S. has experienced drastic changes in renewable energy policies during the last decade, some of which have had a substantial effect on feed prices. However, large variation in nutrient unit prices are still evident even over a much shorter period of time such as what has occurred since January 2011 (Table 1).

What affects nutrient unit prices? Market prices of all feeds affect nutrient unit prices, not just the prices of corn and soybean meal. Therefore, nutrient unit prices change through time and location. We have already shown how nutrients can quickly change through time in Table 1. Because of regional differences in feed prices and availability, nutrient unit prices also show substantial regional differences (Table 3). In this paper we will be using Midwest nutrient unit prices. When examining the effect of time, we will use January to October 2011 prices.

Where do I find the nutrient unit prices? You can purchase a Windows-based software that we wrote (*Sesame*) for $10 at www.sesamesoft.com. Beware that it is NOT the easiest software to use. Alternatively, we publish a regular column in *Progressive Dairyman* where we publish the nutrient unit prices for the major dairy regions of the U.S.

FORAGE COMPOSITION

Nutrient composition used in this paper. Each lot of forage has a unique nutrient composition that affects its value. The nutrient composition of forages used as examples in this paper are reported in Table 2. We used 3 levels of quality for legume hay and grass hay.

A few things are worth mentioning here. First, notice that the quality of alfalfa (and grass) has a much smaller effect on its metabolizable protein than on its crude protein. Metabolizable protein is the sum of the digestible rumen undegradable protein (dRUP) and the digestible microbial true protein (dMTP). The protein of forages is largely degraded in the rumen (70 to 75%), thus making little contribution to dRUP. Microbial protein synthesis is entirely driven by the digestibility of the nutrients (i.e., the TDN content) in the NRC (2001) model. The level of intake of an animal affects TDN: the TDN of a feed for a cow at maintenance is greater than its TDN for a cow producing milk. For lactating cows, at least for now, TDN and NE_L should be reported at 3 times maintenance (i.e., for milk production of 60 to 70 lbs/day).

Second, observe that in alfalfa the non-fiber carbohydrates (NFC) contribute 2 times more to its energy content (i.e., TDN) than the NDF. In grass, the situation is reversed, with NDF contributing significantly more to the energy content than NFC. Total tract NDF digestibility is greater in grass (~47%) than in alfalfa (~39%) of equivalent quality.

How are NE_L and MP calculated? Equations used in the calculation of NE_L and MP according to NRC (2001) are reported in the appendix. Although these equations may seem intimidating at first, they can easily be programmed in a computer spreadsheet.

While 9 chemical entries are required for the calculation of NE_L only 5 measurements will have much effect on NE_L in practice: DM, CP, NDF, lignin, and ash. Other entries can simply be found in feed composition tables.

The calculation of MP requires a measurement of CP, rumen degradability of protein (RUP_CP), and post-ruminal digestibility of RUP (RUPd). Some feed laboratories provide estimates of RUP_CP, but the variation within a type of hay is relatively small and largely inconsequential to the value of the forage. Likewise, table values for RUPd should be used.

What NDF digestibility should be used? The ratio of lignin to protein-free NDF is used to estimate in vivo total tract NDF digestibility (TT-NDFd) in the equation for TDN_NDF reported in the Appendix. The 2/3 exponent is used to convert mass to surface area, hence representing the decrease in NDF digestibility due to the surface interaction (i.e., coating) of cell walls by lignin. This conceptual interaction is necessarily a simplification of the complex anatomy and chemistry of plant cell walls. Some have advocated the use of in vitro NDF digestibility (NDFd) as a proxy for the calculated TT-NDFd used when calculating TDN_NDF. Although this approach is appealing, much doubt remains regarding the relationship between NDFd and TT-NDFd. For example, we have summarized the relationship between TT-NDFd and NDFd for 23 diets where TT-NDFd was measured using total fecal collection in trials conducted at our experimental research station (Figure 2). In this figure, it is apparent that NDFd overestimates differences between treatments and that the magnitude of the difference in NDFd is not related to the magnitude of the difference in TT-NDFd. The ranking within experiment was often OK with NDFd, raising the possibility of using NDFd for energy calculation. It is clear, however, that NDFd cannot be directly substituted for TT-NDFd when calculating the energy of a feed. Much work is needed in this area. Meanwhile, we still recommend using the equation with the ratio of lignin to protein-free NDF for estimating the energy contribution of NDF.

CALCULATING THE VALUE OF A FORAGE

The value of the nutrients. So far, we have shown that nutrient unit prices can be calculated from market information from all feedstuffs traded in an area. We also explained how the nutrient composition of forages for the economically important nutrients are calculated. Determining the value of the nutrients in a given forage involves a series of simple arithmetical operations. These are illustrated for the reference alfalfa in Table 4 using the average price of nutrients for the Midwest in 2011.

Correcting for milk production response. For most feeds, the sum of the values of the nutrients as calculated in the preceding paragraph is its average economic value; but not for forages. While most feeds are substitutable based on their nutrient content, this is not entirely true for forages. What this means is that two rations balanced for exactly the same nutrient density (NE_L, MP, eNDF, neNDF) but using forages of different quality do not result in exactly the same milk production. Cows fed the ration based on a high quality forage respond to forage quality with additional milk production mainly through greater dry matter intake (DMI). Note that this is not the same as the response to feeding forages of different quality, but without any ration re-balancing. Here the rations are identical in their nutritional content, but cows fed rations based on higher quality forages achieve a greater level of milk production.

We used results from many research trials to calculate the response to forage quality. Although one could think of a better marker of quality than the total NDF content of forage, the data did not allow the calculation of anything more than NDF. The resulting equations are shown in Figures 3 and 4 for alfalfa and grass, respectively. Algebraically, the equations to calculate the value per ton of forage due to milk production responses are:

Alfalfa: Value of Response ($/ton) = [(P-Milk x 0.273 x (44 – NDF)] x DM ÷ 100

Grass: Value of Response ($/ton) = [(P-Milk x 0.3 x (53 – NDF)] x DM ÷ 100

where P-Milk is the price of milk ($/cwt). It is important to understand that this adjustment to the value of forages means that forage values are dependent on milk prices. The difference in the value of a high quality forage compared to that of a low quality forage is much smaller when milk prices are low (such as in 2009) then when milk prices are high (as in 2011).

Effect of forage type and quality on the value of forage in 2011. Table 5 summarizes the values of alfalfa and grass hay for 3 levels of quality for the period of January to October 2011. On an average, the range in values due to quality is greater in grass ($124/ton) compared to alfalfa ($73/ton). This could be due to the arbitrary range of quality selected for the two types of forages. On an average, alfalfa is worth $50/ton more than grass. Compared to alfalfa, grass hay shows a greater range in value through time: $109 and $126/ton for alfalfa and grass, respectively. More importantly, the value of forages changes considerably through time even over a short time span of only 10 months.

Contribution to calculated values. The value of a forage is the sum of the values of its important nutrients plus the milk response associated with the forage quality expressed as NDF content. The contribution of each nutrient to the value of a forage is not the same. Table 6 shows the average contribution of NE_L, MP, eNDF, neNDF, and milk response for the first 10 months of 2011 for the reference alfalfa and grass hays. On an average, energy (NE_L) content accounts for nearly 65% of the value of alfalfa hay and 75% of the value of grass hay. Notice that the protein in alfalfa (20% crude protein) is only worth $7/ton more than the protein in grass (12% crude protein). This is because most of the protein in forage is rumen degradable (RDP), and the unit value of RDP ($/lb) is generally null and often even slightly negative (results not shown). Producing forages of greater protein content is of little value unless the protein increase is associated with an increase in the digestibility (energy) of the resulting feeds.

In long hay, most of the NDF is effective, resulting in very small neNDF content (Table 2). Therefore, the contribution of neNDF to the value of long hays could be entirely ignored without meaningful losses in the accuracy of estimating their economic values.

Marginal changes from compositional values. The 4 nutrients used to calculate the value of a forage are calculated from 11 compositional entries. We can calculate the change in the value of our reference alfalfa and grass hay from a one-unit change in each of the 11 entries (Table 7). One should be extremely careful in the interpretation of these results. First, a one-unit change does not represent the same degree of "difficulty" across all compositional elements. For example, it is considerably easier to raise the NDF of grass by one unit than to raise its ether extracts also by one unit. Second, and even more importantly, it is very difficult in nature to change a compositional element by one unit without affecting any of the other compositional elements. For example, crude protein in alfalfa is negatively associated with NDF content. On average, raising crude protein lowers the NDF content (i.e., the plant is more immature). Likewise, NDF and lignin content are positively associated, meaning that an increase in NDF content is generally associated with an increase in lignin content. Keeping these reservations in mind, compositional elements can be loosely grouped into 3 categories.

1. Those with a small effect on the value of hay: RUP, RUPd and NDFe,
2. Those with a medium effect on the value of hay: DM, CP, NDICP, and
3. Those with a large effect on the value of hay: ADICP, ether extracts, NDF, lignin and ash.

Ether extracts and ADICP are relatively constant within hay type compared to NDF, lignin and ash. NRC (2001) reports standard deviations of 0.4 (ADICP), 0.5 (ether extracts), 0.9 (lignin), 1.0 (ash), and 6.3 (NDF) percent. Thus, NDF, lignin, and ash are arguably the most influential compositional entries to hay values. Note that the net effect of NDF on hay values incorporates its positive effect on forage value from its positive contribution to eNDF, and its negative effects on forage value from its negative contribution to NE_L and MP.

CONCLUDING REMARKS

The values calculated in this paper are on a farm-gate basis (i.e., delivered) and not FOB. Therefore, forage growers would have to account for delivery costs when estimating the value of a given hay. In addition, the values calculated in this paper are averages and represent what coherent buyers should be willing to pay. Coherent behavior is often an elusive attribute in feed markets. Some buyers consistently shop for “supreme” quality alfalfa hay because that’s what they have been using for years without ever considering whether other quality levels or even other types of feeds make more economic sense. A very thirsty man is much more willing to pay an exorbitant price for a cold beer, especially if he fails to consider the free water available from a fountain nearby.

REFERENCES

St-Pierre, N. R., and D. Glamocic. 2000. Estimating unit costs of nutrients from market prices of feedstuffs. J. Dairy Sci. 83:1402-1411.

APPENDIX

Equations used to calculate NE_L (NE_3X, Mcal/lb) of forages:

TDN_NFC = 0.98 x (100 – NDF + NDICP – CP – EE – ASH)

TDN_NDF = 0.75 x (NDF – NDICP – LIG) x $(1-(LIG/(NDF-NDICP))^{0.667})$

TDN_CP = CP x exp(-1.2 x ADICP/CP)

TDN_EE = (EE – 1) x 2.25

TDN_1X = TDN_NFC + TDN_NDF + TDN_CP + TDN_EE - 7

DE_1X = (TDN_NFC x 0.042) + (TDN_NDF x 0.042) + (TDN_CP x 0.056) + ((EE-1) x 0.094) - 0.3

TDN_3X = TDN_1X x 0.92

NE_3X = (0.6532 x DE_1X) - 0.5064

Equations used to calculate the metabolizable protein (MP, % of DM) of forages:

dRUP = CP x RUP_CP x RUPd ÷ 10000

dMTP = TDN_3X x 1.3 x 0.64 ÷ 10

MP = dRUP + dMTP

Equations used to calculate effective and non-effective NDF of forages:

eNDF = NDF x NDFe

neNDF = NDF - eNDF

where:

ADICP	=	ADF insoluble crude protein (% of DM)
ASH	=	Ash (% of DM)
CP	=	Crude protein (% of DM)
dRUP	=	Digestible RUP (% of DM)
dMTP	=	Digestible microbial true protein (% of DM)
EE	=	Ether extracts (% of DM)
eNDF	=	Effective NDF (% of DM)
exp	=	The exponential function (i.e., *e* exponent the value in parentheses)
LIG	=	Lignin (% of DM)
NDF	=	Neutral detergent fiber (% of DM)
NDFe	=	NDF effectiveness (% of NDF)
NDICP	=	NDF insoluble crude protein (% of DM)
NE_3X	=	Net energy for lactation measured a 3 times maintenance (Mcal/lb)

neNDF	=	Non-effective NDF (% of DM)
RUP_CP	=	Rumen undegradable protein (% of CP)
RUPd	=	Digestibility of RUP (% of RUP)
TDN_1X	=	Total digestible nutrients at 1 time maintenance (% of DM)
TDN_3X	=	Total digestible nutrients at 3 times maintenance (% of DM)
TDN_CP	=	TDN from the crude protein fraction (% of DM)
TDN_EE	=	TDN from the ether extracts fraction (% of DM)
TDN_NDF	=	TDN from the NDF fraction (% of DM)
TDN_NFC	=	TDN from the NFC fraction (% of DM).

Table 1. Nutrient unit prices in the Midwest between January and October 2011.

Nutrients	Average	S.D.	Min	Max
NE_L (¢/Mcal)	15.2	2.1	11.1	17.4
MP (¢/lb)	31.1	4.8	26.8	40.6
eNDF (¢/lb)	4.7	4.0	0.0	11.9
neNDF (¢/lb)	-8.5	2.8	-12.4	-5.1

Table 2. Nutrient composition of the reference alfalfa hay, reference grass hay, and low and high quality hays used as examples.

		Alfalfa			Grass		
Nutrients[1]	**Units**	**Reference**	**Low**	**High**	**Reference**	**Low**	**High**
Dry matter	%	88	88	88	88	88	88
Crude protein	%	20	16	24	12	8	16
NDICP	%	2.5	2.5	2.5	4.0	4.0	4.0
ADICP	%	1.5	1.5	1.5	1.0	1.0	1.0
Ether extracts	%	2.0	2.0	2.0	2.5	2.5	2.5
NDF	%	40	44	36	60	68	52
ADF	%	30	34	26	40	48	32
Lignin	%	7.0	8.8	5.4	6.5	8.5	4.5
Ash	%	10	10	10	7	7	7
RUP	%CP	25	25	25	30	30	30
RUPd	% RUP	70	70	70	65	65	65
Effective NDF	% NDF	92	92	92	98	98	98
TDN from NFC	%	29.9	29.9	29.9	22.1	18.1	26.0
TDN from NDF	%	15.4	15.8	14.8	28.3	30.8	25.9
TDN from CP	%	18.3	14.3	22.3	10.9	6.9	14.8
TDN from EE	%	2.3	2.3	2.3	3.4	3.4	3.4
TDN at 3X	%	54.0	50.7	57.1	52.9	47.9	57.9
NE_L at 3X	Mcal/cwt	57.6	51.5	63.5	53.0	44.6	61.5
MP at 3X	%	7.99	7.02	8.95	6.73	5.55	7.94
		------------------------------ Units per Ton ------------------------------					
NE_L	Mcal	1014.2	906.7	1118.1	932.6	785.5	1082.3
MP	lbs	140.7	123.5	157.6	118.6	97.6	139.7
eNDF	lbs	647.7	712.4	582.9	1034.9	1172.9	896.9
neNDF	lbs	56.3	62.0	50.7	21.1	23.9	18.3

[1] NDICP = NDF insoluble crude protein; ADICP = ADF insoluble crude protein; NDF = neutral detergent fiber; ADF = acid detergent fiber; RUP = rumen undegradable protein; RUPd = RUP digestibility; TDN = total digestible nutrients; NE_L at 3X = net energy for lactation calculated at an intake of 3 times maintenance; MP at 3X = metabolizable protein calculated at 3 times maintenance.

Table 3. Nutrient unit prices across 3 regions[1], November 2011.

Nutrients	Northeast	Midwest	West
NE_L (¢/Mcal)	12.7	8.6	10.0
MP (¢/lb)	32.2	34.4	42.6
eNDF (¢/lb)	6.2	11.3	15.4
neNDF (¢/lb)	-3.8	5.5	1.4

[1] Northeast prices are for NY and northern PA; Midwest prices are for WI and eastern MN; West prices are for the San Joaquin Valley of CA.

Table 4. Calculation of the value of the nutrients in one ton of the reference alfalfa hay.

	Composition	DM %	Mcal or Pounds per Ton	Unit Prices ¢	Value $/ton
NE_L (Mcal/cwt)	57.6	88	1014.2	15.2	154.15
MP (% DM)	7.99	88	140.7	31.1	43.76
eNDF (% DM)	36.8	88	647.7	4.7	30.44
neNDF (% DM)	3.2	88	56.3	-8.5	-4.79
Total					**223.56**

Table 5. Value ($/ton) of alfalfa and grass hay of 3 quality levels, Midwest, January to October 2011.

Feeds	Average	SD[1]	Min	Max
Alfalfa - Reference	241	37	193	302
- Low	204	36	162	265
- High	277	38	223	338
Grass - Reference	191	46	145	271
- Low	129	47	77	210
- High	253	47	197	332

[1] SD = standard deviation.

Table 6. Average contribution of NE_L, MP, eNDF, neNDF, and milk response to the value of our reference alfalfa and grass hays.

	Alfalfa		Grass	
Component	**$/ton**	**% of Total**	**$/ton**	**% of Total**
NE_L	154.55	64.0	141.75	73.7
MP	43.75	18.2	36.88	19.2
eNDF	30.44	12.6	48.64	25.3
neNDF	-4.78	-2.0	-1.79	-0.9
Milk	17.29	7.2	-33.26	-17.3
Total	240.86	100.0	192.21	100.0

Table 7. Marginal change in value of forage hay ($/ton) from a one-unit increase in each of the compositional entries.

	Change in forage value ($/ton)	
Composition entries	Alfalfa - Reference	Grass - Reference
Dry matter (%)	2.73	2.19
Crude protein (% DM)	2.12	2.23
NDICP (% DM)	1.28	1.14
ADICP (% DM)	-5.17	-5.01
Ether Extracts (% DM)	4.72	4.72
NDF (% DM)	-4.96	-5.10
Lignin (% DM)	-4.42	-5.38
Ash (% DM)	-3.68	-3.67
RUP (% CP)	0.76	0.43
RUPd (% RUP)	0.27	0.20
NDF Effectiveness (% NDF)	0.93	1.40

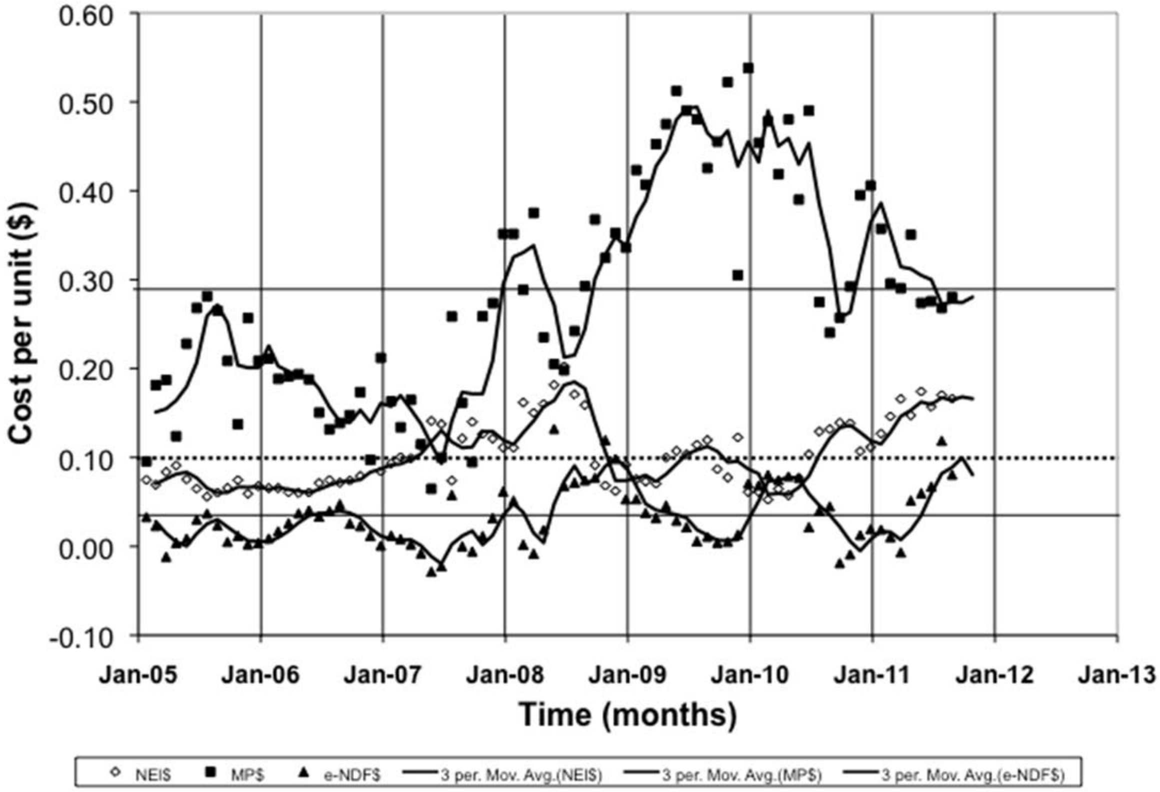

Figure 1. Price of nutrients in the Midwest from January 2005 through September 2011. NEl$ = Net energy for lactation ($/Mcal), MP$ = metabolizable protein ($/lb), and e-NDF$ = effective NDF ($/lb).

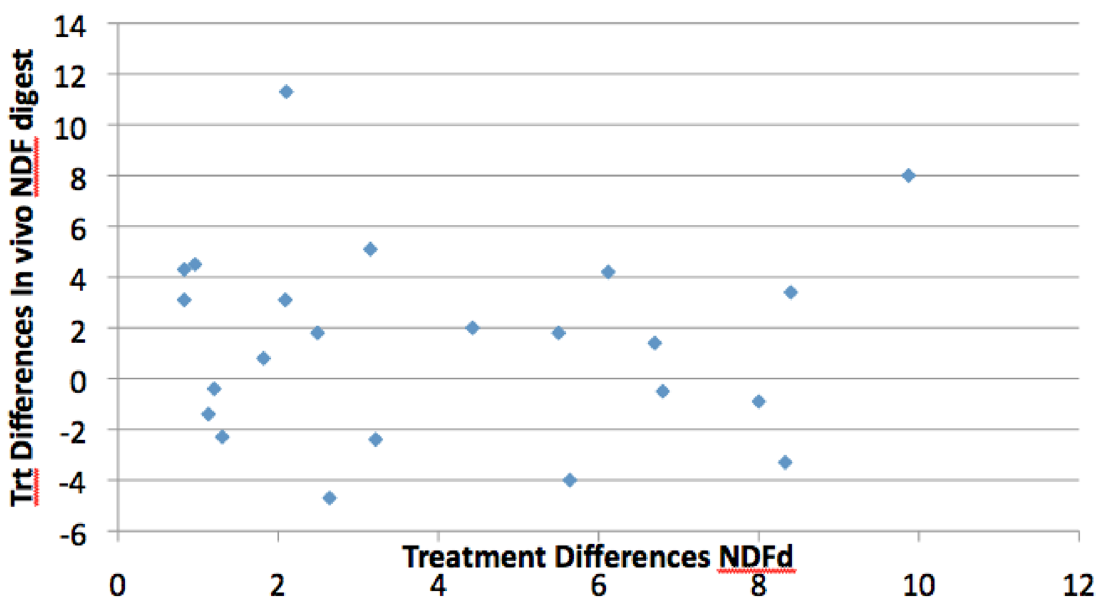

Figure 2. Relationship between whole diet total tract in vivo NDF digestibility (TT-NDFd) expressed as deviation from a control diet and in vitro NDF digestibility (NDFd).

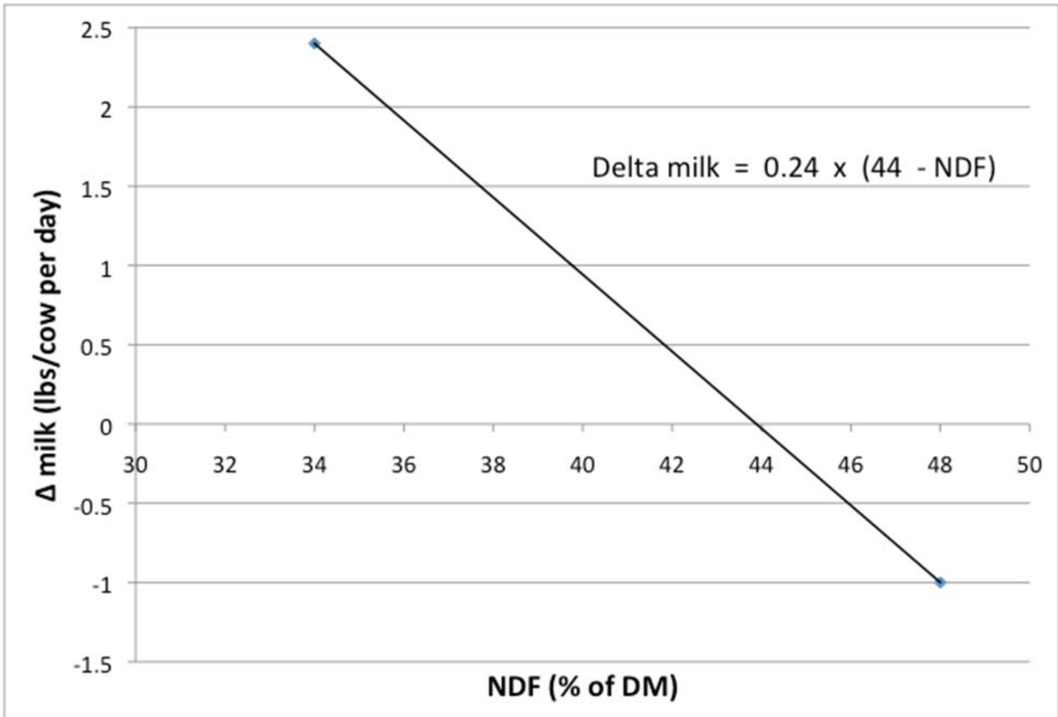

Figure 3. Response in milk production to change in NDF content of alfalfa forage.

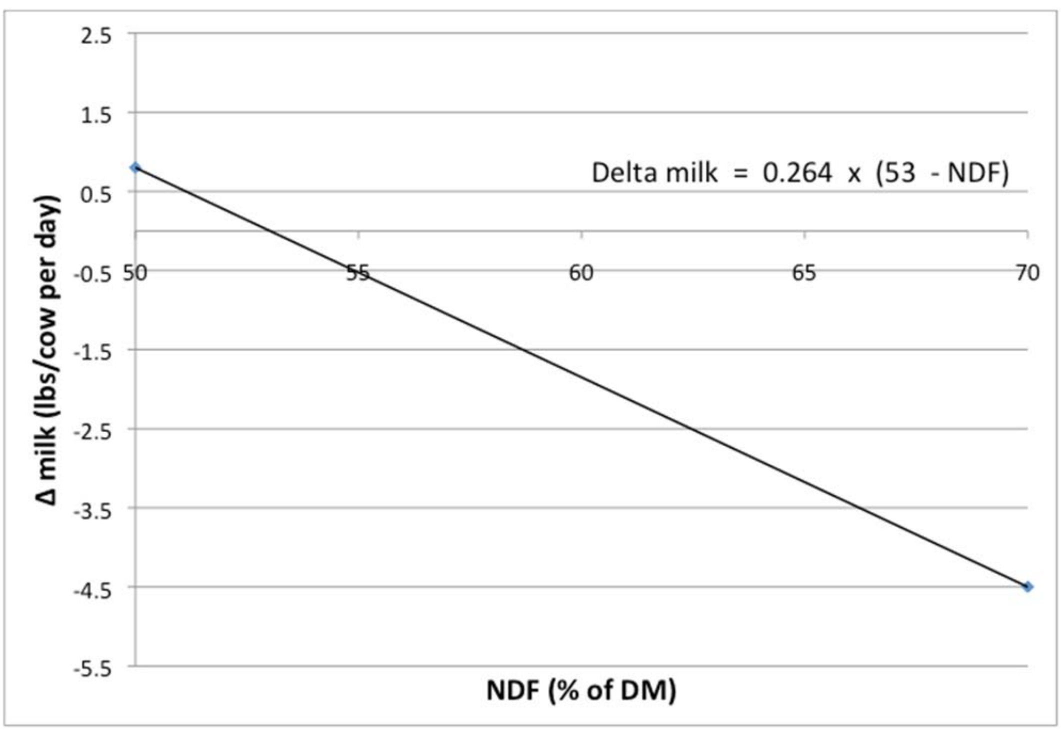

Figure 4. Response in milk production to change in NDF content of grass forage.