Impact of NDF Digestibility on Energy Content of Forages and Dairy Rations

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Introduction

There are numerous advancements in the analytical evaluation of forages and total mixed rations (**TMRs**). This paper will attempt to address new advancements, in particular measurement of NDF digestibility **(NDFD**) in forages and TMRs. The utility of NDFD in dairy cattle nutrition programs will also be discussed.

Forage Energy Prediction

The amount of energy forage contributes to a ruminant diet is arguably the single most important factor in predicting animal performance. Nutrition consultants and dairy producers however infrequently rely on energy content of forage as a primary indicator of forage quality. This perspective is somewhat valid. Empirical equations (Rohweder et al., 1978) were used for many years to predict forage energy content from a single analyte such as acid detergent fiber (**ADF**). Empirical equations to predict forage energy content by and large were accurate but imprecise. The aforementioned statement simply means that when examining a large database of forage energy contents predicted by an empirical equation, the empirical equation accurately predicts the average of the database but cannot precisely predict the energy content of any single forage in the data base. To be of real value, forage evaluation systems must be able to precisely predict the energy content of any single forage.

Weiss, 1996 proposed using a summative approach to predict energy content of forages and other feeds. The concept of a summative approach is simple: measure the principal components in the forage that contribute energy, give each component a digestion coefficient, multiply each component by its respective digestion coefficient, and add the products together. The beauty of a summative approach is that it can be used on any forage, grain, commodity, or even total mixed rations. The major drawback of the summative approach is extensive laboratory measurements are needed. Four principal components need to be accurately and precisely measured in the laboratory: crude protein (CP), neutral detergent fiber (NDF), fat, and non-fiber carbohydrate (NFC), which additionally require the measurement of ash and neutral detergent fiber crude protein to facilitate the final determination of NFC. The digestion coefficients assigned to CP, fat, and NFC are well defined by research (Weiss, 1993); however, the digestion coefficient for NDF (NDFD, % of NDF) is not well defined by research and thus requires, if possible, measurement in the laboratory.

An example of a summative energy equation adopted by the NRC, 2001 to predict the energy content of legume grass silage is presented in Table 1. The reader should be aware the summative equation concept presented in Table 1 has been modified for corn silage (Schwab and Shaver, 2001). Recently we evaluated (Lundberg et al. 2004) the utility of summative energy equations using 48 h in vitro NDFD as the digestion coefficient for NDF by comparing predicted TDN to in vitro digestible organic matter (IV d OM) which is a reasonable assessment of in vivo digestibility. Results from our evaluation are presented in Table 2. Using ADF as a predictor of IV d OM accounted for .61 of the variance of IV d OM in corn silage as compared to a .98 coefficient of determination between summative predicted TDN and IV d OM when NDFD was used as the digestion coefficient for NDF. These data clearly demonstrate the improved capability of summative equations using NDFD as an energy predictor.

Measuring NDF Digestibility

Accurately and precisely predicting the NDFD content of the forage NDF is extremely important in generating a quantitative summative forage energy prediction. Unfortunately NDFD is one of the more difficult assays to conduct in the laboratory. Most laboratories cannot conduct the assay because an in vitro NDFD laboratory procedure requires rumen fluid from a live cannulated cow.

Forage NDFD can be measured in one of two ways. First, forages can be placed in small dacron bags and inserted into the rumen of a cow via a ruminal cannula. The amount of NDF prior to ruminal incubation is compared to the amount of NDF remaining after ruminal incubation and NDFD is calculated. This is called an in situ method. The in situ method is a very viable method to estimate NDFD of forage NDF and is often used in research and other forage evaluation programs. Because of the lack of a large uniform database, the 2001 NRC, however, does not recommend the in situ method as its basis for NDF of forages.

The 2001 NRC uses lignin based calculation to predict potential NDF digestibility because lignification within a plant species can be negatively associated with NDF digestibility. While using lignin is a logical marker to predict NDFD it should be noted that acid detergent lignin is a arduous laboratory assay and is not well predicted by NIRS. The NRC, 2001 also advises the use of an in vitro system as the basis for direct determination of forage NDFD. Recently Robinson et al, 2004 evaluated using the NRC, 2001 lignin model to estimate NDFD and found little relationship between NDFD as estimated by lignin and in vitro NDFD content of feeds (Figure 1). In addition Robinson et al, 2004 found a superior relationship using in vitro NDFD measurements as compared to using lignin to estimate NDFD in prediction systems to estimate in vivo digestibility in sheep. Similarly, Jung et al 1997 found relatively weak relationships between acid detergent lignin and in vivo NDFD in sheep for C4 grasses such as corn silage. The recommendation of NRC, 2001 to use lignin to estimate NDFD was not made based on analytical superiority over the in vitro systems, rather the lignin data base was more defined, making interpretation easier at the time. At present in vitro NDF digestibility determination is playing a larger role in estimating NDF digestion coefficients for forages and diet energy predictions as compared to using lignin. .

Few changes have been made to the in vitro NDFD assay (Goering and Van Soest, 1970) over the years, but some researchers and laboratories have reduced the incubation times from 48 hr to 30 or 24 hr, citing that shorter incubation times better describe the digestion potential of NDF in high producing lactating dairy cows. Reducing the incubation time of the in vitro NDFD assay to 30 or 24 hr is logical because feed is not retained in the rumen of a high producing dairy cow for 48 hr. In the larger sense, however, this issue is somewhat irrelevant because changing the incubation time of the assay reduces the amount of NDF digested; therefore, NDF digestibility values obtained from 30 or 24 hr digestions cannot easily be compared leaving the industry with multiple NDFD universes. The recommendation of a 48 hr NDFD value by the NRC, 2001, is to facilitate calculating TDN content of forages at maintenance intakes (which is TDN). While it can be argued that 30 h in vitro NDFD values may better represent in vivo

NDFD at maintenance the pragmatic issue with NDFD at this time is for laboratories to report forage NDF digestibility's that have a common scale and reference so the dairy industry can comprehend their meaning. Because the NRC, 2001 advises the use of a 48 hr in vitro NDF digestibility procedure to calculate TDN contents of forages at maintenance intakes, it is logical to identify with a 48 h NDFD reference but 30 h in vitro NDFD values can be used as long as the user is well verse in the system and the energy predictions it produces.

Listed in Table 3 are common 30 and 48 h in vitro NDFD (% of NDF) values for forages, byproducts and total mixed rations. These values can be used as reference values to aid interpretation of NDFD values received on individual forage, byproducts or total mixed rations from the laboratory.

The NDFD content of forage can be predicted using NIRS, but generally there is some loss of precision. Combs, 1998 used NIRS to predict in vitro 48 h NDFD contents of legume grass forages with success. The NIRS NDFD equations developed by Combs (1998) have been enhanced and are commercially available and are currently being used in commercial forage testing laboratories. Development of accurate and precise NIRS equations for the NDFD content of corn silage are also available but are less precise because of the narrow range of NDFD in corn silage and the heterogeneous nature of corn silage (Lisa Baumann, 2000-2002, personal communication).

Ultimately, prediction of NDFD in forages by NIRS would be preferred because laboratories using NIRS prediction systems can be easily standardized. It is likely that large databases of forage NDFD contents currently being developed will facilitate accurate and precise measures of forage NDFD by NIRS. Such projects are in progress and therefore it is likely that prediction of NFDF in forages using NIRS will improve in the future. It should also be noted that in vitro 30 or 48 h NDFD assays can be difficult to conduct. Variability in cannulated cows, diet rumen fluid interactions and procedural differences can result in NDFD determination variation.

Utility of NDF Digestibility

There are two primary reasons why forages and total mixed rations are evaluated for NDF digestibility. First, as described above NDFD is used in summative equations to estimate energy content of forages and total mixed rations. The NDFD content of a forage or total mixed ration can have a dramatic impact on the energy value of the diet. As the NDF content of alfalfa and corn silage rise {other nutrients (e.g. CP, NDF, ash, fat etc) are constant} the TDN content of the forage rises, Figure 2. A rise in forage TDN content obviously results in the in a rise in dietary energy content and potential milk yield. Second, in a review of recent research Oba and Allen, 1997 defined that a 1 unit rise in NDFD content in the diet results in a .37 lbs/day rise in dry matter intake (Figure 3). Thus changing NDFD in the forage base of diets results in a dual mechanism whereby caloric intake is increased. Simply lactating dairy cows will consume more forage which is of a higher energy content when forages are high in NDFD.

Recently we (Hoffman and Bauman, 2003) evaluated these concepts in trial with lactating dairy cows (Table 4). Early-mid lactating dairy cows were fed diets containing red clover augmented with normal corn silage or brown mid-rib corn silage. The forage feeding strategies resulted in diets that differed in NDFD content (approximately 45.0, 50.0 and 55.0 % of NDF). As described by Oba and Allen, 1997, we observed that cows at more dry matter (DM) and produced more milk when fed forages that had a higher NDF digestibility. Of particular interest is cows exhibited a marked increase in NDF intake (Table 4) which is logical because as NDFD is improved NDF passage rate from the rumen is increased allowing cows to consume more dry matter (or NDF).

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Table 1. Example of summative calculations made to estimate the energy content of legume grass silage.

Item	*Abreviation*	*Unit*	*Value*	Formula	*TDN Units*	
Protein Fractions						
Crude Protein	*CP*	*% of DM*	21.9	CP * .93	Ecp=	20.37
Neutral Detergent Fiber Crude Protein	*NDFCP*	*% of DM*	4.2			
Fiber Fractions						
Neutral Detergent Fiber	*aNDF*	*% of DM*	40.0	((NDF)*(NDFD/100))*.75	Endf=	14.40
Neutral Detergent Fiber Digestibility, 48 h	*NDFD*	*% of NDF*	48.0			
Carbohydrates and Fats						
Non Fiber Carbohydrate [⊥]	*NFC*	*% of DM*	29.1	(NFC*.98)	Enfc=	28.50
Fat		*% of DM*	3.2	((.97*(Fat-1))*2.25	Efat=	4.80
Macro Minerals						
Ash		%of DM	10.0			
Energy Calculations:2001 NRC						
Total Digestible Nutrients,1X	*TDN*	*% of DM*		Ecp+Endf+Enfc+Efat-7		61.06
Net Energy , Lactation, 3X	*Nel*	*Mcals/lb*		((.0245*TDN)-.012)/2.2046))		0.62

[⊥] NFC = 100-(CP+NDF+Ash +Fat-NDFCP)

**** Note. Not for use with corn silage.

TABLE 2. Effect of TDN models on relationships between corn silage TDN and in vitro digestible organic matter (Lundberg et al 2004).

	TDN Model	Dependant variables	r^2	Intercept	Slope	SE
1	Adams, 1980	ADF	0.61	47.9	0.43	2.5
2	Rohweder et al., 1978	ADF	0.61	32.3	0.65	2.5
3	Adams, 1980	ADF	0.57	48.4	0.42	2.6
4	Rohweder et al., 1978	ADF	0.57	33.0	0.64	2.6
5	NRC, 2001	CP, ADF CP, NDF, IV d NDF, ash, fat, NDF CP	0.98	10.8	0.96	0.6

Table 3. Typical NDF digestibility values for forages, total mixed rations and byproduct feeds.

Feed	In Vitro NDF Digestibility, % of NDF [1,2]					
	High	Medium	Low	High	Medium	Low
	48 h NDF Digestibility			30 h NDF Digestibility		
Alfalfa Hay	55.4	49.8	44.2	53.5	46.2	38.9
Alfalfa Silage	58.2	53.1	48.0	55.9	51.3	46.7
Grass Hay	64.8	54.2	43.6	na	na	na
Grass Silage	62.9	53.7	44.5	na	na	na
Legume/Grass Hay	59.4	48.0	36.6	na	na	na
Legume/Grass Silage	59.5	54.3	49.1	na	na	na
Ryegrass Silage	na	63.1	na	na	55.6	na
Red Clover Silage	50.3	47.1	43.9	na	na	na
Sorghum/Sudan Silage	na	57.2	na	na	49.2	na
Straw	na	32.5	na	30.5	26.6	22.7
Corn Silage	63.8	58.9	54.0	52.3	48.0	43.7
Brown Mid-Rib Corn Silage	72.8	68.6	64.4	na	na	na
Small Grain Silage	66.8	56.4	46.0	na	47.9	na
Total Mixed Rations, High Group	63.0	57.1	51.2	na	na	na
Total Mixed Rations, Prefresh	63.5	54.6	45.7	na	na	na
Total Mixed Rations, Postfresh	61.4	55.9	50.4	na	na	na
Total Mixed Rations, Dry Cows	64.9	59.4	53.9	na	na	na
Total Mixed Rations, Heifer Diets	61.5	54.4	47.3	na	na	na
Corn Gluten Feed	na	na	na	na	79.8	na
Distillers Dried Grains	na	na	na	81.2	76.2	71.2
Brewers Grains	na	na	na	na	49.9	na
Wheat Midds	na	na	na	53.0	51.2	49.4
Beet Pulp	na	na	na	89.6	83.6	77.6
Citrus Pulp	na	na	na	na	85.0	na
Soy Hulls	na	92.1	na	na	91.6	na
Whole Cottonseed	na	na	na	61.9	53.3	44.7
Soybean Meal	na	na	na	90.8	87.3	83.8
Barley	na	na	na	na	52.0	na
Corn	na	85.0	na	na	na	na
Steam Flaked Corn	na	na	na	81.5	73.6	65.7

[1] Adapted from data bases of the Marshfield Soil and Forage Analysis Laboratory and Peter Robinson, University of California-Davis.

[2] High NDFD values represent the average plus 1 standard deviation. Low NDFD values represent the average minus one standard deviation. Feeds without high and low values do not contain enough samples to calculate a reliable standard deviation.

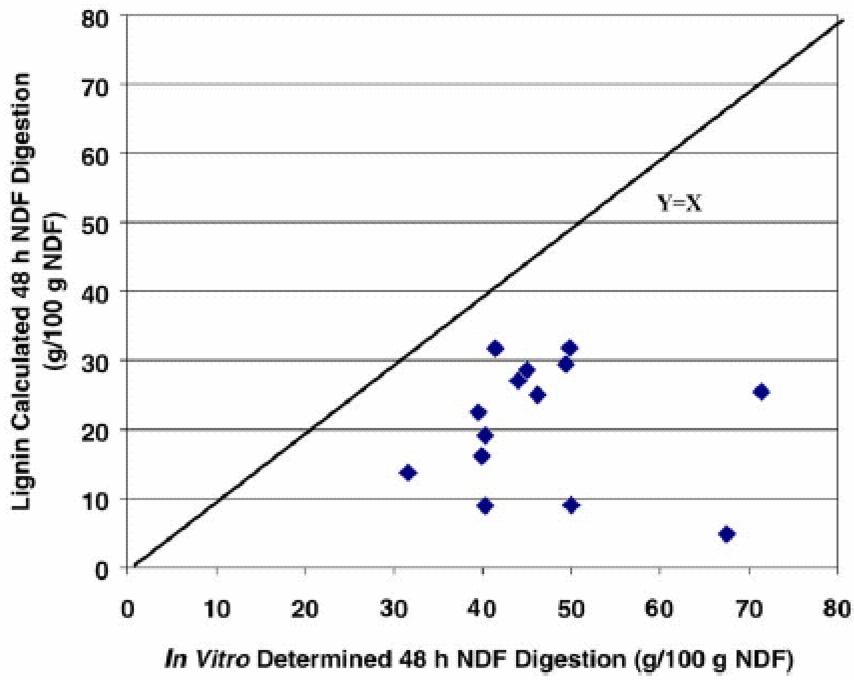

Fig. 1. Relationship between in vitro and lignin calculated estimates of in vivo digestibility of NDF according to NRC (2001) recommendations.

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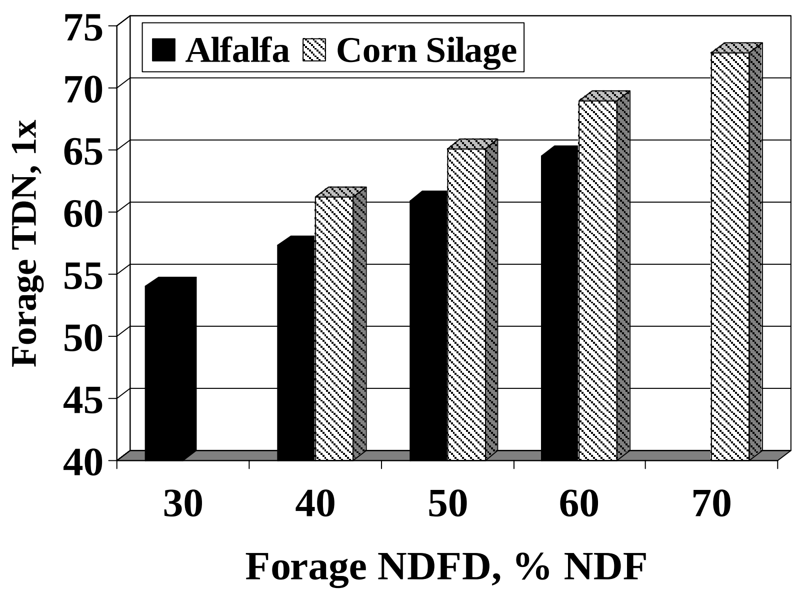

Figure 2. The relationship between NDFD and TDN content in alfalfa and corn silage.

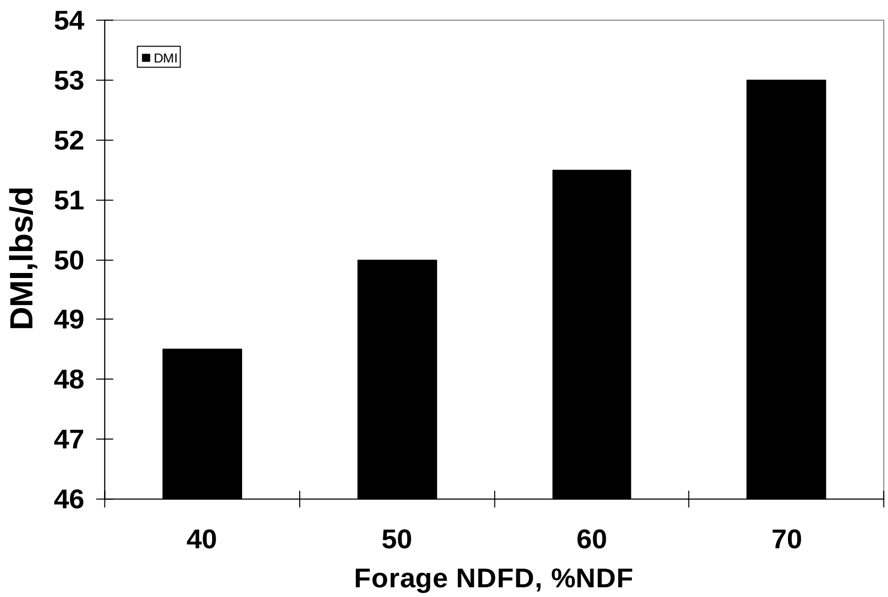

Figure 3. The relationship between forage NDFD content and dry matter intake in lactating dairy cows. Oba and Allen, 1997.

Table 4. Dry matter intake, NDF intake and milk yield of early-mid lactating dairy cows fed diets containing different levels of NDFD. (Hoffman and Bauman, 2003).

	Dietary NDFD, % of NDF		
Item	45 %	50 %	55 %
Dry Matter Intake, lbs/day	45.1	48.6	51.3
NDF Intake, lbs/day	18.7	19.0	21.6
Milk Yield, lbs/day	73.7	76.4	77.2