USING NDF DIGESTIBILITY INFORMATION IN DAIRY CATTLE FEEDING PROGRAMS

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Corn Silage Evaluation

Dry matter intake (DMI) is related to dietary NDF content (Mertens, 1987) and in vitro NDF digestibility (NDFD, % of NDF; Oba and Allen, 1999). The NRC (2001) summative energy equation is based on fiber digestibility calculated using lignin. Whole-plant lignin content was found to have a strong negative relationship with in-vitro NDFD within comparisons of brown midrib (bm3) hybrids to isogenic counterparts (Oba and Allen, 1999b). However, stover NDF and lignin contents increase while NDFD decreases with progressive maturity, while whole-plant NDF and lignin contents are constant or decline as the grain proportion increases (Russell et al., 1992; Hunt et al., 1989). This my partially explain why for 534 corn silage samples, NDFD calculated using lignin according to NRC (2001) accounted for only 14% of in vitro NDFD variation (Schwab and Shaver, unpublished). Michigan State workers (Oba and Allen, 2005; Allen and Oba, 1996; M. S. Allen, personal communication, 2003 Tri-State Nutr. Conf. Pre-Symp.) reported that lignin (% of NDF) explained only half or less of the variation for corn silage in vitro NDFD. These observations coupled with the NRC (2001) suggestion that in vitro NDFD measurements could be used directly in the NRC model led us to implement in vitro NDFD rather than lignin-calculated NDF digestibility in our milk per ton model for corn silage evaluation (MILK2000; Schwab et al., 2003).

An index of forage quality, milk per ton of forage DM (MILK1991; Undersander et al., 1993), was developed using an energy value of forage predicted from ADF content and DMI potential of forage predicted from NDF content as its basis. The milk per ton quality index was later modified for corn silage (Schwab et al., 2003) using an energy value derived from summative equations using in vitro NDFD (Schwab et al., 2003; NRC, 2001) and DMI predicted from both NDF content (Mertens, 1987) and in vitro NDFD (Oba and Allen, 1999b) as its basis. This milk per ton quality index (MILK2000; Schwab et al., 2003) has become a focal point for corn silage hybrid-performance trials and hybrid-breeding programs in academia and the seed-corn industry (Lauer et al., 2005).

An update (MILK2006) is in progress. The MILK2000 model $NE_{L\text{-}3x}$ energy value was derived from the summative $TDN_{maintenance}$ using the NRC (1989) empirical equation (Schwab et al., 2003). In MILK2006, the $NE_{L\text{-}3x}$ energy value will be derived using an adaptation of the TDN-DE-ME-NE conversion equations provided in NRC (2001). Neutral detergent fiber content and NDFD are used to predict DMI (Schwab et al., 2003) in both MILK2000 and MILK2006. However, a one %-unit change in NDFD (% of NDF) from lab-average NDFD will change DMI 0.26 lb. per day (Oba and Allen, 2005; Jung et al., 2004) in MILK2006 versus the 0.37 lb. per day value (Oba and Allen, 1999b) that was used in MILK2000. In MILK2000, variation in NDFD impacts NE_L intake through effects on both $NE_{L\text{-}3x}$ content and DMI (Schwab et al., 2003). However, Tine et al. (2001) and Oba and Allen (1999a) reported that at production levels of intake, NDFD has minimal impact on $NE_{L\text{-}3x}$ content but impacts NE_L intake primarily through effects on DMI. In MILK2006, the NDFD value used for calculating $NE_{L\text{-}3x}$ will be adjusted for differences in DMI predicted from NDFD using an equation adapted from Oba and Allen (1999a). Thus, NDFD will impact NE_L intake and hence the milk per ton quality index mainly through its impact on predicted DMI in MILK2006.

Values for $TDN_{maintenance}$, $NE_{L\text{-}3x}$, and milk per ton calculated using MILK2006 and MILK2000 across a wide range of whole-plant corn NDFD values and extreme quality differences are presented in Tables 1 and 2, respectively. The $TDN_{maintenance}$ differences between MILK2006 and MILK2000 are minimal. The $NE_{L\text{-}3x}$ and milk per ton values are lower and the range in these values is compressed for MILK2006 relative to MILK2000 according to the equation differences between the two models that were described above.

A preliminary analysis of correlations between corn silage NDF, NDFD, starch, and starch digestibility and milk per ton estimates from MILK2006, 2000, 1995, and 1991 models (n = 3727 treatment means) is presented in Table 3. Results show that the MILK2000 model was revolutionary relative to the earlier models, because of its recognition of NDFD as an important quality parameter while the earlier models were influenced mostly by whole-plant starch and grain contents. The MILK2006 model relative to MILK2000 appears to be more evolutionary reflecting the relatively minor fine-tuning of equations, but the spreadsheet will allow for more user-defined flexibility. Model comparisons using other datasets and evaluation of models for potential effects on hybrid rankings are in progress. Future developments in laboratory methods for determining starch digestibility may influence its relationship to milk per ton estimates relative to the other quality measures.

Ivan et al. (2005) evaluated “low-fiber” (26% starch, 49% NDF, 58% NDFD) versus “high-fiber” (22% starch, 53% NDF, 67% NDFD) corn silages in 30% NDF diets fed to lactating dairy cows. Reported per cow per day milk yields were converted to milk per ton of corn silage DM basis using their corn silage DMI data. Actual milk per ton was 168 lb. higher for high-fiber than low fiber corn silage. Model-predicted milk per ton estimates were 132 lb. and 297 lb. higher for high-fiber than low-fiber corn silage from MILK2006 and MILK2000 models, respectively. This suggests reasonable agreement with in vivo data for MILK2006 and better agreement with in vivo data for MILK2006 than MILK2000, but more comparisons are needed.

In Vitro NDFD Analysis

Several commercial testing laboratories offer wet chemistry in vitro NDFD measurements. Ranges for NDFD of forages are presented in Table 4. The NDFD values are highly variable among and within forage types. Introduction of low-lignin, brown midrib hybrids for production of corn and sorghum silages has widened the variation in NDFD for these forage types (Oba and Allen, 1999b). NIRS calibrations for predicting in vitro NDFD on hay-crop forage and corn silage samples are available at some commercial forage testing laboratories. However, Lundberg et al. (2004) found poor prediction by NIRS of legume-grass silage and corn silage in vitro NDFD. It is hoped that NIRS calibration equations can be improved upon in the future.

The NRC (2001) recommended a 48-h in vitro NDFD for use in the NRC (2001) model, and for that reason we used 48-h in vitro NDFD measurements in MILK2000 (Schwab et al., 2003). However, debate continues within the industry about the appropriateness of 48-h vs. 30-h in vitro NDFD measurements. Some argue that the 30-h incubation better reflects ruminal retention time in dairy cows (Oba and Allen, 1999a) and that most of the in vivo trials that have evaluated effects of varying NDFD on animal performance also performed 30-h in vitro NDFD measurements (Oba and Allen, 2005). Labs and their customers also like the faster sample turn around that is afforded by the 30-h incubation time point. For that reason, and also for improved lab operation efficiency, a 24-h incubation time point is being employed by some labs. However, some argue that the 48-h incubation time-point is less influenced by lag time and rate of digestion, and thus is more repeatable in the laboratory (Hoffman et al., 2003). Hoffman et al. (2003) provided data on the relationship between 30- and 48-h in vitro NDFD measurements that showed a strong positive relationship (r-square = 0.84). But, the lab average at a specific incubation time point and the relationship between incubation time points within a lab can be highly variable among labs making the development of a universal incubation time point adjustment equation difficult. The average lignin-calculated corn silage NDF digestibility in the NRC (2001) is 59%. This reference point is important for adjustment of in vitro NDFD values from different labs and varying incubation time points so that the resultant TDN and NE_L values are comparable to NRC (2001) values.

User-defined flexibility will be available within the MILK2006 spreadsheet for entry of 48-, 30-, or 24-h in vitro NDFD incubation time point measurements. But, the labs incubation time point and average results for corn silage at that time point must also be entered into the spreadsheet along with the sample data. The 48-h in vitro NDFD incubation time point will continue to serve as the default in the milk per ton spreadsheets. The Wisconsin Corn Silage Hybrid Performance Trials (Lauer et al., 2005) will likely continue to use the 48-h in vitro NDFD incubation time point because NIRS calibrations for this time point have been developed from corn silage samples obtained in this evaluation program over several years by locations and Justen (2004) did not find the earlier incubation time points to provide any benefit over the 48-h time point for hybrid selection.

Average in vitro NDFD values for selected high-fiber by-product feeds (Peter Robinson, CA-Davis, personal communication) are presented in Table 5. The NDFD values are highly variable among these high-fiber by-product feeds. In vitro NDFD values for these high-fiber by-product feeds were poorly related to lignin-calculated (NRC, 2001) NDF digestibility. High digestible NDF (dNDF; % of DM) for soy hulls and beet pulp relative to other high-fiber by-products suggest a high potential for using these ingredients at reasonable inclusion rates to partially replace forage with low fiber digestibility to increase diet dNDF. Monitoring and maintaining effective NDF in the diet is critical when employing this feeding strategy.

In Vitro NDFD and TMR Diagnostics

The distribution of in vitro NDFD for high-group TMR samples from commercial dairies analyzed at the University of Wisconsin Forage Testing Laboratory (Marshfield, WI; Hoffman, 2003) is presented in Figure 1 with an average NDFD of 57.2% of NDF. The NDFD range for these high-group TMR samples is wide and raises concern over intake limitations on the low end and lack of effective fiber on the high end. Analyzing for in vitro NDFD offers another tool for troubleshooting fiber status of dairy cattle diets.

RFQ vs. RFV

Relative feed value (RFV; Rohweder et al., 1978), used for forage evaluation and hay marketing, is based on NDF and ADF concentrations as predictors of intake potential and energy value, respectively. RFV has evolved to the point where it is commonly available on commercial forage test reports, used routinely in evaluations and comparisons of hay-crop forage quality, and used in the marketing of hays. Data from Wisconsin quality-tested hay auctions show that dairy producers pay $0.90 per point of RFV above the RFV of a base quality alfalfa (Undersander, 2002). But, RFV does not account for differences in NDFD.

We (Shaver et al., 2002) proposed incorporating NDFD measurements into the RFV calculations, where forage energy value would is derived using summative equations and DMI potential is predicted using NDF and NDFD. The new quality estimate has been termed relative forage quality (RFQ; Undersander and Moore, 2002). The regression of RFV versus RFQ is presented in Figure 2. The graph and its low R-square value (0.68) show that RFQ varies above and below its line of equality with RFV. For example, samples with RFV of 140 have RFQ values ranging from 110 to 170. The use of NDFD measurements in forage evaluation schemes may detect variation in forage quality not previously detected in schemes based solely on fiber concentrations. The foregoing discussion may partially explain why dairy producers often report widely different animal performance from lots of hay with the same RFV. Factors that cause NDFD to vary include plant species, varieties within a species, stage of maturity at harvest, climatic condition that the crop was grown under, and interactions between these factors.

RFQ, which incorporates NDFD, might give a better relationship with animal performance than RFV, but confirmation with animal performance trials is needed. Kendall and Combs (2004) fed control (77% NDF, 41% NDFD) and ammoniated (76% NDF, 62% NDFD) wheat straw to lactating dairy cows in diets containing wheat straw at either 8.5% (28% NDF diets) or 16% (32% NDF diets) of DM. Milk yield was 1.5 to 2.1 kg/cow/day higher for cows fed the high-NDFD wheat straw diets. Mertens et al. (2005) and Raeth-Kinght et al. (2005) fed lactating dairy cows alfalfa hays (30 or 15% of diet DM in each report, respectively) that contained either low NDF (36 to 37% of DM) of “varying” NDFD (38 to 41% of NDF) or “high” NDF (41 to 42% of DM) of “varying” NDFD (41 to 45% of NDF). Milk yield was not increased by the “higher” NDFD alfalfa hays, but this lack of response to NDFD could likely have been expected a priori given the small NDFD differences between the hays and the low NDF content of the hays. More animal performance trials are needed before RFQ can be used with confidence by the industry.

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Table 1. Impact of NDFD (average lab NDFD 58% of NDF) in whole-plant corn harvested at 35% DM content with kernel processing on TDN_{1x} (%), NE_{L-3x} (Mcal/lb.) and milk (lb.) per ton using MILK2006 or MILK2000 with nutrient composition adapted from NRC (2001) for "normal" corn silage (8.8% CP, 45% NDF, 27% starch, 4.3% ash, and 3.2% fat).

NDFD%	MILK2006 TDN_{1X}	MILK2006 NEL_{3x}	MILK2006 Milk/ton	MILK2000 TDN_{1X}	MILK2000 NEL_{3x}	MILK2000 Milk/ton
46	65.3	0.66	2936	66.4	0.69	3074
50	67.0	0.67	3037	68.2	0.71	3244
54	68.8	0.68	3138	70.0	0.73	3413
58	70.5	0.69	3237	71.8	0.75	3579
62	72.3	0.70	3336	73.6	0.77	3743
66	74.0	0.72	3434	75.4	0.79	3905
70	75.8	0.73	3530	77.2	0.81	4065

Table 2. Impact of "low" (45% DM, unprocessed, 8.8% CP, 54% NDF, 46% NDFD, 20% starch, 4.3% ash and 3.2% fat) versus "high" (30% DM, processed, 8.8% CP, 36% NDF, 70% NDFD, 34% starch, 4.3% ash and 3.2% fat) quality extremes in whole-plant corn on TDN_{1x} (%), NEL_{3x} (Mcal/lb.) and milk (lb.) per ton using MILK2006 or MILK2000.

Quality	MILK2006 TDN_{1X}	MILK2006 NEL_{3x}	MILK2006 Milk/ton	MILK2000 TDN_{1X}	MILK2000 NEL_{3x}	MILK2000 Milk/ton
"Low"	56.2	0.55	2242	57.3	0.58	2418
"High"	76.3	0.74	3617	79.9	0.84	4256

Table 3. Preliminary analysis of correlations for selected corn silage nutrients and their digestibility coefficients with milk per ton estimates from MILK 2006, 2000, 1995, and 1991 models. Data (n = 3727 treatment means) provided by J. G. Lauer (UW-Madison Agronomy Department).

r-values	Milk 2006 Milk per ton[1]	Milk 2000 Milk per ton[2]	Milk 1995 Milk per ton[3]	Milk 1991 Milk per ton[4]
NDF%	-0.46	-0.40	-0.94	-0.99
Starch%	0.48	0.44	0.75	0.74
NDFD, % of NDF	0.49	0.70	0.16	-0.10
StarchD, % of Starch	0.30	0.21	-0.25	-0.27

[1]Calculated as per Schwab et al. (2003) except for modifications discussed herein.
[2]Calculated as per Schwab et al. (2003).
[3]Calculated as per Undersander et al. (1993) except for in vitro DM digestibility adjustment.
[4]Calculated as per Undersander et al. (1993) using ADF and NDF.

Table 4. Variation within forages for neutral detergent fiber digestibility measured in situ or in vitro.

Forage	**NDFD (% of NDF)**
Nocek and Russell, 1988	
Legumes	31 – 63
Grasses	41 – 77
Corn Silage	32 – 68
Allen and Oba, 1996	
Alfalfa	25 – 60
Whole-Plant Corn	30 – 60
Hoffman, 2003 (UWFTL)	
Legumes	35 – 65
Grasses	25 – 75
Corn Silage	40 – 75
Chase, 2003 (Dairy One)	
Legumes	34 – 57
Grasses	41 - 70
Corn Silage	45 - 64

Table 5. Content and digestibility of NDF for selected high-fiber by-product feeds.

Ingredient	**NDF, % DM**[1]	**NDFD, % NDF**[2]	**dNDF, % DM**
Forages	40 – 60	30 – 60	10 – 35
Corn gluten feed	36	80 (1)[3]	29
Distillers grains	39	75 (14)	29
Brewers grains	47	50 (2)	24
Wheat midds	37	50 (3)	19
Beet Pulp	46	85 (10)	39
Citrus pulp	24	85 (2)	20
Soy hulls	60	90 (2)	54
Whole cottonseed	50	50 (36)	25
Cottonseed hulls	85	20 (4)	17
Almond hulls	37	40 (5)	15

[1]NRC, 2001.
[2]30-h NDFD (% NDF) adapted from Dr. Peter Robinson, CA-Davis.
[3](n).

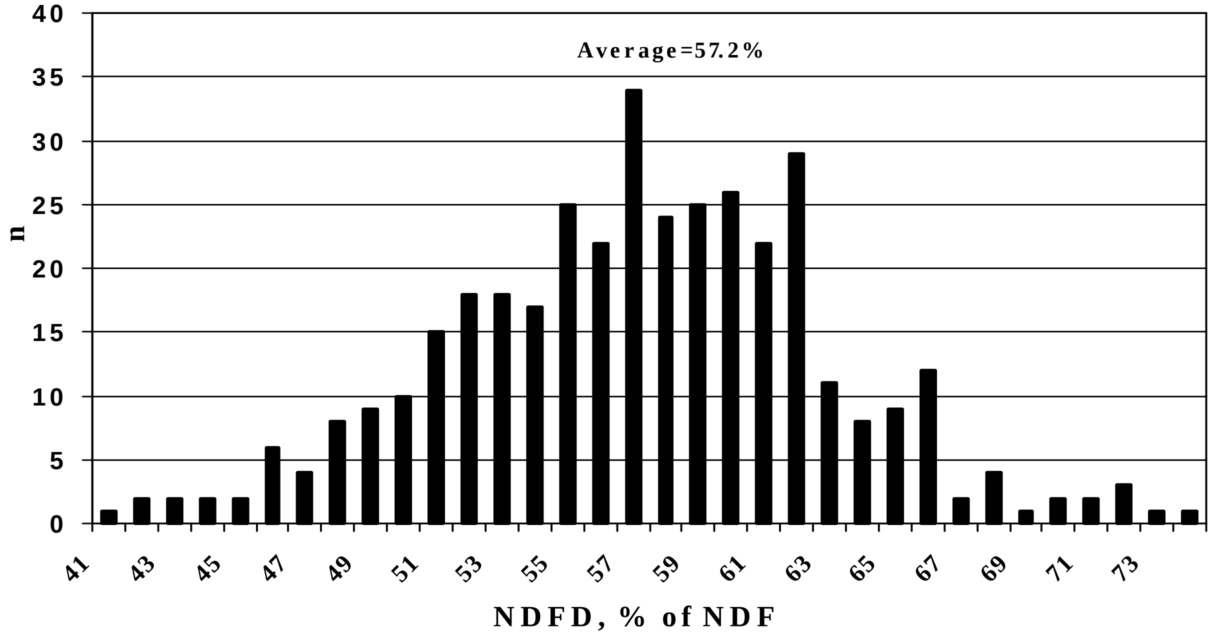

Figure 1. Distribution of 48-h in vitro NDFD (% of NDF) in data set of 377 high-group TMR samples from commercial dairies analyzed at UW Soil & Forage Analysis Lab, Marshfield, WI (Hoffman, 2003).

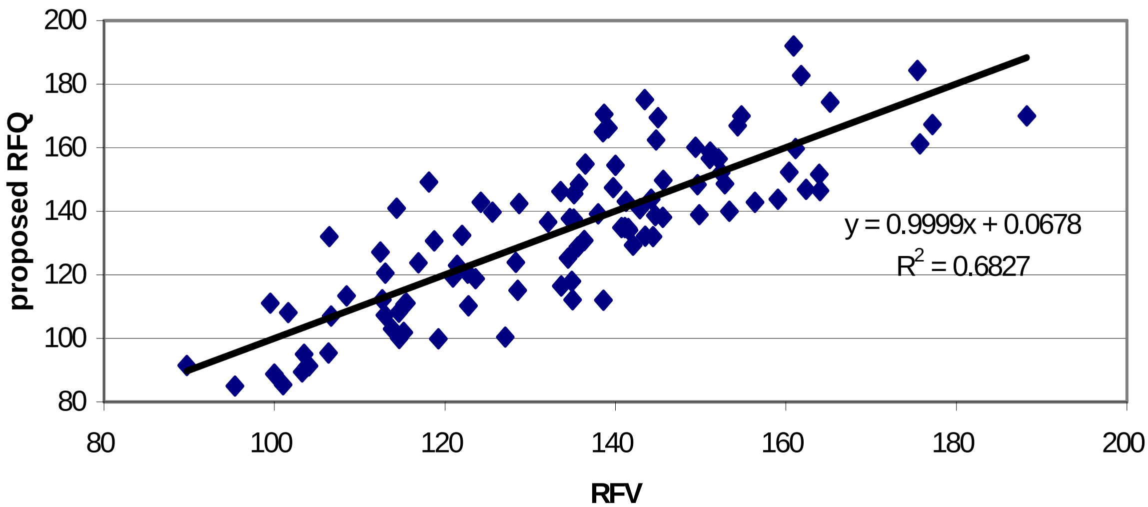

Figure 2. Current RFV versus proposed RFQ (Undersander and Moore, 2002).