Corn Silage Evaluation:
MILK2000 Challenges and Opportunities with MILK2006

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Introduction

An index of forage quality, milk per ton of forage DM (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 (Schwab et al., 2003; NRC, 2001) and DMI predicted from both NDF content (Mertens, 1987) and digestibility (NDFD, % of NDF; 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 and will be discussed herein.

Model NE_{L-3x} and DMI

We (Schwab et al., 2003) modified the NRC (2001) $TDN_{maintenance}$ summative energy equation for corn silage to include starch and non-starch NFC components with a variable predicted starch digestibility coefficient, and a direct laboratory measure of the NDF digestibility coefficient rather than one calculated using lignin content. The NE_{L-3x} energy value was derived from $TDN_{maintenance}$ using the NRC (1989) empirical equation in MILK2000 (Schwab et al., 2003). In MILK2006, the NE_{L-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 digestibility 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-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-3x}

content but impacts NE_L intake primarily through effects on DMI. In MILK2006, the NDFD value used for calculating NE_{L-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.

Non-fiber Carbohydrates and Their Digestibility

Dairy cattle nutritionists have long used non-fiber carbohydrate (NFC) as a quasi-nutrient rather than starch specifically. However, NFC is a calculated value (100-NDF-CP+NDFCP-Fat-Ash; NRC, 2001) comprised of varying proportions of starch, sugar, soluble fiber, organic acids, and is subject to errors associated with analyzing five nutrients used to calculate NFC. Although the NRC 2001 summative energy equation was based on NFC, starch rather than NFC is being used in summative energy equations (Schwab et al., 2003) by many commercial feed testing laboratories especially for corn silage which they have been long been analyzing for starch content and have developed NIRS calibrations for starch determination. However, determining digestion coefficients for starch to use in summative energy equations has been difficult. The NRC 2001 model uses an NFC true digestibility coefficient of 98% and arbitrary processing adjustment factors. The MILK2000 model uses a non-starch NFC (NFC minus starch) true digestibility coefficient of 98% (NRC, 2001) and varies the starch true digestibility coefficient from a minimum of 76% (Firkins et al., 2001) to a maximum of 98% (NRC, 2001) using whole-plant DM and kernel processing as regression equation variables to predict apparent total tract starch digestibility (Figure 1; Schwab et al., 2003). Both approaches though are limited in their ability for detecting potential variation in starch digestibility across a wide array of samples, and novel lab assays are needed.

Starch, supplied in Midwestern and Northeastern diets primarily from dry or high-moisture corn grain and whole-plant corn silage, is an important source of energy for dairy cattle. However, the digestibility of corn starch can be highly variable (Nocek and Tamminga, 1991; Orskov, 1986; Owens et al., 1986; Rooney and Pflugfelder, 1986; Theuer, 1986). Various factors, particle size (fine vs. coarse grind), grain processing (steam flaked vs. dry rolled), storage method (dry vs. high-moisture corn), moisture content of high-moisture corn, type of corn endosperm, and corn silage maturity at harvest, chop length, and kernel processing, influence starch digestibility in lactating dairy cows. Because both physical and chemical properties of starch influence starch digestion, assessment of starch digestibility in the laboratory has been challenging.

In an attempt to address variation in starch digestibility, NRC (2001) suggested empirical processing adjustment factors (PAF) to adjust NFC digestion coefficients for high-starch feeds. However, since no system to measure variation in PAF for feedstuffs is available the PAF's are subjective book values with minimal practical utility. For corn silage, U.S. Dairy Forage Research Center workers developed a kernel processing score (KPS; Ferreira and Mertens, 2005; Mertens, 2005;) to assess adequacy of kernel processing in corn silage. But, the relationship between KPS values and in vivo starch digestibility measurements is not well defined. Ruminal in-vitro or in-situ degradation, either alone or in combination with in vitro post-ruminal enzymatic digestion of the

ruminal residues, have been explored by some groups (Sapienza, 2002). Some commercial laboratories are attempting to employ in situ or in vitro systems to evaluate starch digestibility, but to date methods are highly variable between laboratories. Regardless of the method it is doubtful that samples can be fine ground as fine grinding of samples may mask differences among samples (Doggett et al., 1998). Relationships between in situ/in vitro measurements and in vivo starch digestibility are often not well defined. We recently developed an enzymatic lab assay, Degree of Starch Access (DSA), which is sensitive to differences in particle size, moisture content, and vitreousness of corn-based feeds (Blasel et al., 2006).

The DSA assay was found to be quite sensitive (Blasel et al., 2006) to particle size (R^2 = 0.99) and moderately sensitive to DM content (R^2 = 0.76) and endosperm type (R^2 = 0.59), which are three primary factors that influence starch digestibility in corn grain. However, The DSA assay is a laboratory starch recovery procedure that does not result in a direct estimate of starch digestibility and only reveals differences in starch recoveries. For example, the DSA procedure would recover 95 percent of the starch in finely ground corn but only 5 percent of the starch in whole shelled corn. Thus, the DSA values provide an index of the variation in degree of starch access among feeds. We (Shaver and Hoffman, 2006) reviewed eight trials in the scientific literature (Taylor and Allen, 2005; Remond et al., 2004; Oba and Allen, 2003; Crocker et al., 1998; Knowlton et al., 1998; Yu et al., 1998; Joy et al., 1997; Knowlton et al., 1996) with lactating dairy cows that reported total tract starch digestibility and particle size, moisture content, and endosperm type of the corns tested. From these data, we estimated their DSA values and evaluated the relationship between DSA and their measures of total tract starch digestibility (Figure 2). This regression equation can be applied to starch recovery values generated from the DSA assay to provide an estimate of total tract starch digestibility (termed Starch Digestibility$_{DSA}$). Starch Digestibility$_{DSA}$ can then be used in summative energy equations (Schwab et al., 2003; NRC, 2001) directly to calculate energy values for corn-based feeds on a standardized basis.

More field and in vivo evaluations of these laboratory assays related to starch digestibility (KPS, DSA, and in situ/in vitro) are needed. Therefore, the MILK2006 model will continue to use the regression approach of MILK2000 (Schwab et al., 2003) as the default method for determining starch digestibility. But, user-defined options will be available within the MILK2006 spreadsheet for determining starch digestibility from available KPS, DSA, or in situ/in vitro data. For hybrid performance trials where an objective is to assess true hybrid differences for kernel endosperm properties, the harvest maturity, whole-plant DM content, and sample particle size should be kept as similar as possible since these factors all influence the starch digestibility determinations.

Fiber and Its Digestibility

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, but whole-plant NDF and lignin contents are constant or decline as 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% (P < 0.001) 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 the corn silage milk per ton models (Schwab et al., 2003). Use of NDF and NDFD in the corn silage milk per ton models has been discussed above.

Several commercial testing laboratories offer wet chemistry in vitro NDFD measurements. NIRS calibrations for predicting in vitro NDFD on corn silage samples are available at some commercial forage testing laboratories. However, Lundberg et al. (2004) found poor prediction by NIRS of 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.

Model Comparisons

Values for $TDN_{maintenance}$, NE_{L-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-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 MILK 2006, 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.

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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.

Figure 1. Influence of whole-plant corn silage dry matter content on predicted apparent total tract starch digestibility. Unprocessed corn silage (■), Y = 144.8 – (1.67x), R^2 = 0.85. Processed corn silage (▲), Y = 121.6 – (0.88x), R^2 = 0.77. Predicted starch digestibility coefficients adjusted to a maintenance level of intake using a 4-percent decline in digestibility per multiple of maintenance (NRC, 1989) with a maximum true starch digestibility of 98% (NRC, 2001) for use in the Schwab et al. (2003) summative energy equation.
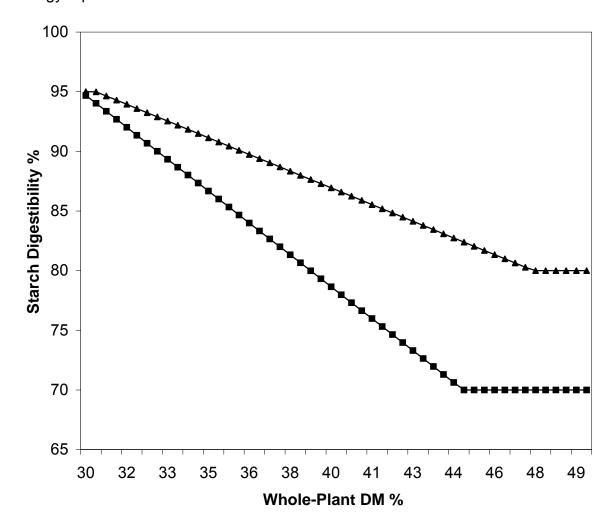
Figure 2. Relationship between Starch Digestibility$_{DSA}$ as predicted from DSA starch recovery and total tract starch digestibility in lactating dairy cows. Relationship is based on starch recovery estimated from particle size, moisture content and corn endosperm data from eight published research trials which evaluated total tract starch digestibility in lactating dairy cows (Shaver and Hoffman, 2006).