The Impact of Improving NDF Digestibility of Corn Silage on Dairy Cow Performance

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Introduction

Forages are a necessary component of diets for lactating dairy cows because they provide coarse fiber needed to optimize rumen function. However, forages alone provide insufficient nutrients to achieve high milk yield and they must be supplemented with other feed ingredients. Because forage quality is highly variable, their quality must be assessed before diets are formulated. Forages have been traditionally analyzed for crude protein and fiber concentrations because of their direct effect on diet formulation. More recently in vitro neutral detergent fiber digestibility (**IVNDFD**) has been identified as an important quality parameter that is highly variable among corn silages and has consistent effects on productivity of dairy cows. However, it is important to understand the unique characteristics and limitations of IVNDFD of corn silage to maximize the benefit of enhanced IVNDFD. This paper will answer some frequently asked questions regarding the interpretation and utilization of IVNDFD data of corn silage.

Why is in vitro fiber digestibility important?

In vitro NDF digestibility of corn silage is extremely variable; 24-h IVNDFD ranged from 35.1 to 48.1 (%NDF) for corn silages analyzed at Dairy One Forage Lab in 2009 (www.dairyone.com; **Table 1**). This variation in range was greater than that of NDF content of those same corn silage samples (%DM; 37.0 to 48.3%). In general, the IVNDFD of corn silage is poorly related to the concentration of NDF, ADF or CP, and IVNDFD has become widely used as an important and independent measure of forage quality. Approximately 1/3 of corn silage samples analyzed for CP and NDF concentrations were also evaluated for IVNDFD at Dairy One Forage Lab during the last 3 years, indicating that nutritionists and dairy producers believe that IVNDFD is an important quality parameter of forages.

While many parameters of forage quality affect diet formulation and possibly diet cost, few actually affect feed intake and milk yield when diets are properly formulated. The IVNDFD of forages has consistent effects on productivity of dairy cows, making this analytical value a very important quality parameter of forages. Several years ago we reported that a one-unit increase in in-vitro or in-situ digestibility of NDF was associated

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with 0.37 and 0.55 lb/d increase in dry matter intake and 4% fat-corrected milk yield, respectively (Oba and Allen, 1999b). This relationship was developed by statistical analysis of treatment means from experiments reported in the Journal of Dairy Science.

Table 2 summarized animal studies published in the Journal of Dairy Science during the last 12 years, in which the impacts of IVNDFD on performance of lactating dairy cows were evaluated. Most studies compared brown midrib corn silage with conventional or dual-purpose corn silage and reported greater DMI, milk yield, or both for cows fed brown midrib corn silage that was consistently greater in IVNDFD. Some studies took different approaches to evaluate the impacts of enhanced IVNDFD of corn silage. Ivan et al. (2005) compared corn silage with low and high cell-wall content on milk production, and reported that the hybrid with high cell-wall content had greater IVNDFD, increasing DMI and milk yield. Similarly, Thomas et al. (2001) compared a leafy corn silage hybrid, which is higher in IVNDFD, with a dual purpose corn hybrid, and reported greater milk yield for cows fed the leafy corn silage hybrid. Neylon and Kung, Jr. (2003) improved IVNDFD of corn silage by increasing cut height at harvest, and reported greater milk yield for cows fed corn silage with enhanced IVNDFD. Thus, recent literature also strongly supports the idea that the quality of NDF, determined by IVNDFD measurements, is positively related to animal performance.

It is important to note that IVNDFD of corn silage can be improved by management effort primarily by selection of appropriate hybrids. In vitro NDF digestibility of corn silage may be improved by the use of some lactic acid bacteria inoculants (Weinberg et al., 2007), esterase-producing inoculants (Kang et al., 2009) or fibrolytic enzymes (Eun et al., 2007; Eun and Beauchemin, 2007). Although IVNDFD of corn silage is greatly affected by growing environment, it is possible to improve IVNDFD of corn silage at a given growing environment.

What is in vitro digestibility?

The IVNDFD of corn silage is determined by incubating dried ground samples in flasks with ruminal microbes for a given period of time. Corn silage samples are dried and ground (usually to pass through a 1-mm screen) so that a representative sample can be taken. The ground samples are placed in individual flasks, and incubated with ruminal fluid containing ruminal microbes collected from cows with a ruminal cannula. The flask also contains buffers, macro-minerals, trace-minerals, nitrogen sources, and reducing agents to maintain pH and provide nutrients required for growth of ruminal bacteria. Because oxygen is toxic to ruminal bacteria, flasks are gassed with carbon dioxide to maintain anaerobic conditions, and temperature is held at 104° F (body temperature) during the incubation. As a variation of this method, dried and ground corn silage samples are sealed in porous dacron bags which are incubated in groups in jars containing ruminal fluid and media.

Every effort is made to provide the optimum environment for survival and growth of fiber-digesting bacteria in the incubation media. This is extremely important because digestion is a function of both enzyme activity and structural characteristics of substrates. If enzyme activity is limiting because of inadequate buffering or lack of essential nutrients, IVNDFD will be reduced, and more importantly differences in IVNDFD among forages will be compressed and not reflective of the true differences among corn silage samples.

It is important to recognize that IVNDFD is a biological rather than a chemical evaluation of forage quality; microbial activity in ruminal fluid of cows can vary with diet and over time relative to feeding which affects the results. Thus, measurements of in vitro digestibility are associated with greater intrinsic variation compared with chemical measurements such as CP and NDF. This variation can be reduced by feeding the donor cows a high forage diet, sampling ruminal fluid at the same time relative to feeding, and blending ruminal fluid from several cows for each incubation.

In vitro digestibility coefficients are not necessarily the same as in vivo digestibility because the environment in the rumen is often less than optimum for fiber-digesting bacteria. For example, ruminal fluid pH is often lower than optimum for the fibrolytic bacteria because highly fermentable diets are typically fed to high producing cows. In addition, forage fiber particles in the rumen are longer than those of ground forages used for in vitro measurements of digestibility. Longer particle size limits the surface area for microbial degradation per unit of fiber mass. Therefore, in general, in vitro digestibility coefficients of forages should be greater than in vivo digestibility coefficients as long as an optimum fermentation environment such as pH, temperature, and anaerobic conditions are carefully maintained in the incubation media. In addition, the range in NDF digestibility of forages measured in vitro is greater than the range measured in vivo (Oba and Allen, 1999b) because the same retention time is used across samples although actual retention time of forages likely vary with rate of digestion (Allen, 2000).

What is the optimum incubation time?

Dairy NRC (2001) stated "Digestible NDF can be obtained using a 48-hour rumen in vitro assay . . . to calculate digestible NDF at maintenance". We think that 48 hours is too long to use for an incubation time for two reasons:1) the retention time of indigestible NDF in cows at maintenance is likely less than 48 h, and 2) grinding corn silage samples greatly increases their rate of digestion so the incubation time must be lowered to compensate.

The primary use of IVNDFD data is to rank corn silages by their potential to stimulate intake and milk production because IVNDFD of corn silages is an indicator of the filling effects of their fiber in the rumen. Thus, we need to select the optimum incubation time, which allows us to detect the differences in filling effect of corn silage fiber in the rumen. To accomplish this goal, we need to know the length of time that fiber stays in the rumen. While total fiber leaves the rumen though digestion and passage, indigestible fiber leaves the rumen by passage only. Therefore, the retention time of indigestible fiber reflects the maximum time that fiber stays in the rumen. The retention time of indigestible NDF, which is the reciprocal of its turnover rate in the rumen, ranged from 26.8 to 32.0 hours for cows producing 33.6 kg of milk/d (Oba and Allen, 2000), and from 27.0 to 30.3 hours for cows producing 36.2 kg/d (Oba and Allen, 2003). This retention time is expected to be shorter for cows producing more than 40 kg/d. If we are interested in filling effects of forage when fed to high producing dairy cows, corn silage samples need to be estimated assuming a shorter retention time of digesta in the rumen. Therefore, the incubation time for IVNDFD should not be any longer than 30 hours, if forage quality for high producing dairy cows is of interest.

"If 48-h IVNDFD is highly correlated with 24- or 30-h IVNDFD, selection of a specific incubation time does not really matter". This argument may sound logical, but an essential part of data may be missed unless an inappropriate incubation time is selected. For an example, comparing two samples of corn silage, a 3 unit difference in 48-h IVNDFD may not seem significant. However, if the IVNDFD data obtained from the same samples but using a 24-h incubation shows a 10-unit difference between corn silages, a significant difference in animal performance may be expected. Although the relative ranking between forages stays the same, an appropriate conclusion may not be drawn unless the right incubation time is selected. If these corn silages are fed to high producing cows, and are to be ranked by their filling effects in the rumen, 24 or 30 h of incubation is the right choice. Selection of the appropriate incubation time is important to make the right decision based on in vitro digestibility data.

Can NIRS methods be used to analyze IVNDFD?

Several commercial labs provide service for IVNDFD analysis by near-infrared reflectance spectroscopy (NIRS). The NIRS is a technology that estimates chemical composition and bonds of forage samples by measuring reflectance of light with near infra-red wavelengths and using that to predict IVNDFD. However, NIRS measurements still need to be calibrated with the data obtained from wet-chemistry, and different equations need to be used for each forage species and often for each growing environment of forages. Therefore, the accuracy of a measurement depends on accuracy of analysis in wet-chemistry. Mentink et al. (2006) reported that biological measurements such as in situ protein fractions and IVNDFD are difficult to predict using NIRS because the extent of error in reference methods is high relative to the range of measured values. As such, IVNDFD values predicted by NIRS need to be interpreted with caution.

Can IVNDFD data be used to predict energy content of corn silage?

The recent Nutrient Requirements of Dairy Cattle (NRC, 2001) suggests that 48-h in vitro digestibility can be used as a measure of digestible NDF at maintenance. The NRC (2001) discounts the energy content of forages based on actual intake level of animals in which a forage is fed and TDN concentration of diets (i.e., diets with greater TDN content discount energy content of feeds at a greater rate as intake increases). Thus, dairy NRC (2001) appears to do a better job conceptually in estimating energy density of forages compared with previous editions. Indeed, the energy content of forages is lower if fed to cows with greater feed intake. It is difficult to adjust the energy content of the corn silage for IVNDFD because the response in feed intake for forages is affected by their IVNDFD and this response differs by level of milk production (Oba and Allen, 1999). For example, total tract NDF digestibility was only 2.2 percentage units higher for brown midrib corn silage with 9.7 percentage units higher IVNDFD than its isogenic control corn silage because DMI increased 2.1 kg/d across cows. The difference in total tract NDF digestibility between the brown midrib corn silage and the control was negatively related to the response in DMI among cows; total tract NDF digestibility was 10 units higher when DMI decreased 2 kg/d but 10 percentage units lower when DMI increased 8 kg/d for the brown midrib corn silage compared to the control (Oba and Allen, 1999). Forages fed in high grain diets also likely have lower digestibility compared with those fed in low-grain diets because of sub-optimal enzymatic capacity for fiber digestion in the rumen. Changes made in the current NRC (2001) also did not solve the intrinsic problem that limits the use of in-vitro digestibility for estimation of energy content of forages: inconsistent measurements.

Because of the biological nature of in vitro digestibility measurements, it is challenging to get a same "absolute" value among several analytical laboratories. Consistency of measurements within a laboratory may be improved by adopting the best procedures and careful training of technicians. But, ruminal fluid required for determination of IVNDFD is collected from different animals fed different diets at each analytical laboratory and variation in enzyme activity potentially affects the results to a great extent; IVNDFD might be 50% for a sample analyzed in one lab and 40% in another. It is not likely to obtain a consistent value for IVNDFD across several laboratories. This is one limitation for use of IVNDFD data for energy value. If IVNDFD is used to estimate energy content of forages, a consistent standard for enzymatic capacity must be used for the in-vitro measurements across all laboratories. In addition, an incubation time of 48 h is too long to estimate actual NDF digestibility even at a maintenance level (as discussed above), and compensatory digestion of NDF in the large intestine makes predicting energy concentration from IVNDFD a challenge. Therefore, in-vitro digestibility measurement does not provide an "absolute" energy value that can be used for diet formulations.

How can IVNDFD data be used?

Even though we cannot get an absolute energy value from in-vitro digestibility measurements, IVNDFD still provides very useful data for nutritional management of dairy herds. For instance IVNDFD is a powerful tool to rank corn silages by their quality. As discussed earlier **(Table 2**), diets containing corn silages having different IVNDFD coefficients consistently affect animal performance. Positive effects of enhanced IVNDFD are greater for cows yielding more milk. This is likely because their maximum feed intake is limited by physical fill in the rumen to a greater extent compared with lower-yielding cows. Milk production responses to brown midrib corn silage which has enhanced IVNDFD were positively correlated with milk yield before the experiment (Oba and Allen, 1999a). Lower producing cows had little response in DMI and milk yield to the corn silage with greater IVNDFD while higher yielding cows responded by increasing feed intake and milk yield. Lower production responses for lower producing cows are likely because their feed intake is not limited by physical fill of the diets. Thus, corn silages having greater IVNDFD should be allocated to higher yielding cows that will benefit the most. If a farm can feed different lots of corn silage to 2 or more groups of lactating cows, there is an opportunity to increase the benefit of enhanced IVNDFD by feeding the corn silage with greater IVNDFD only to cows that will benefit the most. Because corn silages with enhanced IVNDFD might cost more to buy or produce (greater seed cost, lower yield), animals must respond enough to justify the investment for enhanced IVNDFD.

The IVNDFD data may also affect how diets are formulated. When grain is less expensive than forages, dairy diets are normally formulated to include the maximum amount of grain without causing any digestive disorders such as ruminal acidosis or laminitis. On the other hand, when grain prices increase, feed costs can be reduced by increasing the forage proportion in the diet. Because forage NDF is filling and often limits feed intake, forages with greater IVNDFD will allow more forage to be fed without compromising milk production. In a previous experiment (Oba and Allen, 2000), cows fed a corn silage with enhanced IVNDFD (55.9%) in a high forage diet (without supplemental corn grain), produced as much milk (33.7 vs. 33.5 kg/d) as cows fed a corn silage with lower IVNDFD (46.5%) in a diet which contained dry ground corn at 29.2% of dietary dry matter. Similarly, Weiss and Wyatt (2002) compared a high-fiber corn silage with a dual-purpose corn silage. Although diets containing the high-fiber corn silage had greater forage NDF content than diets containing corn silage with high starch concentration, milk production was not different probably because of the greater IVNDFD of the former silage. Identification of corn silages with greater IVNDFD will allow more corn silage to be fed and decrease feeding costs without reductions in milk yield when grain is costly. This creates significant flexibility in diet formulation especially because grain costs relative to forages are highly variable.

Analysis of corn silage for IVNDFD is also an important trouble-shooting tool. For instance, milk yield sometimes decreases when switching from old corn silage to the new crop. It is a good idea to sample the current forage before switching so that it can be sent to the lab for IVNDFD analysis. Although a milk production decrease when switching to a new crop of corn silage might result from excessive kernel passage through the cow, physical fill might be a dominant factor limiting feed intake and decreasing milk yield if the new corn silage is significantly lower in IVNDFD. In addition, if a new corn silage is significantly greater in IVNDFD than a corn silage that was being fed, the new diet may depress milk fat content unless the diet is adjusted. If the silo is opened a couple of weeks before feeding to high producing cows and fed to the low milk group or heifers, there is sufficient time to take a representative sample, analyze it for IVNDFD, and make necessary adjustments in diet formulation. Assessment of IVNDFD of new corn silage with that from a previous year can help explain a milk production drop or prevent a potential problem before it occurs.

The impact of forage IVNDFD on chewing activities is another area of interest that warrants further research. Physically effective NDF (peNDF) is an important parameter of diet formulation for lactating dairy cows because it affects ruminal pH by altering chewing activities and salivary buffer secretion. Corn silages with enhanced IVNDFD may be physically more fragile, thus less effective at stimulating chewing. Grant (2010) suggested that forage IVNDFD can be used to adjust peNDF values due to the positive relationship between IVNDFD and fragility. However, impacts of enhanced IVNDFD of corn silage on chewing activities are not consistent in literature. Oba and Allen (2000) reported that feeding brown midrib corn silage did not decrease ruminating time per day or per kg of NDF intake, but Taylor and Allen (2005) reported that cows fed brown midrib corn silage decreased ruminating time and total chewing time. This discrepancy may be partly explained by the difference in IVNDFD between brown midrib corn silage used in these two studies; 30-h IVNDFD of brown midrib corn silage was 55.9 and 66.6%, respectively for Oba and Allen (2000) and Taylor and Allen (2005). There might be a threshold for forage IVNDFD to negatively affect chewing activities.

Conclusion

In vitro NDF digestibility of corn silages positively related to animal performance and varies greatly. The IVNDFD data should not be used to adjust energy density of forages but is very useful to rank forages for their filling effects of NDF in the rumen. The IVNDFD analysis allows us to identify forages with greater potential to increase intake and milk production so that we can allocate them to high producing cows which will benefit the most. Analysis of IVNDFD provides essential information to make good decisions in nutritional management, and improves the profitability of dairy operations.

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Table 1. Mean and normal range in CP, NDF, and 24-h IVNDFD for corn silage analyzed during 2007-2009 at Dairy One (www.dairyone.com).

	N	Mean	Minimum	Maximum
2007				
CP, %DM	18,715	8.2	7.2	9.3
NDF, %DM	18,667	43.4	37.8	49.0
24-h IVNDFD, %NDF	6,319	39.8	33.7	46.0
2008				
CP, %DM	18,356	8.1	7.1	9.1
NDF, %DM	18,395	43.3	37.9	48.7
24-h IVNDFD, %NDF	6,570	39.9	33.3	46.5
2009				
CP, %DM	18,010	8.1	7.1	9.1
NDF, %DM	18,028	42.7	37.0	48.3
24-h IVNDFD, %NDF	6,028	41.6	35.1	48.1

Table 2. Effects of enhanced 30-h forage IVNDFD on DMI, milk yield, and 4% FCM yield in recent publications.

Publication and Treatments	Forage IVNDFD (% NDF)	Dietary NDF (% DM)	DMI (kg/d)	Milk Yield (kg/d)	4% FCM Yield (kg/d)
Ballard et al., 2001 (JDS 84:442-452) [a]					
Mycogen (TMF corn silage)	28.2	35.3	…	31.1*	32.4*
Cargill (brown midrib corn silage)	45.7	34.7	…	33.4*	34.1*
Castro et al., 2010 (JDS93:2143-2152) [b]					
Normal corn silage	51.3	36.1	24.7*	40.6	35.2
Brown midrib corn silage	60.3	35.2	26.4*	41.0	36.8
Normal corn silage	51.3	38.8	24.7*	38.1	36.1
Brown midrib corn silage	60.3	39.5	25.6*	39.8	35.9
Ebling and Kung, Jr. 2004 (JDS 87:2519-2527)					
Conventional corn silage	39.9	33.9	23.4*	41.4*	36.2
Brown midrib corn silage	54.0	33.5	25.9*	44.3*	37.3
Gehman et al., 2008 (JDS91:288-300)					
Dual-purpose corn silage	49.1	33.4	20.1	36.4	34.1
Brown midrib corn silage	61.0	33.7	21.1	39.5	37.4
Dual-purpose corn silage	49.1	33.4	20.2	37.8	35.7
Brown midrib corn silage	61.0	33.7	21.5	37.1	34.6
Ivan et al., 2005 (JDS 88:244-254)					
Corn silage with lower cell-wall content	50.7	30.8	24.2*	33.5*	31.7*
Corn silage with high cell-wall content	54.8	33.2	25.4*	35.7*	34.3*
Corn silage with lower cell-wall content	50.7	30.8	26.5	34.6	33.4*
Corn silage with high cell-wall content	54.8	30.8	27.1	35.5	34.9*

Neylon and Kung, Jr., 2003 (JDS 86:2163-2169)					
Corn silage with lower cut height	48.4	34.2	25.4	45.2*	40.2
Corn silage with higher cut height	50.7	33.5	25.6	46.7*	39.9
Oba and Allen, 1999a (JDS 82:135-142)					
Control corn silage	39.4	31.6	23.5*	38.9*	35.7*
bm3 corn silage	49.1	30.8	25.6*	41.7*	38.2*
Oba and Allen, 2000 (JDS 83:1333-1341)					
Control corn silage	46.5	29.1	22.8*	33.5*	31.8*
bm3 corn silage	55.9	28.7	23.6*	36.9*	32.9*
Control corn silage	46.5	38.4	20.5*	30.4*	29.9*
bm3 corn silage	55.9	37.5	22.0*	33.7*	33.0*
Taylor and Allen, 2005 (JDS 88:1425-1433)					
Control corn silage	54.0	26.0	23.6	39.8	36.9
bm3 corn silage	66.6	25.7	25.5	42.5	39.2
Control corn silage	54.0	25.8	25.5	40.6	38.3
bm3 corn silage	66.6	25.5	24.9	40.6	37.2
Thomas et al., 2001 (JDS 84:2217-2226)					
Dual-purpose corn hybrid	49.2	37.1	28.6	45.1*	44.4
Leafy corn silage hybrid	53.9	36.1	27.7	46.6*	45.8
Weiss and Wyatt, 2002 (JDS 85:3462-3469)					
Dual-purpose corn silage	35.4	28.9	23.9	33.3	33.3
High fiber corn silage	40.1	31.9	23.7	34.0	33.3

Dual-purpose corn silage	35.4	31.6 (18.1[c])	23.4	33.8	33.6
High fiber corn silage	40.1	27.6 (20.4[c])	23.7	35.5	33.5
Weiss and Wyatt, 2006 (JDS 89:1644-1653) [d]					
Dual-purpose corn silage	58.3	32.6	24.8	34.9*	35.1
Brown midrib corn silage	65.2	32.3	24.5	36.4*	34.4
Dual-purpose corn silage	58.3	32.6	25.0	35.7*	36.6
Brown midrib corn silage	65.2	32.3	25.2	37.4*	35.8

* Significant effects of treatment (*P* < 0.05)

[a] Data were not used for the statistical analysis as *P*-value for IVNDFD was not reported

[b] 48-h in situ NDFD was reported

[c] Forage NDF (% of dietary DM)

[d] 48-h IVNDFD was reported

SESSION NOTES