FORAGE QUALITY VARIATION

R. D. Shaver, Ph.D., PAS

Professor and Extension Dairy Nutritionist
Department of Dairy Science
College of Agricultural and Life Sciences
University of Wisconsin – Madison
University of Wisconsin – Extension

Introduction

Forages comprise 35% to 70% of the dry matter (**DM**) in diets for lactating dairy cows. Variation in forage quality can impact DM intake, diet energy density, dietary grain and protein supplementation amounts, feed costs, lactation performance, and cow health. Forage quality is highly variable among and within forage types (NRC, 2001). Forage species, variety or hybrid, stage of maturity at harvest, cutting, environmental factors, production and harvest practices, storage method (i.e. hay vs. silage, bunker vs. bag, etc.), and ensiling practices all are factors that contribute to this variation. This paper will evaluate forages for their variation in content of selected nutrients and some aspects of digestibility.

Forage Nutrient Composition

Means and standard deviations for crude protein (**CP**) and neutral detergent fiber (**NDF**) and calculated means for total digestible nutrients at a maintenance level of intake (**$\mathbf{TDN_{1x}}$**) and non-fiber carbohydrates (**NFC**) of selected forages from NRC (2001) table 15-1 are presented in Table 1. Crude protein content is highest and NDF content is lowest for legume forages. The TDN_{1x} estimate is reasonably similar between legumes and grasses, mainly because the less lignified NDF for grasses compared to legumes results in a higher calculated digestible NDF for grasses, which offsets their lower NFC and CP contents when using the NRC (2001) summative energy equation. However, forage DM intake is negatively related to NDF content in high producing dairy cows (Mertens, 1987), which may reduce energy intake from grass compared to legume forages. The NDF content of corn silages can be comparable to legume forages, due to dilution with grain that comprises a high proportion of whole-plant corn silage harvested at normal to advanced stages of maturity. Essentially the high NFC content of corn silage results in high TDN_{1x} estimates relative to other forages when using the NRC (2001) summative energy equation. Coefficients of variation (standard deviation divided by the mean times 100) across forages ranged from 12% to 46% and 7% to 16% for CP and NDF contents, respectively. Corn silage has been thought to be reasonably consistent, but Table 2 shows the wide range in NDF and starch contents found in one commercial testing laboratory over one year, which likely reflects variable proportions of grain in whole-plant corn silage. Extensive variation in DM, CP, and NDF contents found within bunker silos is presented in Table 3, which emphasizes the importance of meticulous face management with careful use of loader buckets or face shavers to minimize batch to batch variation and the importance of obtaining samples representative of what is actually being mixed.

Forage NDF Digestibility

Intake of DM is positively related to NDF digestibility (NDFD, % of NDF; Oba and Allen, 1999). 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, 1999). Several commercial testing laboratories in the U.S. now offer wet chemistry in vitro NDFD measurements. Near infrared reflectance spectroscopy (**NIRS**) calibrations for predicting 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 NDFD. It is hoped that NIRS calibration equations can be improved upon in the future.

Average NDFD values for selected high-fiber by-product feeds (personal communication with Dr. Peter Robinson, CA-Davis) are presented in Table 5. The NDFD values are highly variable among high-fiber by-product feeds. 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. The distribution of NDFD in high-group TMR samples from commercial dairies analyzed at the University of Wisconsin Forage Testing Laboratory (**UWFTL**; Marshfield, WI) 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 NDFD offers another tool for troubleshooting fiber status of dairy cattle diets.

Relative feed value (**RFV**; Rohweder et al., 1978), used for forage evaluation and hay marketing, is based on NDF and acid detergent fiber (ADF) concentrations as predictors of intake potential and energy value, respectively. Relative feed value 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, the RFV estimates do not account for differences in NDFD. We (Shaver et al., 2002) proposed incorporating NDFD measurements into the RFV calculations, where forages energy value would be estimated using summative equations and DM intake potential would be estimated 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. We are hopeful that RFQ, which incorporates NDFD, will yield a better relationship with animal performance, but this has yet to be confirmed in feeding experiments.

Forage NFC Composition And Digestibility

The NFC content of feedstuffs has usually been calculated by difference (100% - %NDF - %CP - %fat - %ash). The NRC (2001) NFC equation corrects for CP contained in the NDF fraction. This correction can be significant for hay-crop forages and some high fiber by-product feeds, and can result in up to a 4-percentage unit higher calculation of dietary NFC content. Also, the accuracy of the calculated NFC value for feedstuffs depends on the accuracy of the component nutrient analyses. Lundberg et al. (2004) reported low accuracy of NIRS for measuring ash content of corn and legume-grass silages. A 5%-unit error in NIRS determination of ash content would cause a 5%-unit error in the calculated NFC value resulting in nearly a 5%-unit error in the TDN_{1x} estimate. Dirt contamination associated with mowing alfalfa low to the ground, use of diskbine mowers, and the pushing/packing process of silage making can cause wide variation in ash content of forage samples. Accuracy of component nutrient analyses, even nutrients once ignored, does make a difference, especially when employing the summative energy approach!

The NFC fraction is comprised of varying proportions of starch, sugar, pectin, and silage fermentation acids. NRC (2001) used a true NFC digestibility coefficient of 98%. Total-tract digestibility of starch in corn silage is affected by stage of maturity at harvest and kernel processing (Schwab et al., 2003). Schwab et al. (2003) replaced the NFC fraction of corn silage with starch and non-starch fractions. Non-starch NFC was calculated by subtracting percent starch from percent NFC, and a digestion coefficient of 98% was assigned to the non-starch NFC fraction (NRC, 2001). Some commercial forage testing laboratories have been analyzing samples for starch for several years, and now have NIRS calibrations for starch determination. There were no laboratory procedures available to determine starch digestibility, so Schwab et al. (2003) developed regression equations from data in the literature to predict total-tract starch digestibility from whole-plant DM content. Apparent total-tract corn silage starch digestibility was predicted from corn silage DM content (Refer to Figure 3):

Starch digestibility $_{\text{Unprocessed}}$ (%) = 144.8 – (1.67 * DM %);($R^2 = 0.85$, $P < 0.0001$),

Starch digestibility $_{\text{Processed}}$ (%) = 121.6 – (0.88 * DM %); ($R^2 = 0.77$, $P < 0.001$).

Slopes of these regression equations indicate that DM content had a greater impact on the starch digestibility of unprocessed than processed corn silage. At 35% whole-plant DM, predicted apparent total-tract starch digestibility for unprocessed and processed corn silage was 86% and 91%, respectively. At lower DM concentrations the difference between processed and unprocessed silage was smaller and increased as DM concentration increased. This may be due to the starch in dryer kernels being less available for digestion. The Schwab et al. (2003) prediction of starch digestibility from whole-plant DM content and kernel processing was developed from limited data. The effect of whole-plant DM content and its interaction with processing would likely vary depending on hybrid type, soil type, growing conditions, and dry-down rate. The processing effect would likely vary depending on chop length and roll clearance. Attempts to model for these factors would be difficult because of the current lack of literature data. Improved laboratory methods are needed for determining starch digestibility of diverse corn silage samples (i.e. highly variable DM content, chop length, roll clearance, kernel hardness, etc.).

Silage Fermentation Profiles

Silage fermentation analyses (pH, lactic acid, VFA, ethanol, and ammonia; Refer to Table 6) have long been used in university and industry research trials to assess silage quality. These analyses are now available for evaluating silage quality on farms through some commercial forage testing laboratories. In some cases fermentation analyses can qualitatively explain poor silage nutritive value or low intakes. Analyses are usually performed using GC or HPLC methods, but some labs use NIRS on undried samples which appears to be feasible (Reeves, 1989).

Dietary Cation-Anion Difference

Formulation of dairy cattle diets for dietary cation-anion difference (**DCAD**) is becoming more common (Beede, 2003). Formulation of negative DCAD pre-fresh diets is done to reduce milk fever and hypocalcemia, and some data suggests that formulation of highly positive DCAD diets for early lactation cows may improve performance (Beede, 2003). The necessary components of the equation for calculating DCAD are sodium, potassium, chloride, and sulfur. Potassium, and even chloride, can vary widely in forages (Beede, 2003). DCAD analysis should be done using wet chemistry techniques rather than NIRS. Some commercial testing laboratories currently provide DCAD analysis.

Conclusions

Forage quality is highly variable among and within forage types for nutrient composition as well as digestibility. Routine and accurate forage testing is critical to the success of dairy cattle feeding programs, because of the high variability in quality encountered on commercial dairies.

Literature Cited

Allen, M., and M. Oba. 1996. Fiber digestibility of forages. Pages 151-171 *in* Proc. MN Nutr. Conf. Bloomington, MN.

Beede, D. 2003. Optimum dietary cation-anion difference for lactating dairy cows. Pages 109-122 *in* Proc. 4-State Applied Nutr. & Mgmt. Conf. LaCrosse, WI.

Chase, L. E. 2003. Update on forage digestibility. Page 25 *in* Proc. 2003 Dealer Seminars. Cornell Univ. Coop. Ext. Anim. Sci. Mimeo Series. No. 223.

Hoffman, P. C. 2003. New developments in analytical evaluation of forages and total mixed rations. Proc. Symposium & Joint Mtg. Of WI Prof. Nutrient Applicators, WI Custom Operators, and WI Forage Council. WI Dells, WI.

Kung, L., and R. Shaver. 2001. How good is your silage making? Hoard's Dairyman. Sept. 25, 2001. pg. 597.

Lundberg, K. L., P. C. Hoffman, L. M. Bauman, and P. Berzaghi. 2004. Prediction of forage energy content by near infrared reflectance spectroscopy and summative equations. Prof. Anim. Sci. In press.

Mertens, D. R. 1987. Predicting intake and digestibility using mathematical models of ruminal function. J. Anim. Sci. 64:1548-1558.

National Research Council. 2001. Nutrient Requirements of Dairy Cattle. 7th rev. ed. Natl. Acad. Sci., Washington, DC.

Nocek, J. E., and J. B. Russell. 1988. Protein and energy as an integrated system. Relationship of ruminal protein and carbohydrate availability to microbial synthesis and milk production. J. Dairy Sci. 71:2070-2107.

Oba, M. and M. S. Allen. 1999. Evaluation of the importance of the digestibility of neutral detergent fiber from forage: effects on dry matter intake and milk yield of dairy cows. J. Dairy Sci. 82:589-596.

Reeves, III, J. B., T. H. Blossser, and V. F. Colenbrander. 1989. Near infrared reflectance spectroscopy for analyzing undried silage. J. Dairy Sci. 72:79-88.

Rohweder, D.A., R. E. Barnes, and Jorgensen, N. 1978. Proposed hay grading standards based on laboratory analysis for evaluating quality. J. Anim. Sci. 47:747-759.

Schwab, E. C., R. D. Shaver. J. G. Lauer, and J. G. Coors. 2003. Estimating silage energy value and milk yield to rank corn hybrids. J. Anim. Feed Sci. Technol. 109:1-18.

Shaver, R. D., D. J. Undersander, E. C. Schwab, P. C. Hoffman, J. G. Lauer, D. K. Combs, and P. C. Hoffman. 2002. Evaluating forage quality for lactating dairy cows. Pages 77-94 *in* Proc. Inter-Mountain Nutr. Conf. Salt. Lake City, UT.

Stone, W. C., L. E. Chase, and T. L. Batchelder. 2003. Corn silage and haylage variability within bunker silos. J. Dairy Sci. (Suppl. 1):168 (abstr.).

Undersander, D. J. 2002. Wisconsin tested hay auctions. http://www.uwex.edu/ces/forage/pubs/auction.htm.

Undersander, D., and J. E. Moore. 2002. Relative forage quality. Univ. of WI Extension Focus on Forage Series. Vol. 4, No. 5. http://www.uwex.edu/ces/crops/uwforage/RFQvsRFV.htm.

Undersander, D.J., W.T. Howard, and R.D. Shaver. 1993. Milk per acre spreadsheet for combining yield and quality into a single term. J. Prod. Ag. 6:231-235.

Table 1. Nutrient composition of selected forages adapted from NRC (2001) table 15-1.

Forage	CP% (SD) {n}	NDF% (SD) {n}	TDN$_{1x}$ %	NFC%
Legumes,				
all hay	20.2 (2.6) {12218}	39.6 (6.3) (12178}	58.9	30.5
all silage	20.0 (3.0) {8576}	45.7 (6.5) {8567}	56.6	23.7
Grasses, cool season,				
all hay	10.6 (3.1) {4702}	64.4 (6.2) {4695}	56.3	19.2
all silage	12.8 (3.7) {4401}	60.7 (7.5) {4390}	55.7	18.6
Coastal Bermuda grass hay	10.4 (2.3) {325}	73.3 (5.1) {41}	52.9	9.5
Barley, silage	12.0 (2.6) {528}	56.3 (7.0) {387}	60.2	22.3
Oat,				
hay	9.1 (2.9) {422}	58.0 (6.3) {419}	55.9	23.5
silage	12.9 (1.6) {634}	60.6 (5.7) {632}	56.8	15.4
Wheat,				
silage	12.0 (3.0) {471}	59.9 (7.4) {471}	57.2	17.8
straw	4.8 (1.9) {161}	73.0 (7.1) {107)	47.5	15.1
Corn silage,				
<25% DM	9.7 (2.2) {70}	54.1 (4.6) {70}	65.6	30.3
32-38% DM	8.8 (1.2) {1033}	45.0 (5.3) {1033}	68.8	40.0
>40% DM	8.5 (3.9) {705}	44.5 (5.9) {705}	65.4	41.1
Grain sorghum silage	9.1 (2.6) {1168}	60.7 (8.2) {864}	56.7	22.2
Sorghum sudan,				
hay	9.4 (2.2) {726}	64.8 (5.2) {717}	54.4	17.6
silage	10.8 (3.2) {140}	63.3 (7.2) {139}	54.4	13.8

Table 2. Variation in NDF and starch content in corn silage samples at Dairyland Laboratories (Arcadia, WI; Dave Taysom personal communication) over one year.

Nutrient	n	Mean	Range
NDF, % of DM	7,889	42	30 – 54
Starch, % of DM	7, 618	28	13 - 43

Table 3. Percentage deviation from minimum analytical result from across the face of nine haylage and eleven corn silage bunkers on nine commercial dairies in New York (Stone et al., 2003).

% Deviation	DM	CP	NDF
Haylage			
Average	21.0	17.6	14.7
Minimum	5.2	3.3	5.4
Maximum	44.7	52.1	24.8
Corn Silage			
Average	12.3	11.0	8.6
Minimum	1.3	2.5	0.5
Maximum	55.0	29.5	18.6

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).

Table 6. Common fermentation end products in various silages. (Kung and Shaver, 2001).

Item	Legume Silage, 30 - 40% DM	Legume Silage, 45 - 55% DM	Grass Silage, 30-35% DM	Corn Silage, 30-40% DM	HM Corn, 70-75% DM
pH	4.3 - 4.7	4.7 - 5.0	4.3 - 4.7	3.7 - 4.2	4.0 - 4.5
Lactic acid, %	7 - 8	2 - 4	6 - 10	4 - 7	0.5 - 2.0
Acetic acid, %	2 - 3	0.5 - 2.0	1 - 3	1 - 3	< 0.5
Propionic acid, %	< 0.5	< 0.1	< 0.1	< 0.1	< 0.1
Butyric acid, %	< 0.5	0	0.5 - 1.0	0	0
Ethanol, %	0.2 - 1.0	0.5	0.5 - 1.0	1 - 3	0.2 - 2.0
Ammonia, % of CP	10 - 15	< 12	8 - 12	5 - 7	< 10

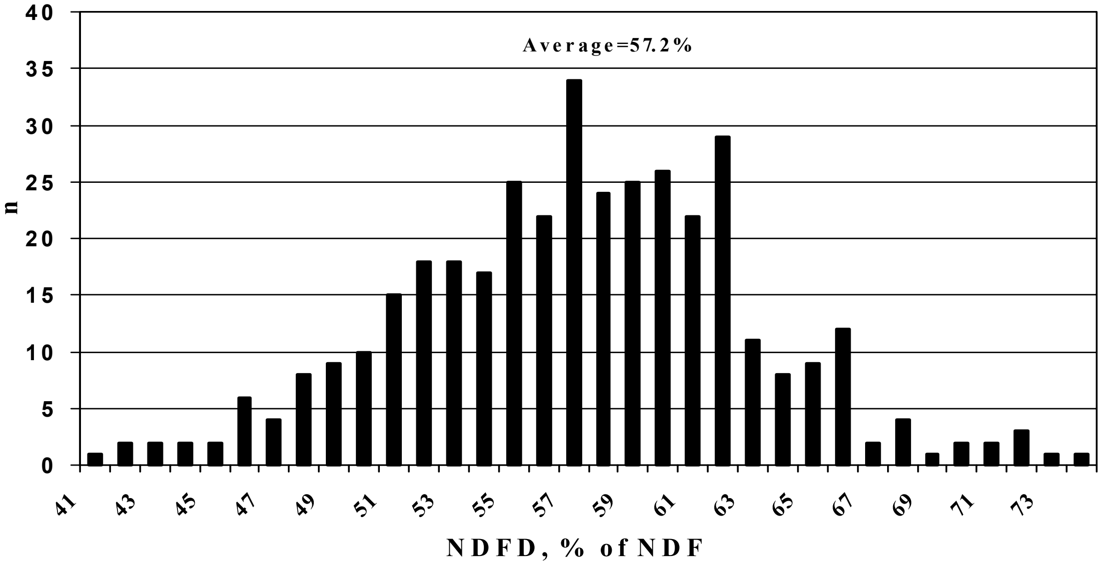

Figure 1. Distribution of 48-h NDFD (% of NDF) in data set of 377 high-group TMR samples from commercial dairies analyzed at UW Soil & Forage Analysis Lab, Marshfield, WI (Hoffman, 2003).

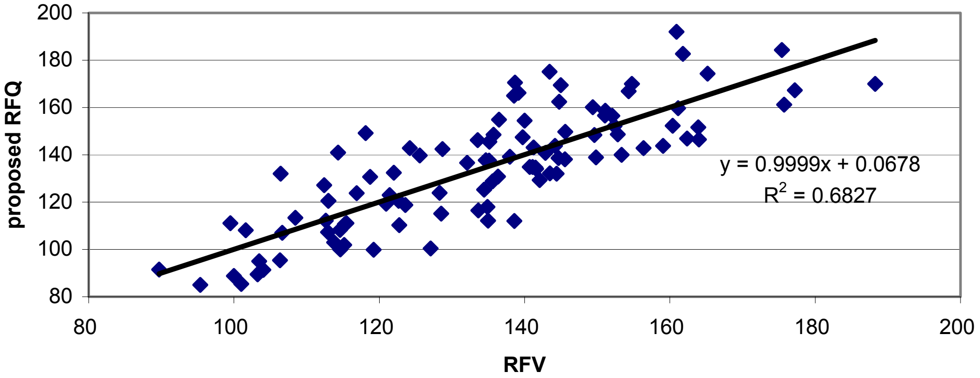

Figure 2. Current RFV versus proposed RFQ (Undersander and Moore, 2002).

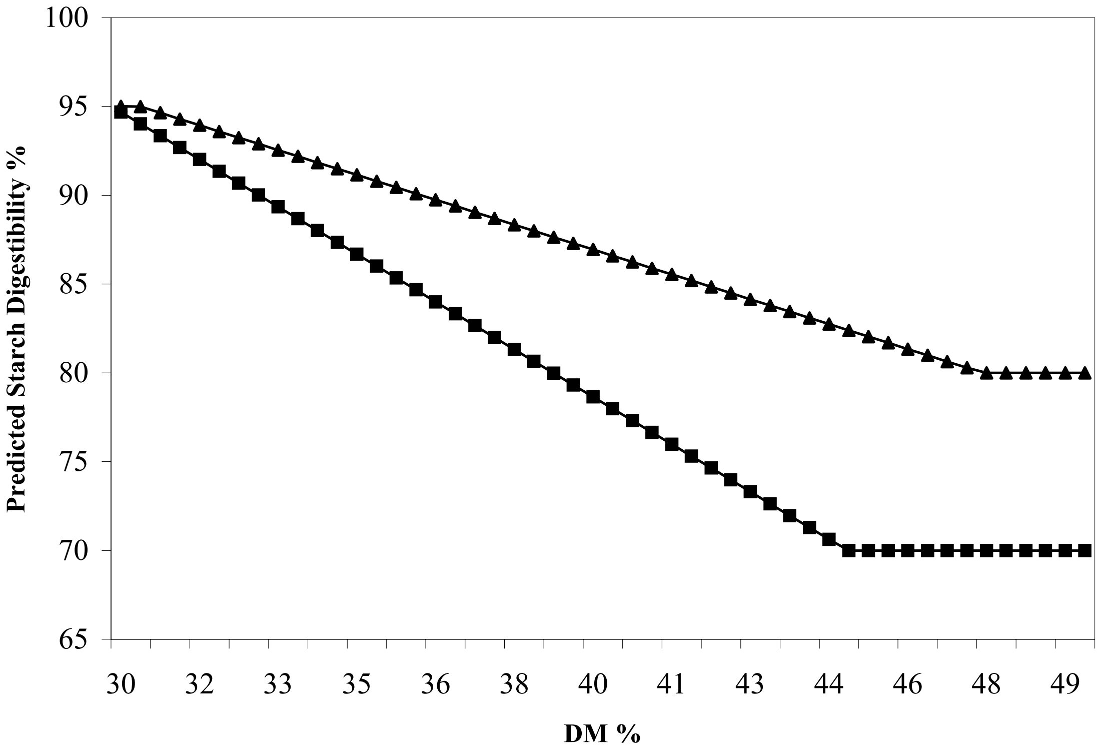

Figure 3. Effect of corn silage dry matter content on predicted apparent total tract starch digestibility. Unprocessed corn silage (■), Y = 144.8 – (1.67x), R^2 = 0.85. Processed corn silage (▲), Y = 121.6 – (0.88x), R^2 = 0.77.