# Replacement of Alfalfa Neutral Detergent Fiber with a Combination of Nonforage Fiber Sources[1]

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## ABSTRACT

Sixteen Holstein cows in midlactation were used in a 4 × 4 Latin square design to determine the effect of replacing alfalfa neutral detergent fiber (NDF), with NDF from a combination of whole linted cottonseed, dried distillers grains, and wheat middlings. The four diets were a basal control diet that was low in forage and fiber [(5.9 g of corn silage NDF and 6.1 g of alfalfa NDF/100 g of dry matter (DM)], a normal forage diet (low forage plus 10 g of additional alfalfa NDF/100 g of DM), and two low forage diets with either 5 or 10 g of NDF from the nonforage fiber sources added per 100 g of DM. Milk yield, milk protein yield, and milk protein percentage were higher, and milk fat percentage and fat yield were lower, for cows fed the low forage diets than for those fed the alfalfa control diet that was higher in fiber. Among the low forage diets, dry matter intake, milk fat percentage, and fat yield all increased linearly as NDF content increased. The ratio of acetate to propionate in the rumen and rumination times were greater for the normal forage control diet than for the high nonforage fiber diet. Added NDF from these nonforage fiber sources increased milk fat percentage and yield, but this increase was less than the NDF from alfalfa and less than predicted. In agreement with results of similar previous trials, milk protein yield and percentage were increased when alfalfa NDF was replaced with fiber from nonforage fiber sources.
(**Key words**: effective fiber, cottonseed, dried distillers grains, wheat middlings)

**Abbreviation key**: **AH** = alfalfa haylage, **CS** = corn silage, **DDG** = dried distillers grains, **HFA** = high fiber alfalfa diet, **HNF** = high nonforage fiber diet, **LNF** = low nonforage fiber diet, **NFFS** = nonforage fiber sources, **WCS** = whole linted cottonseed, **WM** = wheat middlings.

## INTRODUCTION

Dairy cattle require a minimum amount of effective dietary fiber for optimal DMI, milk yield, and health. Effective fiber has been defined as that which stimulates rumination, rate of digesta passage, salivation, ruminal acetate production, and, consequently, milk fat percentage (9). The NRC (11) suggests that lactating dairy cows receive at least one-third of the total dietary DM as long hay or its DM equivalent as medium to coarsely chopped silage or other forage to provide adequate effective fiber. A minimum of 19 to 21% of dietary ADF and 25 to 28% NDF is recommended; 75% of the ration NDF should be supplied as forage. These recommendations provide no adjustments for the physical effectiveness of the fiber, interactions among fiber sources and nonfiber carbohydrates, or animal characteristics that may influence ration design.

Various nonforage fiber sources (**NFFS**)—including whole linted cottonseed (**WCS**), dried distillers grains (**DDG**), and wheat middlings (**WM**)—have been used in the diets of lactating cows to supplement conventional forage fiber during periods of low forage supply or high forage prices. The value of WCS, DDG, and WM fed as replacement protein or oil sources is well documented (4, 5, 6, 8, 18). Until recently, little information was available on the effectiveness of the fiber in these feeds, but the effective fiber values of a number of individual NFFS as replacements for alfalfa haylage (**AH**) fiber have been estimated (7, 10, 12, 15, 17). However, information is limited on the performance of these feeds used in combination in the same diet or used at varying levels.

The purpose of this study was to assess the linearity of the production responses to NFFS fed at graded percentages in the diet. The NFFS mixture consisted of a combination of WCS, DDG, and WM fed in a constant ratio at two dietary percentages.

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TABLE 1. Ingredient composition of diets.

| Feed | Diet[1] | | | |
| --- | --- | --- | --- | --- |
| | Control | LNF | HNF | HFA |
| | (% of DM) | | | |
| Haylage | 18.1 | 18.1 | 18.1 | 48.7 |
| Corn silage | 11.5 | 11.5 | 11.5 | 11.5 |
| High moisture shelled corn | 48.0 | 38.1 | 29.0 | 26.8 |
| Whole cottonseed | 0 | 4.3 | 8.6 | 0 |
| Distillers grains | 0 | 5.1 | 10.2 | 0 |
| Wheat middlings | 0 | 6.8 | 13.6 | 0 |
| Soybean meal | 9.4 | 7.5 | 5.7 | 0 |
| Roasted soybeans | 9.9 | 5.4 | 0 | 10.84 |
| Meat and bone meal | 0.9 | 0.9 | 0.9 | 0.9 |
| Dairy mineral[2] | 0.98 | 0.98 | 0.98 | 0.98 |
| Limestone | 0.94 | 1.04 | 1.14 | 0 |
| Magnesium oxide | 0.19 | 0.19 | 0.19 | 0.19 |
| Vitamin A, D, and E premix[3] | 0.09 | 0.09 | 0.09 | 0.09 |

[1]LNF = Basal control plus low nonforage fiber, HNF = basal control plus high nonforage fiber, and HFA = high alfalfa diet.

[2]Contains 11% Ca, 5% P, 0.6% S, and 50% NaCl.

[3]Contains 6.6 million IU of vitamin A, 2.2 million IU of vitamin D, and 11,000 IU of vitamin E/kg.

## MATERIALS AND METHODS

### Cows and Diets

Sixteen multiparous Holstein cows were used in four replications of a 4 × 4 Latin square design. Cows were blocked by stage of lactation, averaged 108 DIM at the beginning of period 1, and ranged from 47 to 204 DIM. One cow was removed because of chronic traumatic reticuloperitonitis.

Housing consisted of a conventional tie-stall barn; stall mattresses were used to prevent ingestion of bedding. Cows were fed total mixed diets twice daily for ad libitum intake at 0600 and 1700 h and were milked twice daily prior to feeding.

A basal control diet that was low in forage and fiber (Table 1) contained 6% of DM each from AH and corn silage (**CS**) NDF for a total of 12% of DM from forage NDF (Table 2). An alfalfa diet that was higher in forage and fiber (**HFA**) contained 6% of DM from CS NDF and 16% of DM from AH NDF for a total of 22% of DM from forage NDF. The other two diets were the diets low in nonforage fiber (**LNF**) and high in nonforage fiber (**HNF**). These diets contained the basal control plus an additional 5 or 10% of DM as NDF from a combination of WCS, DDG, and WM. The effective NDF values for the NFFS were predicted from data of previous studies (6, 16). The HNF and HFA were designed to contain an equal percentage of DM as effective NDF.

The high moisture shelled corn was coarsely rolled before it was fed. All cows were fed the same adjustment diet containing 6% of DM from CS NDF and 11% of DM from AH NDF for 14 d prior to the start of the 21-d experimental period. All diets were available for ad libitum intake. Cows were switched immediately to a new diet at the beginning of each period. The DMI were recorded on d 16 to 20 of each period. Orts were weighed and sampled for DM and NDF content.

### Sampling and Analysis of Feed, Milk, and Ruminal Fluid

The WCS, DDG, WM, and roasted soybeans were sampled at the beginning of the trial. Other concentrates and AH were sampled weekly and composited at the end of each period. Orts were weighed and sampled on d 16 to 20 of each period and analyzed for DM. The DM was determined by oven-drying at 60°C for 48 h. All feeds were analyzed for NDF, ADF, DM, CP, and total fatty acids (Table 3). Feed samples were ground in a Wiley mill (2-mm screen; Arthur H. Thomas, Philadelphia, PA). Fiber analysis of feed was performed according to the method of Van Soest (17) with the following modifications recommended by D. R. Mertens (1992, personal communication): for all samples, sodium sulfite (0.5 g per sample) was added, and 1205 U of $\alpha$-amylase (A-3306; Sigma Chemical Co., St. Louis, MO) were added at boiling and again prior to filtration. Four acetone washes were used to extract fat prior to the NDF procedure for selected samples (roasted soybeans, WCS, DDG, and meat and bone meal).

The CP was determined by Kjeldahl analysis (2). Ruminally undegradable protein was estimated from NRC (11) values. Total fatty acid percentages were determined by extraction and methylation of fatty acids $C_{14}$ to $C_{18}$, which then were quantified by GLC (13). The particle size of the AH was determined according to standard S424 of the American Society of Agricultural Engineers (1) on thawed, wet AH. Chemical composition of the diet was calculated from analysis of individual feedstuffs (Table 3).

Milk weights were recorded daily. Morning and evening milk samples were collected on d 16 to 20 of each period and analyzed individually for fat and protein by a commercial DHI Laboratory (Wisconsin DHI Cooperative, Menomonie). Daily milk component percentages were calculated as weighted means. Ruminal fluid samples were collected by aspiration of the stomach tube on d 21 of each period once between 1200 and 1400 h. Samples were acidified to pH 2.0 with 50% sulfuric acid and frozen until analysis for VFA (14). Chewing activity was monitored for one continuous 24-h period on d 19 of each period by observation of each cow once per 5 min.

### Statistical Analysis

Data were analyzed by ANOVA using the general linear models procedure of SAS (12). All independent variables were analyzed using a model including the terms: square, cow within square, period, period by square, treatment, and treatment by square. When interaction terms were not significant ($P > 0.10$), they were dropped from the model, and the data were reanalyzed. Least squares means were generated from this model. Within this analysis, the single degree of freedom contrast of HFA versus HNF was tested in addition to the overall treatment effect. Type III sums of squares were used. To analyze for linear and quadratic effects of fiber addition from the NFFS mixture, the data were truncated to the control, LNF, and HNF treatments and assigned values for the variable fiber of 0, 1, and 2, respectively. Statistical analysis was then conducted as just described, but fiber and interactions between fibers for each treatment in which fiber was not a class variable were replaced. Type I sums of squares were used to measure linear and quadratic effects. For all analyses, differences were reported as significant when $P < 0.05$.

## RESULTS AND DISCUSSION

There were no significant interactions except for square by period for DMI, total chewing time per kilogram of DMI, and total chewing time per kilogram of NDF ($P < 0.10$). This last term was retained in the analysis of these variables. Milk yield, milk protein percentage, protein yield, and DMI were higher for cows fed HNF than for cows fed HFA (Table 4). Although the concentration of nonfibrous carbohydrate, estimated as 100% – (CP + NDF + fatty acids), was similar in HNF and HFA, HFA

TABLE 2. Chemical composition of diets.

| | Diet[1] | | | |
|---|---|---|---|---|
| Component | Control | LNF | HNF | HFA |
| DM, % | 63.5 | 64.5 | 65.7 | 56.8 |
| | (% of DM) | | | |
| CP | 17.3 | 17.3 | 17.1 | 18.2 |
| Fatty acids[2] | 4.8 | 5.2 | 5.5 | 4.3 |
| Total NDF | 19.7 | 23.5 | 27.3 | 26.4 |
| From alfalfa | 6.1 | 6.1 | 6.1 | 16.2 |
| From corn silage | 5.9 | 5.9 | 5.9 | 5.9 |
| From NFFS[3] | 0 | 5.7 | 11.3 | 0 |
| ADF | 11.5 | 13.9 | 16.2 | 19.0 |
| ADF From forages | 8.7 | 8.7 | 8.7 | 17.4 |
| RUP | 6.5 | 6.5 | 6.2 | 6.1 |
| $NE_L$,[4] Mcal/kg of DM | 1.84 | 1.82 | 1.81 | 1.73 |
| 100% – (CP + NDF + Fat) | 58.2 | 54.0 | 50.1 | 51.1 |

[1]LNF = Basal control plus low nonforage fiber, HNF = basal control plus high nonforage fiber, and HFA = high alfalfa diet.

[2]Represents sum of $C_{14}$ to $C_{18}$ fatty acids.

[3]The combination of nonforage fiber sources.

[4]Calculated from NRC (11) values for individual feedstuffs.

TABLE 3. Chemical analysis of feeds used in diets.

| Feed | DM | NDF | ADF | CP | Fatty acids[1] |
|---|---|---|---|---|---|
| | Dietary component | | | | |
| | (% of DM) | | | | |
| Haylage[2] | 51.9 | 33.4 | 28.7 | 21.7 | 1.8 |
| Corn silage[3] | 37.1 | 50.9 | 30.1 | 6.2 | 1.9 |
| High moisture shelled corn | 70.7 | 11.8 | 2.7 | 8.8 | 4.2 |
| Cottonseed | 90.7 | 39.3 | 37.6 | 21.0 | 19.2 |
| Distillers grains | 90.6 | 25.6 | 13.3 | 25.4 | 9.3 |
| Wheat middlings | 90.5 | 38.9 | 12.7 | 18.1 | 6.5 |
| Soybean meal | 88.7 | 11.9 | 9.0 | 45.3 | 3.2 |
| Roasted soybeans | 95.8 | 10.7 | 7.5 | 38.2 | 18.4 |
| Meat and bone meal | 96.5 | 0.0 | 0.0 | 51.0 | 10.0 |

[1]Represents sum of $C_{14}$ to $C_{18}$ fatty acids.

[2]Mean particle length was 7.6 mm.

[3]Mean particle length was 7.7 mm.

provided less fermentable energy and less total energy because of lower energy density and lower DMI. These factors, plus the lower intake of RUP, could have contributed to the lower milk yield and protein secretion. Yield of FCM was not different among cows fed the four diets. The DMI increased linearly as additional NFFS was added to the control in LNF and HNF.

The ability of the NDF in WCS to stimulate chewing fluctuates with variation in the particle size of the AH it replaces (10). Although the AH particle size used in the current study (Table 3) was similar to that used in our earlier trials, the NDF concentration of the AH (Table 3) was considerably lower than that of previous trials because of unusually cool preharvest weather. Effective NDF replacement values for NFFS may vary with changing forage chop length and fiber level or composition. As the mean particle length or NDF content of the forage increases, ruminal retention time and the forage mat effect increases, which may slow the passage rate of NFFS, thus enhancing fiber digestibility. The milk fat percentage and fat

TABLE 4. Milk yield and composition, DMI, and chewing activity.

| Production variable | Diet[1] | | | | | Effect | |
|---|---|---|---|---|---|---|---|
| | Control | LNF | HNF | HFA | SE | TRT[2] | HFA vs. HNF |
| | | | | | | *P* | |
| Milk, kg/d | 33.7 | 34.1 | 33.0 | 30.4 | 0.5 | ** | ** |
| 4% FCM, kg/d | 27.4 | 28.4 | 29.0 | 28.4 | 0.1 | NS[3] | NS |
| Protein, kg/d | 1.09 | 1.10 | 1.09 | 0.93 | 0.02 | ** | ** |
| Fat,[4] kg/d | 0.93 | 0.99 | 1.05 | 1.08 | 0.04 | * | NS |
| Protein, % | 3.24 | 3.21 | 3.28 | 3.09 | 0.02 | ** | ** |
| Fat,[4] % | 2.75 | 2.93 | 3.21 | 3.55 | 0.09 | ** | ** |
| DMI,[4] kg | 20.8 | 22.4 | 23.4 | 21.5 | 0.7 | * | * |
| | (min/d) | | | | | | |
| Chewing activity | | | | | | | |
| Ruminating | 375 | 404 | 400 | 460 | 14 | ** | ** |
| Eating | 246 | 253 | 244 | 320 | 10 | ** | ** |
| Total chewing | 621 | 657 | 644 | 780 | 19 | ** | ** |
| Total chewing/kg of DMI | 31.3 | 29.7 | 28.0 | 36.9 | 1.3 | ** | ** |
| Total chewing/kg of NDF[4] | 157.3 | 126.6 | 106.4 | 135.3 | 6.2 | ** | ** |

[1]LNF = Basal control plus low nonforage fiber, HNF = basal control plus high nonforage fiber, and HFA = high alfalfa diet.

[2]Overall treatment effect.

[3]$P \geq 0.05$.

[4]Significant linear effect of NDF from nonforage fiber sources ($P < 0.05$).

*$P < 0.05$.

**$P \leq 0.01$.

yield for cows fed the control diet, LNF, and HNF increased linearly as additional NFFS was added (Table 4), suggesting that the effectiveness of the NFFS was constant.

Although the incremental addition of NFFS to the control diet increased milk fat percentage, ruminal VFA ratios did not change (Table 5). Response of ruminal VFA to the addition of alfalfa fiber in the HFA followed a normal pattern of increased acetate and decreased propionate. The apparently poor correlation of milk fat percentage with ruminal VFA patterns when dietary fiber is elevated with NFFS has been noted in previous trials (7, 16, 18).

Time spent eating and ruminating is a measure of the physically effective fiber value of NFFS (3, 10, 12). Ruminating and eating times were higher for cows fed HFA and did not differ among cows fed the other three diets (Table 4). A linear decrease in total chewing time per kilogram of NDF occurred as NFFS content of the diet increased. Although WCS appeared to stimulate rumination when used as the sole source of NFFS in a previous trial (7), the level of WCS in the current study was considerably lower. These results confirm earlier findings (7, 16, 18) that most NFFS appeared to be poor stimulators of chewing.

Milk fat percentage was lower for cows fed HNF than for cows fed HFA. The NFFS combination did not support milk fat percentage as well as expected from previous studies with individual NFFS (7, 18). Effectiveness of the NDF in the NFFS mixture was determined as in the study by Clark and Armentano (7). Slope for the change in milk fat percentage per added unit of NDF from NFFS was determined by linear regression of the three mean fat percentages from the control diet, LNF, and HNF. The slope of this line was 0.043, and $r^2 = 0.97$. The response to added NDF from the mixed NFFS was clearly linear over this range, supporting the use of a single NDF effectiveness factor. The slope for alfalfa NDF was determined by the change in milk fat percentage between cows fed the control diet and cows fed HFA, divided by the added units of NDF from alfalfa [$(3.55 - 2.75) \div 10.1 = 0.079$]. A slope ratio or NDF effectiveness factor for the NFFS mixture can be calculated as 0.043/0.079 = 0.54. This value is low compared with the predicted value of 0.84. The predicted value was calculated using NDF effectiveness factors of 1.30, 1.0, and 0.57 for WCS, DDG, and WM, respectively, from previous studies (7, 18).

The reasons for the discrepancy between predicted and actual effectiveness values for the NFFS mixture are unclear. The unusually low NDF content of the AH in this study may have resulted in a faster ruminal rate of passage for both the AH and NFFS, reducing the effectiveness of NFFS as fiber sources. A major limitation of the slope ratio approach is the lack of a truly standard fiber source that is also relevant to dairy producers. Another limitation is the likely change in the nature of dietary nonstructural carbohydrate as different fiber sources are used. However, the advantage of the slope ratio method is that it reduces the variation among experiments; because differences in slope ratio cannot be attributed to reducing the nonstructural carbohydrate content of the diet, they are more likely to reflect some attribute of the fiber. Milk fat percentage among cows fed each diet was also less consistent than originally designed (Table 4). The influence of this variation on milk fat

TABLE 5. Ruminal VFA.

| | Diet[1] | | | | | Effect | |
|---|---|---|---|---|---|---|---|
| VFA | Control | LNF | HNF | HFA | SE | TRT[2] | HFA vs. HNF |
| | (mol/100 mol) | | | | | *P* | |
| Acetate (A) | 57.5 | 55.5 | 54.7 | 62.2 | 1.4 | ** | ** |
| Propionate (P) | 27.4 | 29.6 | 29.6 | 21.5 | 1.5 | ** | ** |
| Butyrate | 10.5 | 10.5 | 11.5 | 11.3 | 0.35 | NS[3] | NS |
| Isobutyrate | 0.9 | 1.1 | 0.8 | 1.0 | 0.13 | NS | * |
| Valerate | 1.5 | 1.5 | 1.5 | 1.5 | 0.14 | NS | NS |
| Isovalerate | 1.9 | 1.8 | 1.7 | 2.0 | 0.14 | NS | NS |
| A:P | 2.2 | 1.9 | 1.9 | 3.0 | 0.15 | ** | ** |

[1]LNF = Basal control plus low nonforage fiber, HNF = basal control plus high nonforage fiber, and HFA = high alfalfa diet.

[2]Overall treatment effect.

[3]$P \geq 0.05$.

*$P < 0.05$.

**$P \leq 0.01$.

percentage and milk yield is unknown. Unknown interactions among NFFS and other dietary ingredients may occur in the rumen when combinations of NFFS are used.

To estimate the variability of estimates of NDF effectiveness, data on milk fat percentage from each square were analyzed separately to calculate four independent slope ratios. The mean NDF effectiveness in this case was 0.57, the standard deviation was 0.32, and the corresponding standard error was 0.16. This measurement of the variability of NDF effectiveness factors is a best case scenario, because the alfalfa and other feedstuffs used, as well as other potentially interacting environmental factors, were all kept constant. Also, the wide variation in milk fat percentage between the control and HFA in the present trial makes this trial more sensitive for determining NDF effectiveness than some previous trials (7).

## CONCLUSIONS

Our goal was to test a method used to evaluate the fiber value of NFFS in dairy rations. To measure effective fiber accurately and apply this measurement to practical use, it is important that the response to NDF be linear. Another important component is that estimates of effective fiber be repeatable. It is clear from these results that fiber effectiveness estimates based on milk fat percentage response were not highly repeatable, partly because of the inherent low precision of a bioassay in large animals and partly because of feed characteristics of the standard forage, the NFFS feeds, and the other dietary components. However, it is equally clear that there was a response to fiber provided from NFFS and that this response was linear over the range tested. Also, a positive response is at least qualitatively consistent across trials. These fiber sources caused production changes, even though they did not increase chewing activity or alter VFA patterns. Maximum productivity in terms of milk protein and fat production were obtained by feeding lower forage diets supplemented with NFFS. Therefore, assessment of the response to fiber from the milk fat percentage, although clearly only semiquantitative at best, provided the best predictor of short-term performance in the case of this mixture of NFFS.

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