Influence of intake, NDF source and ruminal pH on in situ fiber disappear

M. Basalan, E. Polat, and F. N. Owens

Story in Brief

To measure the impact of ruminal pH on in situ disappearance of fiber, three ruminally cannulated heifers (387.5 kg) in a 3 by 3 Latin square experiment were fed a single diet, consisting of 90% concentrate based on ground corn grain, at three different levels of intake (1% and 1.5% of body weight daily or free choice) in an attempt to obtain different ruminal pH values. NDF from three different fiber sources (alfalfa hay, prairie hay and wheat straw) were placed in dacron bags and incubated in situ for 0, 6, 12, 24, or 96 h. NDF disappearance at 96 h ranged from 14 to 33%, being greater ($P < .05$) with wheat straw than with alfalfa hay. Rate of disappearance of hemicellulose and ADF, expressed as a fraction of that disappearing at 96 h were quadratically related to pH with disappearance being minimum at pH of 5.9 and 5.4 respectively. Stepwise regression revealed that when ruminal pH was below pH of 5.2 to 5.6, depending on the source of fiber, pH had no impact on disappearance of either hemicellulose or ADF. However, above this pH, disappearance of hemicellulose and ADF increased quadratically with alfalfa hay but not with prairie hay or wheat straw. Results indicate that rate and extent of fermentation differ with fiber source and that low ruminal pH inhibits disappearance of NDF from alfalfa hay in a curvilinear fashion rather than abruptly at a pH of 6.0.

Key words: NDF, hemicellulose, fermentation.

Introduction

Grains form majority of diets for feedlot cattle so that gain and economic efficiency can be maximized. However, the amount and quality of forage included in such diets can impact productivity. A fiber deficiency can result in various metabolic disorders, including rumenitis, acidosis, and liver abscesses (Marshall et al. 1992). The NRC for Dairy Cattle (1989) suggested that diets should contain a minimum of 25 to 28% NDF of which 75% should come from forage sources based on research by Clark et al. (1997) and Beauchemin (1991). Mertens (1997) also recommended that optimal dietary NDF intake 1.1% of body weight in dairy cows that, with an intake at 4% of body weight daily, equates to 27.5% of diet dry matter. Cereal grains, being rich in non-structural carbohydrates, particularly starch, are rapidly fermented in rumen. When fed as the majority of the diet, starch can drive ruminal pH below 5.5, a pH level where rate of fiber digestion is depressed. Low ruminal pH has been proposed to explain why adding grain to foraged diet will decrease feed intake and why forage digestibility is low in concentrate-rich diets (Caton and Dhuyvetter 1997). Mertens (1997) reported that forage fiber digestion starts to decline whenever ruminal pH falls below 6.7. Compared to species that digest starch, ruminal bacteria that digest cellulose are quite sensitive to and inhibited by low rumen pH (Hoover 1986). Russell (1979) indicated that the population of cellulolytic bacteria in the rumen decreases when pH falls below 5.7 while amylolytic bacteria survive when pH falls below 5.0 (Russell 1979). Decreased cellulase activity and microbial attachment, as well as production of inhibitors by starch digesting bacteria may all contribute to diminished cellulolysis at a low pH (Poore et al. 1987). Bourquin et al. (1994) suggested further that cellulolytic microbes also may switch from digesting cell walls to digested readily fermented carbohydrates when pH is low. Grant and Mertens (1992) suggested that the optimal pH for rumen microbes (cellulolytic) is between 6.5 and 6.8. They postulated that decreasing pH from 6.8 to 5.8 increases lag time, the period of time from the start of incubation until digestion begins, and decreases rate of NDF digestion based on in vitro studies where pH was adjusted by adding base or acid. In vivo, the ruminal pH will fluctuate between meals and microbes have a time period to adapt to their environment. Consequently, in vivo digestion cannot be directly predicted from in vitro estimates. Response to low pH also may differ with feedstuff type, as fiber sources differ in nutrient content and in fiber composition (ADF, hemicellulose, lignin).

The objective of this study was to determine the degree to which low ruminal pH will depress rate and extent of in situ disappearance of NDF, ADF, and hemicellulose from several widely fed roughage sources.

Materials and Methods

Animals: Three continental crossbreed heifers (mean weight 388 kg) approximately 3 y of age were assigned randomly to a 3X3 Latin square. Heifers were ruminally fistulated and individually penned at the OSU Nutrition and Physiology Center.

Diet: Prepared by OSU Feedmill, the diet consisted of 90% concentrate and 10% roughage (Table 1) based largely on ground corn grain. Concentrate content of the diet was high so that ruminal pH would be depressed. Heifers were randomly assigned to be fed different amounts of feed in each period of the Latin square. Rather than altering the diet to influence ruminal pH, we fed a single diet at different levels of intake, in an attempt to remove the impact of diet composition on the microbial population in the rumen. The three intake levels were ad libitum (free choice) or restriction to 1.5% or 1% of body weight daily. Animals given ad libitum access to feed were slightly restricted (fed at the peak level consumed during the 14 d adaptation period) in order to avoid metabolic disorders and refusal of feed during the in situ measurement period. Heifers were fed 3 times each day (0800, 1600 and 2400) to reduce fluctuations in ruminal pH. Heifers were adapted to their intake level for the first 14 d of each period. Animals had free access to the water throughout the experiment.

TABLE 1. Composition of diet fed to heifers in experiment I, DM

Ingredient	Percentage
Rolled Corn	70.00
Ground alfalfa hay	17.50
Cottonseed hulls	10.87
Cane molasses	1.50
Trace mineralized salt	0.12

Procedure and Analysis. Two forage samples (alfalfa hay and prairie hay) were obtained from 3 feedlots located in the Oklahoma Panhandle on September 1st, 1997. Wheat straw was obtained from OSU Equine Center. These feeds were chopped to mean length of 1 in. Approximately 2.0 g of each sample were placed in separate 6.35 X 13.70 cm dacron bags and heat-sealed. Bags containing samples were dried at 55C for 24 h. NDF content of each feed was analyzed before bags were placed in the rumen. Neutral detergent solubles were removed before the bags were incubated in the rumen. Fiber analysis were conducted using an Ankom200 (Ankom, Turk Hill St. NY). Duplicate dacron bags containing each of the three feedstuffs were placed in the rumen and allowed to ferment for 96, 24, 12, 6 and 0 h. To eliminate variability in dacron bag rinsing procedures, bags were inserted at 4 different times and retrieved at a single time (0900) that corresponded to 1 h after the previous meal. The 0 h bags were rinsed en mass with bags retrieved from the rumen. Dacron bags inserted at each time were combined into a single large net laundry bag to ensure that ruminal location would be similar for all bags within a time period and simplify recovery of the bags. All bags were rinsed at 39C under running tap water and placed in buckets. Water in each bucket was agitated by hand and changed at 5 min intervals over a 60 min period. Then, each individual bag was rinsed under a stream of running tap water for another minute. After drying at 55C for 48 h, bags were weight and bags containing all samples were re-extracted with neutral detergent solution. After drying and re-weighing to determine residual NDF, bags containing samples were extracted with acid detergent solution to determine ADF content again using the Ankom200. Ruminal pH was recorded every 4th h and rumen fluid was obtained, filtered through four layer of cheesecloth, and frozen for subsequent analysis for ammonia N content.

Data were analyzed using the SAS GLM procedure by regressing disappearance of NDF, ADF, and hemicellulose (NDF minus ADF) for individual times against mean ruminal pH for the animal during the incubation period. Disappearance of NDF for individual feeds was regressed against incubation time to examine differences among feeds. Disappearance rate for NDF expressed as a percentage of fermentable NDF (disappearance at 96 h minus disappearance at 0 h) was calculated by regression of the natural log of residual fermentable NDF against time either including or excluding zero values for disappearance at 0 h. Including values gives an estimate of NDF disappearance assuming that time lag prior to the onset of NDF disappearance was nil whereas regressions based on 6h, 12 h, and 24 h values permit lag to occur prior to the onset of NDF digestion. NDF disappearance rates were regressed against ruminal pH and ruminal pH squared in an attempt to determine the slope of the relationship between NDF disappearance and pH.

Results and Discussion

Components of fiber in the three feedstuffs incubated in situ are presented in Table 2. Alfalfa hay had less NDF and ADF than prairie hay or wheat straw. Ruminal pH values as well as extent of NDF, ADF, and hemicellulose disappearance after various incubation times averaged across feed intake levels and across feedstuffs are presented in Table 3. Surprisingly, pH was not significantly altered by level of feed intake as expected. Consequently, effects of intake level on disappearance should be independent of ruminal pH.

TABLE 2. NDF, ADF and hemicellulose contents of feeds (% DM).

Feed	Neutral detergent fiber (NDF)	Acid detergent fiber (ADF)	Hemicellulose[1]	Hemicellulose (% of NDF)

Alfalfa Hay	51.8	40.7	11.1	21.4
Prairie Hay	73.3	46.2	27.1	37.0
Wheat Straw	75.9	46.6	29.3	38.6
[1]Hemicellulose = NDF(%) – ADF(%)				

Extent of disappearance was greater with the highest than the lowest intake level for NDF at 6, 12, and 96 h of incubation. ADF and hemicellulose disappearance paralleled NDF disappearance. When level of grain in the diet is increased, rate of fiber digestion usually declines (Mould and Orskov, 1983, and Grant 1994), however such a response may be due to a decrease in ruminal pH. In vitro, addition of starch also decrease rate of fiber digestion (Mould and Orskov, 1983, and Miron et al., 1990), but in this trial, diet composition and thereby the substrates available for fermentation and pH were not altered by intake level. Through increasing the rate that microbes are forced to multiply in the rumen, the faster ruminal turnover with higher feed intakes may have increased activity of resident microbes though no published literature to support this concept is available.

With the exception of 96 h, disappearance at all hours was greater for alfalfa hay than for prairie hay and wheat straw (Table 3). This was partly due to greater washout at 0 h for alfalfa hay than for other feeds. At 96 h, disappearance of wheat straw NDF was greater than for the other two feeds. If disappearance at 96 h is used as an index of potential extent of fiber digestion, wheat straw had greater potential NDF, ADF, and hemicellulose disappearance than either prairie or alfalfa hay.

In all cases, disappearance of fermentable NDF, ADF, and hemicellulose increased as ruminal pH increased though the level of significance was consistently greater for ADF than for NDF or hemicellulose. Among the feeds tested, only alfalfa hay had a regression against pH that was significant for NDF and for hemicellulose disappearance. These results support the general concept (Grant and Mertens 1992) that fiber digestion rate is depressed when pH is decreased. Linear and quadratic effects of pH on NDF disappearance from various feeds are shown in Figure 1. In all cases, disappearance decreased in a curvilinear fashion though significance of these relationships differed with feed, only being significant for alfalfa hay. At a pH of 5.2, disappearance of NDF was similar for all feeds, but as pH was increased, NDF disappearance increased markedly only for alfalfa hay. This supports the contention that response to ruminal pH differs with specific feed being measured. In this case, the feed with the highest potential rate of NDF disappearance was altered most by pH depression.

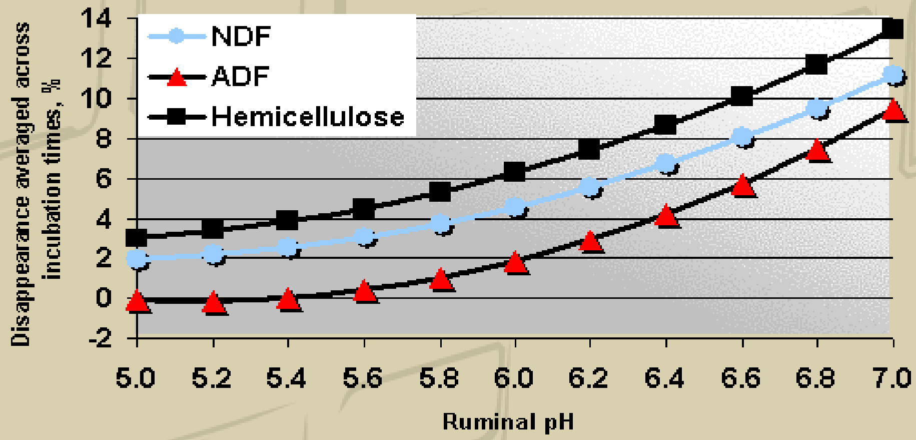

Figure 1. Mean disappearance of neutral detergent fiber, acid detergent fiber and hemicellulose disappearance from alfalfa hay, prairie hay, and wheat straw regressed against mean ruminal pH.

For dilution of the diet and ruminal contents, high NDF level should be preferable. A slow rate of ruminal disappearance has advantages and disadvantages. Slow ruminal disappearance will help retain both dilution and "scratch factor" in the rumen for hours after a meal. Consequently, less NDF needs to be fed. With high roughage diets, a slow rate of ruminal disappearance will increase ruminal bulk and may reduce feed intake, but with the low roughage diets fed to feedlot cattle, excessive bulk should not be a problem. One adverse effect of slow ruminal disappearance is that more undigested fiber must be pushed through the small and large intestines. If ruminal pH is constant, NDF disappearance rate will be constant and the rumen will be in steady state conditions. However, ruminal pH is not constant. If ruminal pH fluctuates during the day, rate of NDF disappearance will vary. As ruminal pH increases with time after a meal or fasting, VFA supply from the fiber source will be increase and residual NDF will decrease both from ruminal outflow and fermentation. Hence, pH dependence of NDF fermentation will enhance steady state conditions for VFA production but will decrease steady state of ruminal mass and NDF concentration in the ruminal mass. Such fluctuations in ruminal mass and delayed production of VFA might be expected to decrease meal frequency and increase variability in meal size, a condition conducive to both feedlot bloat and acidosis. A roughage ideal for high roughage diets, where ruminal pH is high and relatively constant may not be ideal for maintaining steady state ruminal conditions and regular meal size for feedlot cattle.

Results from this research support the idea that fiber fractions as well as different feeds may respond differently with decreased pH. Xu and Harrison (1996) indicated that fiber fractions were not correlated with NDF degradation. Grant (1994) also noted that the response to lowering pH in vitro was different for alfalfa hay than for bromegrass hay. In contrast to our results, Poore et al. (1991) reported that degradable NDF digestion from wheat straw was less than from an alfalfa based diet (Poore et al. 1991). In comparison to disappearance of NDF in vitro at pH values near neutral by Grant and Mertens (1992), our disappearance values and rates are quite low. This may be due to the lower pH of ruminal contents than in ruminal fluid used in their in vitro studies.

High grain diets in feedlot usually drive the ruminal pH below 6.0. Considering the steady increase in NDF digestion between the pH of 5.0 and 6.0, elevating the pH may be beneficial for feeding strategies. Low quality forage sources such as wheat straw and prairie hay may be better option for limited forage addition in feedlots, if the economics and purpose of adding roughage is well defined.

Table 3. Impact of intake level and feed source on in situ disappearance of fiber fractions.

	Intake level, %BW/d						Feed						
	1.0		1.5		2.0		Alfalfa hay		Prairie hay		Wheat straw		SEm
Ruminal pH	5.5		5.8		5.5								
NDF disappearance													
0 h	5.3		5.2		5.2		9.9	a	3.5	b	2.4	c	0.323
6 h	8.5	b	9.5	ab	10.3	a	14.8	a	5.8	b	7.7	c	0.541
12 h	9.9	b	10.9	ab	12.2	a	15.0	a	7.0	c	11.0	b	0.496
24 h	14.5		14.5		14.4		17.2	a	10.5	b	15.7	a	0.791
96 h	26.1	b	27.2	b	31.0	a	27.9	b	25.1	b	31.3	a	1.373
ADF disappearance													
0 h	-1.0		-0.8		1.2		-0.6		0.0		0.0		0.977
6 h	-2.6	b	1.4	ab	2.7	a	-2.7	a	2.8	b	1.3	ab	1.610
12 h	0.7		1.7		2.4		-3.1	a	3.0	b	5.0	b	1.696
24 h	5.7		4.5		5.4		0.3	b	6.1	a	9.3	a	1.598
96 h	15.6	b	16.2	b	21.7	a	11.6	b	19.8	b	22.1	a	1.664
Hemicellulose disappearance													
0 h	-5.7		-5.6		-5.5		-10.9	a	-0.6	b	-2.6	b	0.677
6 h	0.4		2.3		3.2		-0.6	a	0.5	a	6.0	b	1.192
12 h	2.8	b	4.0	ab	6.4	b	-0.3	a	2.4	a	11.1	b	0.955
24 h	10.0		9.7		9.8		4.0	c	7.7	b	17.8	a	1.196
96 h	27.6	b	30.0	b	33.9	a	24.3	b	28.2	b	38.6	a	1.616

[a, b] Means with different superscripts differ ($P < 0.05$).

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