Effects of Dietary Forage Source and Amount of Forage Addition on Intake, Milk Yield, and Digestion for Lactating Dairy Cows

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ABSTRACT

Lactating cows were used to determine the effects of increasing forage content from alfalfa (*Medicago sativa* L.) hay or Tifton 85 bermudagrass (*Cynodon* sp.) hay on dry matter intake (DMI), milk yield, and nutrient digestion. Forage proportions and neutral detergent fiber (NDF) content of diets were (dry basis) 1) 45% corn (*Zea mays* L.) silage (control), 33.5% NDF; 2) 15% bermudagrass hay and 30% corn silage, 39.5% NDF; 3) 30% bermudagrass hay and 15% corn silage, 46.6% NDF; 4) 15% alfalfa hay and 30% corn silage, 35.5% NDF; or 5) 30% alfalfa hay and 15% corn silage, 33.5% NDF. The DMI was greater with alfalfa diets than with bermudagrass diets, with low hay diets than with high hay diets, and with the control diet than with the hay diets. Digestibility of NDF in bermudagrass diets was greater than that in alfalfa diets, in high hay diets than in low hay diets, and in hay diets than in the control diet. In vitro NDF digestion was most rapid for bermudagrass hay, intermediate for corn silage, and slowest for alfalfa hay. Results suggest that NDF from bermudagrass was digested more completely and rapidly than was NDF from corn silage or alfalfa, which improved the rate of passage despite the high NDF content of diets containing bermudagrass. Milk yield followed trends for DMI. The control diet and diets containing alfalfa elicited the greatest DMI and milk yield, but DMI per 100 kg of body weight for Holsteins was equal for diets containing either bermudagrass or alfalfa. High quality bermudagrass can be used in rations for lactating dairy cows.
(**Key words**: forage, intake, neutral detergent fiber, lactation)

Abbreviation key: **AHD** = alfalfa hay diets, **BHD** = bermudagrass hay diets, **HHD** = high hay diets, **LHD** = low hay diets, **NDFI%** = NDF intake as a percentage of BW, **SP** = standardization period, **TP** = treatment period.

INTRODUCTION

Diets containing large quantities of forages can alter feed DMI because of the amount of fiber present, the digestibility of the fiber, and the passage rate of undigested residues from the digestive tract. Differences in the extent and rate of digestion exist for different forage species. Mertens and Ely (13) reported that the primary differences between alfalfa and Coastal bermudagrass were in NDF, lignin contents, and the proportion of NDF that is slowly digested. Although alfalfa contained less NDF than did Coastal bermudagrass, the NDF in alfalfa was more lignified than the NDF in Coastal bermudagrass, and the NDF in Coastal bermudagrass, on a percentage basis, had a larger rapidly digestible fraction, a larger slowly digestible fraction, and a smaller indigestible fraction than did the NDF in alfalfa. Van Soest (21) suggested that cell-wall constituents limit intake when the proportion of these constituents increases to more than 55 to 60% of the DM; thus, intake becomes increasingly restricted because of the volume occupied by the fibrous mass. Mertens (10) reported lower FCM yield for cows fed diets containing Coastal bermudagrass hay than for cows fed diets based on corn silage or alfalfa, despite similar dietary NDF contents. Changes in FCM corresponded to differences in DMI across diets, suggesting that factors other than dietary NDF influenced DMI and milk yield. Waldo (22) proposed that greater intake of legumes than grasses at equal digestibilities resulted from the smaller volume occupied by legumes in the gastrointestinal tract per unit of DMI.

Improved bermudagrasses are well adapted to broad regions of the South. Typically, bermudagrass is high in NDF, which may limit DMI, and ber-

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TABLE 1. Composition of the diets.[1]

	Diet[2]				
		BHD		AHD	
Composition	Control	LHD	HHD	LHD	HHD
	(% of diet)				
Ingredient					
Ground corn	23.7	27.1	30.4	27.1	30.4
Soybean meal (48% CP)	10.4	7.1	3.8	7.1	3.8
Animal protein source[3]	4.1	4.1	4.1	4.1	4.1
Mineral premix[4]	1.0	1.0	1.0	1.0	1.0
Calcium carbonate	0.8	0.7	0.5	0.7	0.5
Dicalcium phosphate	0.7	0.7	0.9	0.7	0.9
Salt	0.5	0.5	0.5	0.5	0.5
Whole cottonseed	13.8	13.8	13.8	13.8	13.8
Corn silage	45	30	15	30	15
Bermudagrass hay	...	15	30	...	...
Alfalfa hay	...	...	...	15	30
Chemical					
DM, %	59.1	63.1	73.5	63.4	73.7
CP, % of DM	19.4	18.7	18.5	18.6	18.5
ADF, % of DM	17.9	20.3	22.8	21.0	20.5
NDF, % of DM	33.5	39.5	46.6	35.5	33.5

[1]Dry basis.

[2]BHD = Bermudagrass hay diet, AHD = alfalfa hay diet, LHD = low (15%) hay diet, and HHD = high (30% hay) diet.

[3]Approximately 70% CP and 7.5% fat, containing meat and bone meal, hydrolyzed feather meal, poultry by-product meal, flash-dried blood meal, fish meal, and animal fat.

[4]Contained 0.7% Ca, 12.37% Mg, 0.28% P, 8.4% K, 10% S, 34 mg/kg of Co, 870 mg/kg of Cu, 104 mg/kg of I, 4880 mg/kg of Fe, 2749 mg/kg of Mn, 30 mg/kg of Se, 6110 mg/kg of Zn, 780,377 USP units of vitamin A/kg, 99,200 USP units of vitamin D/kg, and 2220 IU of vitamin E/kg.

mudagrass generally has a low NE_L content. However, improved varieties of bermudagrasses may be of sufficient quality to be used in dairy rations. In two small plot tests (7), in vitro DM digestibilities of Tifton 85 bermudagrass were 11 and 14.1% higher than those of Coastal bermudagrass (60.3% vs. 54.3% and 57.3% vs. 50.2%). Forage yields were also greater for the Tifton 85 bermudagrass. Selection for higher quality may result in bermudagrass that provides sufficient nutrients to maintain milk yield of lactating dairy cows. Higher quality bermudagrasses are also adapted for forage production in hot, humid climates.

The objective of this work was to determine the effects of dietary forage sources and amounts of forage addition on the DMI, milk yield, digestibility of dietary nutrients, and passage rates of digesta in lactating dairy cows.

MATERIALS AND METHODS

Forty lactating dairy cows (20 Holstein and 20 Jersey) averaging 49 DIM were selected for the study. Cows were housed in shaded concrete lots with access to individual free stalls and individual electronic feeding gates (American Calan, Inc., Northwood, NH) and were adapted to the experimental area and the control diet. The cows were trained to use the electronic feeding gates during a 14-d training period. Cows were fed for approximately 10% orts daily; the diets, provided as TMR, were adjusted daily based on as-fed feed intake during the previous day. During a 14-d standardization period (**SP**), all cows received the control diet (Table 1). Cows were ranked within breed by DMI (kilograms) per 100 kg of BW during the SP and were blocked by rank into eight blocks of 5 cows for random assignment to one of five experimental treatments within the block. In addition, the performance data that were collected during the SP were used for covariate analysis of data from the treatment period (**TP**). Following the SP, cows were allowed to adapt to the experimental treatments for 7 d. During adaptation, cows were fed for ad libitum intake. No data from the 7-d adaptation period were used in statistical analysis. A 42-d TP followed adaptation, during which the experimental data were collected.

Diets and Experimental Treatments

Experimental treatments were 1) control (no hay), 2) low bermudagrass hay, 3) high bermudagrass hay, 4) low alfalfa hay, and 5) high alfalfa hay. Low hay diets (**LHD**) contained 15% hay (percentage of DM) that was substituted for an equal amount of corn silage DM, and high hay diets (**HHD**) contained 30% hay (percentage of DM) that was substituted similarly for corn silage (Table 1). The ratio of forage to concentrate did not change. Dietary components were adjusted weekly based on the DM content of individual feedstuffs, which was determined by drying the components to a constant weight in a forced-air oven at 60°C. Dietary ingredients and chemical composition are presented in Table 1.

Tifton 85 bermudagrass, established 2 yr prior to use in this work, was produced on a Tifton sandy loam soil. The bermudagrass received 113 kg of a 24-6-12 mixture of N, P_2O_5, and K_2O, respectively, on March 3 and again on July 7 prior to the harvest for the present experiment, which occurred on July 23 following 25 d of regrowth from the previous cutting. Chemical analyses of diets (Table 1) and of forages (Table 2) are reported. The bermudagrass variety (*Cynodon* sp.) was Tifton 85, a recently released hybrid with superior yield and digestion characteristics (1, 7). The alfalfa hay (*Medicago sativa* L.) used in this study was a western grown hay that had been shredded and compressed into high density, large square bales for shipment.

Sampling

Individual feed intake was measured daily by subtracting the amount of orts from the amount of feed offered for individual cows, and milk yield was measured by calibrated weight jars at each milking (twice daily) during the SP and TP. Milk for composition analysis was collected every 7 d from two consecutive milkings. Cows were weighed every 7 d immediately following the p.m. milking and prior to access to feed or water. Samples of feed ingredients and diets were collected every 7 d, dried to a constant weight in a forced-air oven at 60°C, and allowed to air-equilibrate. These dried feed samples were ground through a 1-mm screen using a Wiley mill (Arthur H. Thomas Co., Philadelphia, PA) and were stored for chemical analysis.

Three Holsteins per treatment group with the greatest DMI prior to marker administration were selected for the digestive marker phase of the study, which was conducted during the 5th wk of the TP. Chromic oxide was used as an indigestible external marker to determine apparent digestibility. Cows were dosed twice daily with gelatin capsules containing 10 g of Cr_2O_3 (20 g daily) starting on d 29 of the study. Dosing started 5 d prior to fecal collections and continued for the duration of the fecal collection period. Cobalt-EDTA, prepared as the lithium salt according to the method of Udén et al. (20), was used to measure the passage of liquid digesta. On the morning of the 6th d of Cr_2O_3 equilibration, cows were given orally a single dose of 11.5 g of Co-EDTA dissolved in 500 ml of distilled water. Corn silage, alfalfa hay, and bermudagrass hay marked with Yb (4) were used to measure passage of the particulate phase of digesta. Immediately following the pulse-dose of Co-EDTA, cows were offered 250 g of the forage marked with Yb and were allowed access to the forage for 1 h. Fecal samples were taken at 0, 6, 9, 12, 15, 18, 24, 30, 36, 42, 48, 54, 63, 72, 81, 90, and 99 h following pulse-dosing of markers. In conjunction with the fecal sampling, daily samples of feed ingredients, diets, and orts were collected and composited for the sampling period. All samples of feces, feed, and orts were dried at 60°C to a constant weight in a forced-air oven. Samples of feed and orts were composited for the collection period, ground through a 1-mm screen using a Wiley mill, and stored for later analysis. Fecal samples were ground similarly and stored for later analysis.

Samples of dried corn silage, bermudagrass hay, and alfalfa hay, which were ground through a 1-mm screen, were subjected to in vitro digestion to determine the rate of NDF digestion. Duplicate 0.5-g samples were incubated with ruminal fluid at 39°C for 0, 2, 4, 8, 12, 24, 48, and 96 h using procedures described as the first stage of in vitro DM digestion (14). Residues of NDF after 96 h of fermentation were assumed to be the indigestible components of NDF and were subtracted from the residue remaining at each incubation time to yield the percentage of potentially digestible NDF remaining (19). Rates of digestion of the potentially digestible NDF were determined by regression of the natural log-transformed percentages of potentially digestible residual NDF digested on hours of fermentation. The digestion rate was calculated as the change in log concentration of NDF digested per hour.

Analyses

Nitrogen from feed, feces, and orts was determined using a Kjeltec system (Tecator, Inc., Herndon, VA), and CP was calculated as the percentage of N × 6.25. The ADF and NDF from feed, feces, and orts were determined as described by Mertens (11). For forages digested in vitro, contents of the fermentation vessels were transferred directly to beakers for extraction in neutral detergent solution. Residues were recovered

TABLE 2. Chemical composition of forages.[1]

	Alfalfa		Bermudagrass		Corn silage	
	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD
DM, %	91.0	2.4	87.9	1.7	37.6	1.7
CP, % of DM	16.6	1.7	17.3	1.1	8.4	0.5
ADF, % of DM	38.6	3.5	35.0	0.5	25.8	0.8
NDF, % of DM	48.1	4.8	80.7	1.1	45.8	1.5

[1]Mean of seven samples.

with vacuum filtration. Milk was analyzed for fat and protein content by infrared analysis (Multispec; N. Foss Electric, Hillerød, Denmark) and for SCC (Fossomatic 360; N. Foss Electric) by the Southeast Dairy Laboratory (McDonough, GA). Feed and fecal samples were wet-ashed for Yb and Co determination by atomic absorption spectrophotometry (model 3300; Perkin-Elmer Corp., Norwalk, CT). Chromium was determined by colorimetry (model DU-64; Beckman Instruments, Inc., Fullerton, CA) following wet-ashing.

Data were analyzed as a randomized complete block design with a factorial arrangement of treatments. Data from the TP underwent covariate analysis using data from the SP. Sources of variation were breed, block within breed, treatment, breed by treatment, parity, week, and two- and three-way interactions. Contrasts were used to compare hay source [alfalfa hay diets (**AHD**) or bermudagrass hay diets (**BHD**)] amount of hay (LHD or HHD), use of hay versus no hay (control diet), and the interaction of hay source and the amount of hay. Means for each treatment are presented in tables, but statistical comparisons are based on the contrasts of factorial means. Means for both breeds are also presented in tables. When an interaction of breed and treatment existed, statistical comparison of factorial means within breeds were presented; otherwise, statistical comparisons were for means across breeds.

Rate of passage and retention times of forages marked with Yb were determined by fitting a two-compartment model (5) to the concentration of fecal Yb. The ruminal rate of passage and the retention time of the liquid phase of digesta were determined using the regression of the linear descending portion of the natural logarithm of fecal Co concentration. The two-compartment model was not used for Co (liquid digesta phase) because passage rates and mixing of digesta in the lower digestive tract were often based on a limited sample. Only two or three samples or data points following the appearance and peak concentrations of the marker were taken because the liquid phase of digesta passed so rapidly. Therefore, the turnover value for the lower digestive tract has limited precision when based on these few data points (6).

RESULTS AND DISCUSSION

Chemical analyses of forages indicated that the CP content of bermudagrass hay was similar to that of alfalfa hay (Table 2). The high CP content of the bermudagrass hay relative to reported values (15) was probably a result of the early maturity at harvest, and the application of liquid dairy manure and fertilizer to improve fertility of the soil on which the hay was grown. The NDF content of the bermudagrass hay was high relative to the other forages. Very high NDF content is characteristic of the bermudagrasses, including the Tifton 85 cultivar (7); however, Tifton 85 has consistently had higher in vitro DM digestibility than other cultivars (1, 7). Experimental diets contained equal amounts of added hays substituted for corn silage, but, because the alfalfa and bermudagrass hays differed in NDF content, diets also differed in NDF content (Table 1).

Feed Intake

The DMI was greater for cows fed AHD than for those fed BHD, for cows fed LHD than for those fed HHD, and for cows fed the control diet than for those fed hay diets (Table 3). Although no interaction of breed and treatment was noted for DMI and data were analyzed across breeds, much of the difference in DMI could be attributed to the response of Jerseys to dietary treatments. An interaction of hay source and amount was noted, again because of the response of Jersey cows to treatments. Primarily for Jerseys, the DMI declined as bermudagrass content of the diet increased, but DMI increased as alfalfa in the diet increased. Little change in DMI of Holsteins occurred. Reduced DMI for cows consuming BHD occurred primarily for Jerseys and was probably related to the NDF content of the diet (Table 1) and to the high NDF content of bermudagrass hay (Table 2). Jerseys exhibited higher DMI as a percentage of BW, which could be related to the Jersey response to BHD.

An interaction of breed and treatment occurred for DMI per 100 kg of BW (Table 3). For Jerseys, the DMI per 100 kg of BW was greater with AHD than with BHD, for LHD than for HHD, and for the control diet than for hay diets. However, for Holsteins, only the AHD and BHD were different. The DMI per 100 kg of BW for Holsteins was relatively constant across treatments for each forage source despite an increasing proportion of dietary forage from hays. However, for Jerseys, DMI per 100 kg of BW declined sharply as bermudagrass in the diet increased. Jersey cows consuming the control diet had a higher DMI per 100 kg of BW than did Holsteins consuming the control diet, which is frequently observed. For Jerseys, the sharp decline in DMI as the bermudagrass content of the diet increased could be a result of gut fill limitations because of their high DMI per 100 kg of BW. Dado and Allen (2) reported that cows consumed less feed when fed high NDF (35%) diets than when fed low NDF (25%) diets. In that study (2), the addition of ruminally inert bulk equal to about 25% of ruminal volume decreased DMI further for cows fed the high NDF diet but had no effect for cows fed the low NDF diet. That gut fill and space requirements increase as dietary fiber content increases is consistent with the response of Jersey cows in the present trial. Holsteins did not decrease DMI per 100 kg of BW even though DMI per 100 kg of BW exceeded 4% (Table 3).

The NDF content of the diets (Table 1) was greater than recommended minimums (10, 15), and it is logical to assume that DMI in the present study was subject to physical rather than to physiological limits as was cited by Mertens (10). A summary of several experiments indicated that daily NDF intake as a percentage of BW (**NDFI%**) of 1.2 ± 0.1% produced maximum daily 4% FCM yields (12). In the present experiment, NDFI% for Jerseys consuming the control diet, low BHD, high BHD, low AHD, and high AHD were 1.51, 1.67, 1.65, 1.64, and 1.66%, respectively, which is a narrow range given the wide variation in dietary NDF. However NDFI% for Holsteins was 1.44, 1.65, 1.95, 1.56, and 1.42%, respectively. The wide range of NDFI% for Holsteins occurred because they maintained similar DMI across the diets that differed in NDF content. The NDFI% in the present study were high and suggest that high quality bermudagrass did not limit the DMI of Holsteins despite high NDF content. Lactating cows fed diets containing alfalfa silage with NDF contents of 28.3, 31.0, and 33.4% of DM had the greatest DMI for the low NDF diet, but NDFI% were 1.08, 1.11, and 1.2%, respectively (9). Rayburn and Fox (16) predicted NDFI% of approximately 1.1 and 1.65% for rations containing 30 or 50% NDF and also reported that NDFI% for legumes was 10% greater than that for either temperate or tropical grasses. The higher NDFI% predicted for cows fed high NDF diets is consistent with the results observed in the present study. However, the higher NDFI% for cows fed BHD than for those fed AHD in the present study contrasts with the results of Rayburn and Fox (16). Total

TABLE 3. Effect of forage source and hay addition on DMI of lactating cows.[1]

	Diet[2]											
		BHD		AHD								
	Control	LHD	HHD	LHD	HHD	Source[3]		Amount[4]		Source × amount	Hay[5]	
						P	SE	*P*	SE	*P*	*P*	SE
DMI, kg/d												
Holstein	22.9	22.1	22.0	22.5	22.5	0.001	0.2	0.10	0.2	0.01	0.01	0.2
Jersey	19.3	17.7	14.4	19.3	20.5							
DMI/BW,[6] kg/100 kg												
Holstein	4.29	4.16	4.19	4.38	4.27	0.10	0.06	NS[7]	0.07	NS	NS	0.07
Jersey	4.63	4.23	3.62	4.58	4.85	0.001	0.06	0.10	0.07	0.001	0.01	0.07
BW, kg												
Holstein	534.4	530.4	526.8	512.0	531.9	NS	1.3	NS	1.3	0.001	0.0001	1.5
Jersey	427.9	418.7	406.7	418.1	414.4							

[1]Dry basis.

[2]BHD = Bermudagrass hay diets, AHD = alfalfa hay diets, LHD = low (15%) hay diet, and HHD = high (30%) hay diet.

[3]Hay source (bermudagrass vs. alfalfa).

[4]Amount of hay addition (15% vs. 30%).

[5]Hay diets versus no hay diet (control).

[6]Interaction of breed and treatment. Statistical analyses were performed with means from the same breed.

[7]$P > 0.10$.

predicted NDF pool size in the rumen (percentage of BW) was greater for Coastal bermudagrass than for alfalfa (13), and a positive relationship between ruminal NDF (kilograms) and total ruminal volume was reported (2). Greater ruminal fill with higher dietary NDF might be related to the sustained high intakes by Holstein cows in the present study, despite the high NDF content of BHD (Table 1). However, Shaver et al. (18) reported that ruminal fill was greater (90 vs. 76 kg of wet weight) and ruminal turnover time was slower (17.5 vs. 12.6 h) for bromegrass hay than for alfalfa hay at similar OM digestibilities. Those differences resulted in DMI per 100 kg of BW of 3.08 versus 3.49% for the bromegrass and alfalfa diets, respectively, indicating that, despite greater fill and distension of the reticulorumen, DMI per 100 kg of BW was reduced by the higher fiber bromegrass (18).

Apparent Digestibility, Rate of Passage, and In Vitro NDF Digestion

The DMI of Holsteins during the fecal collection period was not different across treatments (Table 4). Intake of CP did not differ by treatment, but ADF intake was greater for cows fed BHD than for cows fed AHD and for cows fed diets containing hay than for cows fed the control diet. Intake of NDF was greater for cows fed BHD than for cows fed AHD, for cows fed HHD than for cows fed LHD, and for cows fed diets containing hay than for cows fed the control diet, largely because of the higher NDF content of BHD (Table 1). The similarity in DMI for Holsteins, despite the higher fiber content of BHD, might be partially explained, by the apparent digestibility of dietary nutrients (Table 4). Apparent digestibility of NDF was greater for BHD than for AHD, for HHD than for LHD, and for diets containing hay than for the control diet. There were no interactions of hay source and amount of hay, which suggests that NDF from bermudagrass was more digestible than NDF from the other forage sources because NDF digestion of the diet improved as bermudagrass in the diet increased. Improved digestion of NDF from BHD should help to sustain DMI, explaining similar intakes for Holsteins when the control diet, BHD, and AHD were compared (Tables 3 and 4). Mertens and Ely (13) reported that the primary differences between alfalfa and Coastal bermudagrass were in the NDF and lignin contents and in the proportion of NDF that was slowly digested. Although alfalfa contained less NDF than did the Coastal bermudagrass, the NDF of alfalfa was more lignified and contained a smaller fraction of slowly digestible NDF and a larger percentage of indigestible NDF (13). Tifton 85 bermudagrass, the cultivar used in the present study, was 11% more digestible than was Coastal bermudagrass (1). Ruiz et al. (17) reported NDF diges-

TABLE 4. Effect of forage source and hay addition on DMI and apparent digestibility of nutrients by Holstein cows during the fecal collection period.[1]

	Diet[2]											
		BHD		AHD								
	Control	LHD	HHD	LHD	HHD	Source[3]		Amount[4]		Source × amount	Hay[5]	
	(kg/d)					*P*	SE	*P*	SE	*P*	*P*	SE
Nutrient intake												
DM	22.3	22.8	22.4	23.4	21.0	NS[6]	1.2	NS	1.2	NS	NS	1.3
CP	4.2	4.3	4.2	4.3	3.9	NS	0.2	NS	0.2	NS	NS	0.2
ADF	4.2	4.7	5.7	4.2	4.4	0.02	0.2	NS	0.2	NS	0.10	0.2
NDF	8.1	9.4	12.3	7.4	7.1	0.001	0.5	0.09	0.5	NS	0.04	0.5
	(%)											
Apparent digestibility												
DM	56.7	62.7	58.5	59.1	56.6	NS	1.4	NS	1.4	NS	NS	1.5
CP	64	64.3	59.2	61.3	59.9	NS	1.3	0.10	1.3	NS	NS	1.3
ADF	24.6	47.9	56.2	35.9	41.1	0.006	2.7	NS	2.7	NS	0.001	2.9
NDF	32.2	54.1	62.6	37.7	40.8	0.001	2.1	0.08	2.1	NS	0.001	2.2

[1]Dry basis.

[2]BHD = Bermudagrass hay diets, AHD = alfalfa hay diets, LHD = low (15%) hay diet, and HHD = high (30%) hay diet.

[3]Hay source (bermudagrass vs. alfalfa).

[4]Amount of hay addition (15% vs. 30%).

[5]Hay diets versus no hay diet (control).

[6]$P > 0.10$.

tibilities of 50.6, 54.1, and 55.2% for TMR based on bermudagrass containing 31, 35, and 39% NDF, respectively. Those researchers (17) speculated that improved digestibility of NDF could have resulted from a positive associative effect of forages and concentrates or as a result of the reduced DMI (17).

Turnover rates and retention times of liquid and forage particulate phases of digesta are summarized in Table 5. A significant interaction of hay source and amount of hay occurred for ruminal turnover rate and ruminal retention time. Ruminal turnover rate of Yb increased as bermudagrass content in the diet increased but declined as alfalfa content increased. As a result, ruminal retention time declined as the content of bermudagrass in the diet increased and increased as the content of alfalfa in the diet increased. Digestion of ADF and NDF was greater for BHD than for AHD (Table 4), potentially allowing for more rapid ruminal turnover of the forage portion of the diet. More rapid ruminal turnover rates and shorter ruminal retention times for diets with higher fiber might appear unexpected, but Woodford et al. (23) reported ruminal retention times of 20.0, 16.7, 15.9, and 17.0 h, respectively, for diets based on alfalfa hay containing 21.2, 24.2, 27.4, and 30.1% NDF. Those researchers (23) also reported that digestibility was not reduced by changes in ruminal retention time or by fiber content of the diet. Simulations predicted more rapid ruminal turnover of NDF from Coastal bermudagrass than from alfalfa, despite the much higher NDF content of the bermudagrass (13). A greater fractional passage rate of cell walls occurred for rations containing 74% of DM from forage than for rations containing 50% forage DM (8). In addition, fractional passage rates were greater when ruminally inert bulk was added (8). Greater bulk associated with the high NDF BHD used in the present study could have contributed to the more rapid ruminal passage rates and shorter ruminal retention times (Table 5).

The ruminal turnover of liquid digesta (marked with Co) decreased as bermudagrass content in BHD increased, but the liquid turnover rate increased as alfalfa content in the AHD increased (Table 5). Perhaps the bulkiness of the high NDF BHD caused greater water retention in the rumen. Shaver et al. (18) reported a longer ruminal retention of a liquid phase marker for bromegrass diets than for alfalfa diets, although the longer retention time was also associated with longer forage retention. In the

TABLE 5. Effects of forage source and hay addition on measurements of rates of passage and retention times of forages and liquids for Holstein cows.

Item	Diet[1]											
		BHD		AHD								
	Control	LHD	HHD	LHD	HHD	Source[2]		Amount[3]		Source × amount	Hay[4]	
						P	SE	*P*	SE	*P*	*P*	SE
Forage marked with Yb												
K_1,[5] %/h	5.9	5.5	6.9	6.9	6.0	NS[6]	0.5	NS	0.5	0.04	NS	0.8
K_2,[7] %/h	15.3	20.4	13.0	18.4	15.8	NS	3.9	NS	3.9	NS	NS	6.7
TT,[8] h	9.4	9.7	8.7	9.9	7.7	NS	1.7	NS	1.7	NS	NS	2.9
RRT,[9] h	17	18.6	14.5	14.6	18.0	NS	1.2	NS	1.2	0.01	NS	2.1
LRT,[10] h	6.7	7.8	7.7	5.9	6.7	NS	1.5	NS	1.5	NS	NS	2.5
TMRT,[11] h	33.1	31.9	30.9	30.4	32.1	NS	2.0	NS	2.0	NS	NS	3.4
Liquid marked with Co												
K_1, %/h	7.8	8.9	7.4	7.8	10.8	NS	1.0	NS	1.0	0.05	NS	1.7
RRT, h	12.9	11.7	13.9	13.1	9.3	NS	1.4	NS	1.4	0.07	NS	2.4

[1]BHD = Bermudagrass hay diets, AHD = alfalfa hay diets, LHD = low (15%) hay diet, and HHD = high (30%) hay diet.

[2]Hay source (bermudagrass vs. alfalfa).

[3]Amount of hay addition (15% vs. 30%).

[4]Hay diets versus no hay diet (control).

[5]Ruminal turnover rate.

[6]$P > 0.10$.

[7]Thought to be turnover rate of contents in hindgut or cecum and proximal colon.

[8]Transit time.

[9]Ruminal retention time.

[10]Retention time in cecum, colon, and possibly mixing in reticulorumen.

[11]Total mean retention time.

present study, the total mean retention time in the digestive tract of the particulate phase marked with Yb was not different across treatments, indicating that, despite the greater NDF content of the BHD, total retention times in the gut were similar to those of alfalfa hay and corn silage marked with Yb.

Figure 1 illustrates rates of in vitro digestion for the potentially digestible NDF of forages used in the study. The rate was most rapid for bermudagrass, intermediate for corn silage, and slowest for alfalfa, although corn silage and alfalfa hay were relatively similar. The rate constants of 0.042, 0.029, and 0.028 for bermudagrass hay, corn silage, and alfalfa hay, respectively, yielded rates of NDF disappearance of 9.7, 6.7, and 6.3% per h, using the calculation of Gill et al. (3). Indigestible NDF remaining at 96 h of digestion were 29.1, 20.3, and 51.25% for bermudagrass, corn silage, and alfalfa, respectively. The more rapid rate of in vitro digestion of potentially digestible NDF for bermudagrass hay might explain the shorter ruminal retention times and similar mean retention times in the total tract of forage particles marked with Yb (Table 5), despite the higher NDF content of BHD. Improved apparent digestibility of NDF of the BHD (Table 4) and more rapid in vitro NDF digestion rate of bermudagrass hay (Figure 1) are consistent with the sustained intakes by Holsteins of diets that were high in NDF (Tables 3 and 4). Gill et al. (3) reported a high correlation between relative feed intake and relative cellulose digestibility in vitro when forage alone was fed. However, those researchers (3) also found that the correlation was nullified when grain was included in the ration (3). In the present study, the more rapid rate of digestion of the in vitro potentially digestible NDF for cows fed bermudagrass forage might help to explain sustained DMI for Holsteins, despite the high NDF content of BHD.

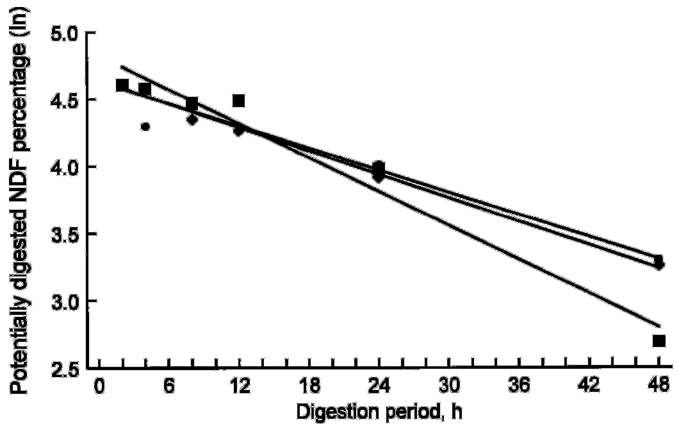

Figure 1. Linear relationship of the natural logarithm of the percentage of potentially digestible NDF remaining regressed on fermentation time for corn silage (♦), bermudagrass hay (■), and alfalfa hay (●).

Milk Yield and Milk Composition

Milk and FCM yields were greater for cows fed AHD than for cows fed BHD and for cows fed LHD than for cows fed HHD (Table 6), reflecting similar trends for DMI (Table 3). However, milk and FCM yields were not different for cows fed diets containing hay than those for cows fed the control diet (Table 6) despite differences in DMI (Table 3). Mertens (9) reported that FCM yield was greatest for cows fed diets based on alfalfa hay, corn silage, or bermudagrass hay when dietary NDF content was 35% for each diet. The optimum NDF content of 35% for maximum FCM yield did not differ between the forage sources, although, when the diets contained 35% NDF, yield of FCM was greatest for cows fed diets based on alfalfa, intermediate for cows fed corn silage, and least for cows fed diets based on bermudagrass (9). In a comparison of diets containing 31, 35, or 39% NDF using different quantities of silages made from corn, dwarf elephantgrass, bermudagrass, or sorghum to achieve the desired NDF content within forage type, yields of milk and FCM declined linearly as dietary NDF increased (17), and differences among forages for yields of milk and FCM followed DMI. Ruiz et al. (17) commented that fiber digestibility appeared to be an important factor influencing DMI and milk yield when different forages were fed in diets containing similar NDF concentrations. Thus, formulation of diets for a specific NDF content, regardless of forage type, resulted in inferior performance when digestion effects on intake and milk yield were not considered.

An interaction of breed and treatment occurred for milk fat percentage (Table 6). Although hay source had little effect on fat percentage in milk of Holstein cows, fat percentage in milk of Jersey cows was greater for those fed BHD. Milk fat percentage was greater when Holsteins were fed HHD than when they were fed LHD, but, for Jersey cows, fat percentage was higher for milk of cows fed LHD. The reason for these opposing results is unknown. A significant interaction of hay source and amount of hay occurred for Holsteins (Table 6). Holsteins had higher milk fat percentages when fed diets containing hay than when fed the control diet, but fat percentages of milk from Jersey cows were not different. However, fat yields were not different by treatment, suggesting that differences in fat yield that were associated with changes in volume of milk yielded were offset by changes in milk fat composition.

Protein percentage in milk of cows fed the diets containing hay was lower than that of cows fed the control diet (Table 6). The control diet contained corn silage as the sole forage source, resulting in a greater dietary starch content, which might have contributed to improved milk protein content. Ruiz et al. (17) suggested that milk protein percentage declined as dietary NDF increased because of reduced nonfibrous carbohydrates in the diet and declining NE_L intake, resulting in less microbial protein yield. However, milk protein yield was greater for cows fed AHD, LHD, and the control diet, which paralleled changes in milk yield. A significant effect of hay source for SCC was higher for cows fed AHD than for those fed BHD; this result was primarily due to one Holstein fed the high AHD and one Jersey fed the low AHD and was unrelated to treatment.

CONCLUSIONS

Holstein cows consuming BHD had slightly lower DMI per 100 kg of BW than did Holstein cows consuming AHD, despite the high NDF content of the BHD. Greater in vitro NDF digestibility of bermudagrass, coupled with the greater apparent digestibility of ADF and NDF of BHD, suggest that improved fiber digestion enhanced ruminal rate of passage for bermudagrass, which sustained DMI despite high total dietary NDF content. Sharp declines in DMI of Jersey cows as bermudagrass content of TMR increased might be related to higher DMI per 100 kg of BW of Jerseys relative to Holsteins, resulting in greater physical space limitations for bulky diets high in NDF. However, the great difference in DMI per 100 kg of BW for Jerseys relative to the Holsteins was unexpected. More rapid NDF digestion rate for bermudagrass is consistent with other studies that showed rapid digestion rates for grasses. Results suggested that optimal dietary NDF depends

TABLE 6. Effect of forage source and hay addition on milk yield and composition.

	Diet[1]											
		BHD		AHD								
Item	Control	LHD	HHD	LHD	HHD	Source[2]		Amount[3]		Source × amount	Hay[4]	
						P	SE	*P*	SE	*P*	*P*	SE
Milk, kg/d												
Holstein	34.1	33.0	31.8	34.1	32.6	0.001	0.2	0.01	0.2	NS[5]	NS	0.2
Jersey	20.7	20.8	19.5	23.3	22.5							
3.5% FCM, kg/d												
Holstein	33.6	33.9	33.5	34.3	34.0	0.01	0.2	0.05	0.2	NS	NS	0.3
Jersey	25.8	26.0	23.7	26.9	26.3							
Milk fat,[6] %												
Holstein	3.33	3.73	3.72	3.54	3.99	NS	0.06	0.05	0.06	0.05	0.01	0.08
Jersey	4.98	5.01	4.83	4.84	4.59	0.05	0.06	0.05	0.06	NS	NS	0.07
Fat yield, kg/d												
Holstein	1.15	1.22	1.21	1.21	1.25	NS	0.06	NS	0.06	NS	NS	0.03
Jersey	1.04	1.05	.95	1.07	1.03							
Milk protein, %												
Holstein	3.17	3.18	3.09	3.11	3.20	NS	0.02	NS	0.02	0.10	0.05	0.03
Jersey	4.04	3.95	3.81	3.88	3.80							
Protein yield, kg/d												
Holstein	1.08	1.05	.99	1.07	1.02	0.001	0.01	0.01	0.01	0.10	0.05	0.01
Jersey	0.84	0.82	0.74	0.86	0.86							
SCC,[7] ×1000/ml												
Holstein	71	165	116	291	422	0.001	25	NS	25	0.05	NS	29
Jersey	296	229	84	259	266							

[1]BHD = Bermudagrass hay diets, AHD = alfalfa hay diets, LHD = low (15%) hay diet, and HHD = high (30%) hay diet.

[2]Hay source (bermudagrass vs. alfalfa).

[3]Amount of hay addition (15% vs. 30%).

[4]Hay diets versus no hay diet (control).

[5]$P > 0.10$.

[6]Interaction of breed and treatment. Statistical analysis were performed with means from each breed.

[7]Analyzed as $\log_{10}$; actual means are reported.

on the forages being used, and optimal NDF content may differ depending on the breed of cow, possibly because of differences in DMI per unit of BW. Formulation of diets for specific NDF without regard for forage type results in inferior performance when digestion effects are not considered. These data indicate that intensively managed, high quality hybrid bermudagrass is a viable forage alternative for lactating dairy cows.

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