Forage Source Alters Nutrient Supply to the Intestine Without Influencing Milk Yield

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ABSTRACT

Eight Holstein cows in early lactation and fitted with ruminal and duodenal cannulas were used in a 4 × 4 Latin square design experiment to determine the influence of forage source on microbial digestion in the rumen and nutrient supply to the intestine and to determine relationships between DMI, ruminal fill, and NDF content of silage. Cows were fed a TMR formulated to contain a 50:50 concentrate:forage ratio. A significant negative correlation was found between dietary NDF concentration (range 32.2 to 37.9%) and DMI (16.7 to 19.6 kg/d). In addition to forage NDF concentration, the lower DMI of cows fed oat or triticale silage (16.7 and 17.2 kg/d, respectively) relative to that of cows fed barley or alfalfa silage (18.6 and 19.6 kg/d, respectively) might reflect a lower true rate of NDF digestion (range 2.39 to 4.09%/h), higher ruminal turnover time (12.9 to 17.1 h), and lower rate of NDF intake (3.31 to 3.96%/h). However, differences in ruminal bacterial yield, ruminal metabolites, and nutrient supply to the intestine associated with different silages had no major effect on dairy cow performance. We concluded that the dairy cow can maintain similar milk yield despite marked differences in the type of end products arising from carbohydrate and protein digestion.
(**Key words**: dairy cows, alfalfa, cereal grain silage, bacterial protein yield)

Abbreviation key: **DAPA** = diaminopimelic acid, $\mathbf{k_d}$ = rate of digestion, $\mathbf{k_{dt}}$ = rate of digestion (true), $\mathbf{k_i}$ = rate of intake, $\mathbf{k_p}$ = rate of passage.

INTRODUCTION

Performance of dairy cows is influenced by DMI, which, in turn, may be influenced by the content and digestion kinetics of NDF in forage (7). Consequently, there are numerous reports (1, 28) on the relationships between dietary NDF concentration and characteristics of diets that limit intake, such as bulk density, ruminal fill, particle distribution, digestibility, time spent eating and ruminating, rate of digestion, and passage rates of digesta from the ruminoreticulum. In a previous study (7), Khorasani et al. reported that cows fed oat or triticale silage with high NDF content had lower DMI than did cows fed alfalfa or barley silage with low NDF. Khorasani et al. (7) also reported that dietary NDF was closely correlated with feed intake depression ($R^2 = 0.94$; $P < 0.05$) of cows in early lactation that were fed small grain cereal silages. Differences in forage composition and thus presumably in the end products of digestion had no major effect on dairy cow performance when the forages were fed for ad libitum intake (7). The objective of this study was to examine the effect of whole-crop barley, oat, triticale, and alfalfa silage on ruminal digestion characteristics and nutrient supply to the intestine so that the mechanism underlying the yield responses that were previously observed could be elucidated. A further objective was to clarify the relationships among ad libitum feed intake, ruminal fill, dietary NDF, and rate and extent of NDF digestion.

MATERIALS AND METHODS

Cows and Diets

Eight lactating Holstein cows (21 ± 8 d of lactation), fitted with ruminal cannulas (10 cm i.d.; Bar Diamond Inc., Parma, ID) and duodenal cannulas (19), were tethered in stalls and had free access to water. Three cows were fitted with a soft T-type duodenal cannula, and five cows were fitted with a hard T-type cannula. The experiment consisted of four periods; cows were blocked with two cows in each block and assigned to four dietary treatments in a 4 × 4 Latin square design. The experimental periods were 3 wk in duration; 2 wk were for adaptation, and 1 wk was for sample collection. Cows were fed four different diets with a 50:50 forage:concentrate ratio (DM basis); preparation of feeds and sampling protocol were as described previously (7). The NDF content of

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the four forages was alfalfa silage (45.6%), whole-crop barley silage (50.6%), whole-crop oat silage (60.8%), and whole-crop triticale silage (54.3%). The concentrates were based on barley, corn, canola oil, canola meal, soybean meal, corn gluten meal, meat and bone meal, and fish meal and contained 23.2% CP (7). The chemical composition of each TMR is presented in Table 1. Cows were fed twice daily at 0800 and 1800 h. Fifty-eight percent of the ration was provided at 0800 h, and 42% was provided at 1800 h.

Milk yield was recorded daily for the duration of the study. Milk samples for protein, fat, and lactose determinations were taken from two consecutive milkings on Monday (p.m.) and Tuesday (a.m.) of each week. The means for milk yield, milk composition, and milk component yield for the last 7 d of each period were used to determine treatment effects.

Ruminal Volume and Digestion Kinetics

Pool sizes for ruminal liquid volume, solid mass, and solid components were estimated by complete evacuation procedures. Ruminal evacuations were done on four separate occasions during the last 3 d of each period. The time of the evacuations varied in relation to feeding to obtain representative samples of digesta for a 24-h period (at 0600, 1300, 2000, and 0010 h). All solid contents that could be removed from the rumen by hand were emptied into an insulated 180-L container, which was covered with plastic and continually flushed with CO_2. Solids were weighed, and a representative subsample (2.5 to 3.0 kg) was taken. Liquid was bailed from the rumen and placed into a polypropylene container that was continually flushed with CO_2. Liquid was weighed, and a representative subsample, in proportion to volume, was taken. The cows were "empty" for 2 to 3 min and without solids for 5 to 10 min. Kinetics of NDF intake, passage, and digestion from ruminal evacuation and duodenal flow data were calculated as described by Robinson and Kennelly (18) using the following equations:

$$\mathbf{k_i}\ \text{(rate of intake per hour)} = \text{NDF intake (kilograms per 24 h)} \times \text{(ruminal NDF pool kilograms)},$$

$$\mathbf{k_p}\ \text{(rate of passage per hour)} = \text{duodenal NDF output (kilograms per 24 h)} \times \text{ruminal NDF pool (kilograms)},$$

and

$$\mathbf{k_d}\ \text{(rate of digestion per hour)} = k_i - k_p.$$

True rate of NDF digestion ($\mathbf{k_{dt}}$) was calculated as

$$k_{dt}\ \text{(per hour)} = (k_i - k_p)/\text{potentially degradable ruminal NDF pool (kilograms)}.$$

The ruminal NDF pool was fractionated into indigestible NDF and potentially degradable NDF pools by incubating pooled samples of ruminal ingesta from each period in large nylon bags in the rumens of three dry cows for 11 d. Cows were fed a dry cow diet at approximately 8 kg/d of DM in two feedings at 0800 and 1800 h. The diet supplied the nutrient requirements of cows as recommended by the NRC (11), and the forage:concentrate ratio was 90:10. The forage portion was 50:50 oat silage:bromegrass silage. The concentrate was based on barley, corn, canola meal, soybean meal, molasses, trace-mineralized salt, and vitamins. The NDF residue in bags at d 11 was considered to be indigestible NDF, but residue that had disappeared was considered as the potentially degradable NDF.

TABLE 1. Composition of forages and TMR.

	Silage				
	Alfalfa	Barley	Oat	Triticale	SEM
	(% of DM)				
Forage					
Starch	1.8	15.9	8.5	7.8	
CP	19.9	12.4	11.5	12.7	
ADF	33.7	28.5	35.7	31.7	
NDF	45.6	50.6	60.8	54.3	
TMR					
CP	21.3	17.8	17.7	17.3	1.7
ADF	21.1	18.9	19.5	19.7	1.9
NDF	32.2	35.4	37.9	36.5	3.0
Cellulose	16.6	15.6	20.8	16.6	4.4
Lignin	4.5	3.2	3.2	3.2	0.8

Apparent Forestomach and Whole-Tract Digestibilities

The Cr-mordanted alfalfa silage was used as a solid-phase digestibility marker. Marked material was weighed on filter paper and placed into the rumen at intervals starting on d 12 (8). The marker was placed manually in the rumen at 0800, 1500, and 2100 h from d 12 to 16 inclusive and at 0100, 0700, 1300, and 1900 h from d 17 to 20 inclusive to achieve steady-state concentrations in duodenal digesta and feces. Samples of duodenal digesta and feces were collected on five occasions during the 72-h collection period from 1030 h on d 17 (at 1036, 0548, 0100, 2012, and 1524 h, respectively). Duodenal digesta were collected by total digesta diversion as described by Robinson and Kennelly (19). Feces were collected,

and apparent whole-tract digestibility was measured as previously described (7). The Cr was analyzed by atomic absorption spectrophotometry as described by Okine and Mathison (14).

Ruminal Fermentation and Bacterial Yield

Ruminal fluid was sampled over a 24-h period commencing on Tuesday (d 18) for pH and concentrations of lactic acid, VFA, and ammonia as described previously. Sampling times were 0750, 0830, 0900, 0930, 1000, 1100, 1200, 1400, 1750, 1830, 1900, 1930, 2000, 2200, 0030, 0200, 0600, and 0750 h. Daily duodenal flow of bacterial N and OM were estimated from the diaminopimelic acid (**DAPA**) concentration of duodenal digesta DM and the N:DAPA ratio of isolated ruminal bacteria (19). Bacteria were isolated from ruminal contents on three occasions from each cow in each period (19). Bacteria were pooled within cow and period and stored at −20°C for later freeze-drying and for analysis of DAPA and N.

Chemical Analyses

Chemical analyses of feed, ruminal ingesta, and duodenal digesta were determined as previously described (7). Ruminal NH_3 N was measured as described by Fawcett and Scott (3). Lactic acid was determined by a gas chromatographic procedure. Samples of ruminal fluid were thawed and centrifuged at 1935 × *g* for 10 min. The supernatant (0.5 ml) was made basic with 3*N* NaOH in methanol, and the mixture was evaporated to dryness. Malonic acid served as an internal standard. One milliliter of 3*N* HCl in methanol was added; the tube was then stoppered and heated at 100°C for 25 min to dissolve the residue. This solution was allowed to stand until the NaCl precipitate settled, and the resulting methyl ester of lactic acid was measured in a Varian 3400 chromatograph (Varian, Walnut Creek, CA) equipped with a 30-cm (0.2 mm i.d.) OV 351 capillary column. A split ratio of 50:1 was used with a column flow rate of 1 ml/min of N_2. Oven temperature was programmed from 80 to 170°C at 25°C/min after an initial hold for 0.5 min. The 170°C temperature was held for 3 min to complete the cycle.

For VFA analysis, samples were thawed and centrifuged at 1935 × *g* for 10 min. Isocaproic acid (200 μl as an internal standard) was added to 1 ml of clear ruminal fluid (previously acidified with 25% H_3PO_4; 1:4 ratio), and a 1-μl solution was injected into a Varian 3400 gas chromatograph equipped with a column (as described for lactic acid determination) at a column flow rate of 30 ml/min. The temperature was initially set at 120°C for 1 min and then changed to 180°C at 10°C/min (injector temperature at 170°C and detector temperature at 200°C). The NDF, ADF, and permanganate lignin were determined by procedures of Robertson and Van Soest (17). Cellulose was determined as the difference between ADF and lignin.

Statistical Analyses

Data on feed intake, milk yield, forestomach and total tract digestion, maximum concentration of lactic acid in the rumen, and ruminal bacteria yield were analyzed by a Latin square design using a model that included group, cow (group), period, and diet. The general linear models procedure of SAS (22) was used to analyze the data for ruminal metabolites (ammonia N, lactate, and VFA) and ruminal pH using a model that included group, cow (group), period, diet, time of sampling, and the interactions group × cow × period × diet, time × group, time × period, and time × diet. The error term for diet was the interaction group × cow × period × diet, and the residual error was used for testing time and interaction time × diet. Differences among dietary treatments were tested for significance ($P < 0.05$) by Duncan's new multiple range test.

RESULTS AND DISCUSSION

DMI and Forestomach and Whole-Tract Digestibilities

Although the NDF content of the alfalfa silage was lower than that of the other silages, the NDF intake of cows fed alfalfa silage was similar to that of cows fed the other diets (Table 2) and reflected the higher DMI of cows fed alfalfa silage (Table 2). The negative correlation ($P < 0.06$; $R^2 = 0.89$) between DMI and NDF content in this metabolic study was supported by data from a production study (7) in which these forages were fed to both early and midlactation cows. In that study, for each percentage unit of increase in dietary NDF concentration, DMI was reduced by 0.95 and 0.38 kg/d for early and midlactation dairy cows, respectively. Christensen (2) also reported that diets containing >36 to 38% NDF in the DM might limit DMI. The NDF contents of the TMR in the present study were 37.9 and 36.5% for cows fed oat and triticale silage, respectively. Although these data provided support for the view that NDF may be a good chemical indicator of forage intake (27), clearly other factors also contributed to the differences in DMI observed in this study. The relatively low DMI

when cows were fed oat or triticale silage compared with DMI of cows fed alfalfa or barley silage, could also have been due to other dietary characteristics that limited intake, including bulk density, digestibility, time spent chewing during eating and ruminating, k_d, and k_p of digesta from the ruminoreticulum (13). The CP contents of the diets could also have influenced DMI because the diets were not isonitrogenous (7). As the dietary CP concentration reflected the CP content of the forages, the diet based on alfalfa contained a higher CP concentration than the diets based on cereal forage. Because total protein intake of cows fed oat silage was lower than NRC (11) requirements, DMI might have been limited by protein deficiency in cows fed oat silage as was suggested by Small and Gordon (24). However, NAN flow to the duodenum was similar for cows fed oat or barley silage, and cows fed the triticale diet had NAN flow similar to that of cows fed alfalfa silage. Thus, these data do not support the view that the protein supply to the rumen or intestine is a major contributor to the differences observed in DMI.

Cows fed the alfalfa diet had a higher ADF intake than cows fed the barley, oat, or triticale diets (Table 2). Cows fed alfalfa had the lowest starch intake, which was similar to the starch intake of cows fed oat silage. Cows fed barley silage had the highest intake, and cows fed triticale silage had intermediate starch intake, reflecting the starch concentration of the various silages.

Cows fed the barley silage diet had higher apparent forestomach DM digestibility than did those fed triticale silage; no other differences among diets were significant. Cows fed diets containing alfalfa or barley

TABLE 2. Influence of treatment on intake and forestomach digestibility.

	Diet				
	Alfalfa	Barley	Oat	Triticale	SEM
DM					
Intake, kg/d	19.6^{a}	18.6^{a}	16.7^{b}	17.2^{b}	0.42
Digestion, %					
Forestomach	39.8^{ab}	40.6^{a}	34.8^{ab}	32.8^{b}	2.57
Whole tract	67.6^{a}	66.1^{a}	64.6^{b}	63.6^{b}	0.76
OM					
Intake, kg/d	17.7^{a}	17.0^{a}	15.4^{b}	15.8^{b}	0.38
Digestion, %					
Forestomach	43.5^{ab}	45.6^{a}	40.4^{ab}	38.0^{b}	2.40
Whole tract	69.0^{a}	67.8^{a}	66.0^{b}	65.4^{b}	0.77
CP					
Intake, kg/d	3.99^{a}	3.17^{b}	2.70^{c}	2.93^{bc}	0.10
Digestion, %					
Forestomach	29.1^{a}	22.6^{a}	8.8^{b}	5.5^{b}	3.83
Whole tract	67.7^{a}	64.8^{ab}	63.3^{bc}	62.5^{c}	0.89
NDF					
Intake, kg	6.31	6.62	6.26	6.22	0.20
Digestion, %					
Forestomach	39.5	47.2	40.4	41.3	2.66
Whole tract	44.6^{ab}	47.3^{a}	42.9^{ab}	41.5^{b}	1.75
ADF					
Intake, kg/d	4.13^{a}	3.52^{b}	3.21^{b}	3.39^{b}	0.11
Digestion, %					
Forestomach	39.4	42.4	32.9	37.7	3.52
Whole tract	45.5^{a}	43.2^{ab}	37.0^{b}	41.2^{ab}	2.30
Cellulose					
Intake, kg/d	3.25^{ab}	2.91^{ab}	3.55^{a}	2.86^{b}	0.21
Digestion, %					
Forestomach	49.3	49.3	51.8	45.5	3.54
Whole tract	54.1	48.7	50.4	47.8	2.57
Starch					
Intake, kg/d	3.87^{b}	5.22^{a}	4.58^{b}	4.70^{ab}	0.24
Digestion, %					
Forestomach	NA[1]	NA	NA	NA	NA
Whole tract	88.5	97.3	87.5	90.4	5.16

^{a,b,c}Means in the same row with different superscripts differ ($P < 0.05$).

[1]Not available.

TABLE 3. Influence of treatment on ruminal fill and turnover rates.

	Diet				
	Alfalfa	Barley	Oat	Triticale	SEM
Total ruminal fill, kg	72.6	76.5	78.8	72.3	1.95
DM, kg	10.6^{ab}	10.8^{ab}	11.8^{a}	10.0^{b}	0.48
% of Intake	53.8^{b}	57.0^{b}	71.3^{a}	58.9^{b}	2.86
Turnover time,[1] h	12.91^{b}	13.69^{b}	17.12^{a}	14.13^{b}	0.69
Ruminal fill, kg					
OM	9.61^{ab}	9.73^{ab}	10.8^{a}	9.13^{b}	0.50
CP	2.04	1.78	1.89	1.77	0.10
ADF	4.42	4.06	4.62	3.96	0.25
NDF	6.81^{b}	7.29^{ab}	8.04^{a}	6.75^{b}	0.37
Cellulose	2.95	2.32	2.44	2.64	0.30
Lignin	1.47^{ab}	1.70^{ab}	2.08^{a}	1.08^{b}	0.25

^{a,b}Means in the same row with different superscripts differ ($P < 0.05$).

[1]Turnover time [ruminal DM (kilograms)/intake (kilograms per day)] × 24.

silage had higher OM intake than cows fed diets containing oats or triticale silage, reflecting the higher DMI of cows fed these diets. Forestomach and whole-tract digestibility of OM was higher for cows fed barley silage than for cows fed triticale silage. Forestomach CP digestion was substantially higher for cows fed alfalfa or barley diets than for the cows fed oat or triticale diets. The apparent digestibility of CP in the whole tract was highest for the alfalfa diet, intermediate for the barley diet, and lowest for the oat and triticale diets. Forestomach digestibilities of NDF were not affected by dietary treatments; however, cows fed the barley diet had a higher whole-tract apparent digestibility than those fed the triticale diet. The ADF apparent total tract digestibility was lower for cows fed oat silage than for cows fed alfalfa silage. Total tract starch digestibility was similar for all diets. Differences in apparent digestibilities of various components of DM have been associated with concentration differences, digestion, passage rates, and the complex relationships among intake, ruminoreticulum pool sizes, and passage rates (13). These complex relationships illustrate the difficulty associated with using a single component of the diet (e.g., NDF) as a predictor of voluntary intake.

Ruminal Volume and Kinetics of Digestion

To distinguish between differences that might have existed between feed intake and time of evacuation of ruminal digesta, ruminal contents were evacuated at different times (0100, 0600, 1300, and 2000 h). Time of sampling had a significant effect on ruminal fill (Figure 1). Cows ruminally evacuated at 0600 h had a lower ruminal fill than that at other evacuation times; no differences were significant in the amounts evacuated at other times. Therefore, samples of ruminal contents from the evacuations were pooled for each cow in each period, and a representative sample was taken for chemical analysis to study the rate of NDF digestion in the rumen. With the ruminal emptying technique, the inclusion of NDF with the potentially digestible NDF or DM may result in a lower k_p and k_d (15). Therefore, conclusions drawn from comparison of k_p and k_d in the present study with those obtained using other methods should be conservative.

The higher NDF intake relative to the lower DMI of cows fed oat or triticale silage reflected the NDF content of those silages. The ruminal evacuation data (Table 3) showed that there were no significant differences in the total ruminal fill of cows fed different silages. However, ruminal fill as a percentage of DMI was highest for cows fed oats, and no significant

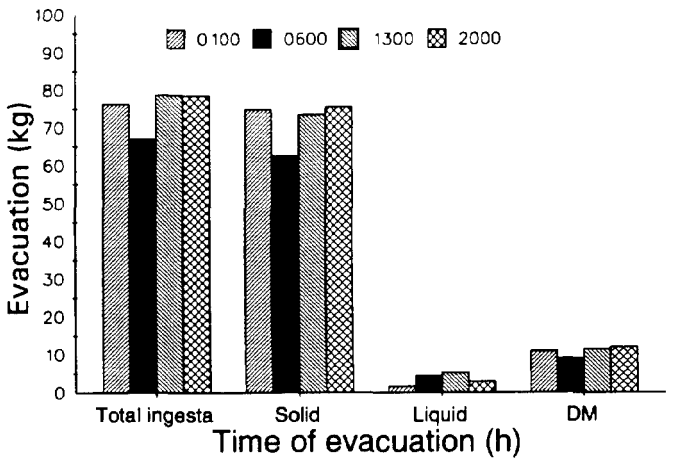

Figure 1. Influence of time of ruminal evacuation on ruminal fill.

TABLE 4. Kinetic parameters for NDF in the ruminal, duodenum, and total digestive tract.

	Diet				
	Alfalfa	Barley	Oat	Triticale	SEM
NDF					
Intake, kg/d	6.31	6.62	6.26	6.22	0.22
Ruminal pool, kg	6.81[b]	7.29[ab]	8.04[a]	6.75[b]	0.36
Duodenal flow, kg/d	3.84	3.47	3.73	3.64	0.18
Fecal output, kg/d	3.44	3.58	3.57	3.61	0.12
NDF rate, %/h					
Rate of intake	3.96[a]	3.95[a]	3.31[b]	3.89[a]	0.16
Rate of passage	2.43	2.20	2.00	2.33	0.15
Rate of digestion	1.52[ab]	1.97[a]	1.32[b]	1.57[ab]	0.12
Rate of digestion (true)	4.09[a]	3.91[a]	2.39[b]	2.74[b]	0.30

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

differences existed among other diets. Relative to other treatments, cows fed oats had a longer ruminal residence time, which resulted in greater ruminal NDF fill than cows fed triticale or alfalfa diets. This high ruminal NDF content reflected the higher NDF content of oat silage and also the lower k_p and k_d of oat silage NDF in the rumen (Table 4).

Cows fed alfalfa, barley, or triticale silage had a similar k_i, which was greater than that for cows fed oat silage (Table 4). Dietary treatment did not affect k_p. Except for cows fed triticale, k_{dt} reflected k_i because k_p was similar among the other dietary treatments. The kinetic parameters for NDF (k_i and k_{dt}) provided further support that DMI was also influenced by rate of NDF digestion because, in general, cows with high k_{dt} also had high DMI.

Ruminal Fermentation

Mean ruminal pH was lower for cows fed alfalfa silage than for cows fed oat or barley silage (Table 5). Regression analysis of DMI against ruminal pH showed that the ruminal pH decreased by 0.349 for each kilogram of increase in DMI ($P = 0.05$; $R^2 = 0.12$; SE = 2.64). Staples et al. (25) observed a reduction in ruminal pH as intake increased from 55 to 100% of ad libitum intake. However, whether the lower ruminal pH of the cows fed alfalfa silage was a result of higher feed intake or a higher rate of ruminal digestion of the alfalfa diet is unclear. However, in addition to DMI, ruminal pH was also negatively correlated with k_i, k_d, and k_p.

As expected, the ruminal concentrations of lactate were highest at 0830 and 1830 h (one-half hour after feeding), and lowest at 0750 h (10 min before feeding; Figure 2). Both mean and maximum ruminal lactate concentrations were higher ($P < 0.05$) for diets containing cereal grain silage than for the alfalfa silage diet (Table 5 and Figure 2). In addition, cows fed barley or triticale silage had higher ruminal concentrations of lactate than did cows fed oat silage (Table 5). The higher ruminal concentration of lactate of cows fed the diet based on barley silage reflected the higher starch content of barley silage (7), but it is unclear why cows fed triticale silage had a higher ruminal concentration of lactate than cows fed oat silage. As lactate concentrations peaked within the 1st h after feeding, the observed differences in lactate concentrations could be attributed to an influence of forage source on k_i, k_{dt}, or the overall ruminal environment for bacteria that yielded lactic acid.

Total ruminal VFA concentrations were higher for cows fed alfalfa silage than for cows fed cereal silage, and no differences were significant among cows fed cereal silages (Table 5). The contribution of individual VFA to the total VFA concentration was markedly influenced by diet. In particular, cows fed alfalfa silage had significantly higher percentages of

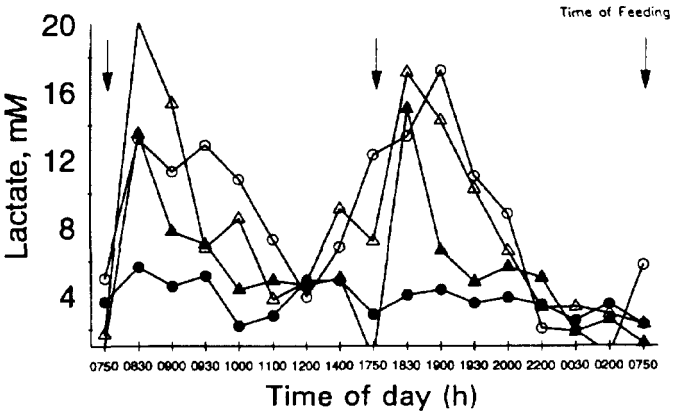

Figure 2. Diurnal patterns of ruminal lactate as influenced by dietary treatment: alfalfa (●), barley (○), oat (▲), or triticale (△).

TABLE 5. Influence of treatment on characteristics of ruminal fermentation.

	Diet				
	Alfalfa	Barley	Oat	Triticale	SEM
Ruminal pH	5.92[c]	6.04[a]	6.02[ab]	5.94[bc]	0.08
NH_3 N, mg/dl	40.6[a]	22.9[b]	22.6[b]	28.5[b]	6.16
Lactate					
Mean, m*M*	3.58[b]	8.67[a]	5.78[b]	8.02[a]	1.02
Maximum, m*M*	9.44[c]	20.60[b]	21.65[b]	30.15[a]	2.42
Total VFA, m*M*	97.63[a]	78.45[b]	71.80[b]	73.52[b]	3.55
VFA, mol/100 ml					
Acetate (A)	63.44[a]	58.81[bc]	60.48[b]	57.07[c]	0.69
Propionate (P)	20.67[c]	23.89[ab]	22.63[bc]	25.10[a]	0.68
Isobutyrate	1.38[a]	1.28[ab]	1.21[ab]	1.27[b]	0.05
Butyrate	10.73[c]	11.87[b]	11.79[b]	12.75[a]	0.27
Isovalerate	1.47	1.66	1.69	1.71	0.06
Valerate	1.96[b]	2.02[a]	1.77[a]	1.74[a]	0.12
Caproate	0.36[b]	0.48[a]	0.43[ab]	0.36[b]	0.03
A:P	3.12[a]	2.51[bc]	2.73[b]	2.31[c]	0.10

[a,b,c]Means in the same row with different superscripts differ ($P < 0.05$).

acetate and lower percentages of propionate and butyrate than cows fed cereal silages. The higher propionate contribution to total VFA for cows fed cereal silages was consistent with the higher lactate concentrations of cows fed these diets. Differences were also observed among cereal silages; cows fed triticale silage had lower acetate and higher propionate and butyrate percentages than did cows fed oat silage. The acetate:propionate ratio was highest for cows fed alfalfa silage, intermediate for cows fed oat or barley silage, and lowest for cows fed triticale silage. The higher concentration of total VFA for the cows fed alfalfa silage reflected the higher true ruminal digestion of alfalfa silage. Conversely, the higher percentages of propionate and butyrate could reflect the higher starch intakes and contents of diets based on cereal silage. However, theoretical calculated fermentation balance as outlined by Owens and Goetsch (16) (data not shown), indicated that energy output from acetate, propionate, and butyrate averaged 27.2 ± 0.5 Mcal and did not differ among dietary treatments. Because the differences in ruminal total VFA concentrations of cows fed cereal silages were not substantial, the VFA of cows fed cereal silage was apparently not affected by the source of the cereal silage. However, it is possible that VFA concentrations might not reflect production rates, especially if ruminal pH influenced relative rates of absorption of individual VFA.

Mean ruminal concentrations of NH_3 N were higher ($P < 0.05$) for cows fed the alfalfa silage diet than for cows fed the cereal silage diets (Table 5), which reflects the higher protein content of the alfalfa silage. Obara et al. (12) reported that ruminal concentrations of NH_3 N were positively related to N intake. Ruminal concentration of NH_3 N was numerically higher for the diet based on triticale silage than for the diets based on barley and oat silage. The contribution of dietary NAN to ruminal NH_3 N was dependent on the N content of the diet and the solubility and degradability of the dietary protein. Khorasani et al. (7) have reported the solubility of protein for barley, oat, and triticale silages used in this study as 68, 63, and 72%, respectively; therefore, the higher ruminal NH_3 N concentration of cows fed triticale silage might reflect the higher soluble protein content of triticale silage. Ruminal concentration of NH_3 N had diurnal characteristics; the lowest concentration was before the morning feeding, and the highest concentrations were between 1830 and 2000 h. For all diets, ruminal concentrations of NH_3 N were above the 5 mg/dl that Satter and Slyter (23) suggested were required to maximize growth of ruminal bacteria.

Ruminal Bacterial Yield

The effects of dietary treatments on duodenal N fractions, microbial N yield, and efficiency of bacterial N capture are shown in Table 6. Total N and NH_3 N flows at the duodenum were higher for the alfalfa and triticale diets than for the barley and oat diets. Duodenal N flow as a percentage of N intake ranged from 68.8% for cows fed alfalfa silage to 93.4% for cows fed triticale silage and appeared to be inversely related to N intake. Higher NH_3 N and total N flow to the

TABLE 6. Duodenal N fractions, including ruminal bacterial composition and yield, as influenced by dietary treatments.

Parameter	Diet				SEM
	Alfalfa	Barley	Oat	Triticale	
N Intake, g/d	637.4[a]	507.8[b]	431.8[c]	469.4[bc]	15.45
Duodenal N flow					
Total N, g/d	455.4[a]	383.3[b]	393.9[b]	446.8[a]	15.0
NH_3 N, g/d	13.9[a]	9.8	11.1[b]	10.7[b]	0.71
Non-NH_3 N, g/d	441.5[a]	376.2[b]	382.9[b]	436.2[a]	17.12
Percentage of N intake	68.8[b]	76.1[b]	88.7[a]	93.4[a]	5.12
Residual N, g/d	215.4[a]	119.9[c]	147.1[b]	181.3[ab]	17.09
Percentage of N intake	33.3[a]	24.9[b]	33.9[a]	38.1[a]	2.58
Bacterial					
Total N, % of OM	11.4	10.8	11.2	10.9	0.29
DAPA,[1] mg/g of OM	6.4	5.3	5.4	5.7	0.38
N, g/mmol of DAPA	3.51	3.98	4.00	3.65	0.21
N, g/d	226.1	256.3	235.8	254.9	16.33
N as % of N intake	35.5[b]	51.2[a]	54.7[a]	55.3[a]	3.52
N as % of non-NH_3 N	54.9[b]	74.6	64.9[b]	62.3[b]	4.23
Ruminal bacterial yield					
N, g/kg of ADOM[2]	30.9[b]	34.2[b]	39.4[ab]	47.9[a]	4.46
Protein captured,[3] %	57.0[b]	72.6	89.7[a]	100.0[a]	6.85

[a,b,c]Means in the same row with different superscripts differ ($P < 0.05$).

[1]Diaminopimelic acid.

[2]Apparently digested OM in the rumen.

[3]Protein captured = 100 × (bacterial CP)/(CP intake − residual).

duodenum of cows fed the alfalfa diet reflected the higher protein content of the alfalfa diet. On average, the alfalfa diet contained 30% more N than the cereal silage diets. Because dietary N intake was higher and because the N flow at the duodenum was lower for cows fed the barley diet than for cows fed the oat or triticale diets, more dietary N supplied by the barley diet was apparently absorbed from the rumen or, alternatively, N recycling to the rumen might have been lower. Dietary treatment did not affect total bacterial N flow to the duodenum, but bacterial N as a percentage of intake was substantially lower for the alfalfa silage diet than for the cereal silage diets, suggesting that RDP was in excess supply. Bacterial N as a percentage of NAN flow to the duodenum was higher for the barley diet, and no significant differences existed among other dietary treatments. Efficiency of microbial protein synthesis is most commonly expressed as grams of bacterial N per kilogram of OM apparently digested in the rumen. Efficiency of microbial protein synthesis per unit of OM apparently digested in the rumen differed for the diets based on alfalfa or triticale silage. The alfalfa diet, with a lower bacterial N yield as a percentage of dietary protein intake, also showed a lower efficiency of bacterial N capture; the triticale diet, with a higher bacterial N yield as a percentage of total N intake, resulted in a higher microbial efficiency (Table 6). When efficiency of bacterial N capture was calculated, based on actual bacterial CP yield and actual CP intake, the actual efficiency of bacterial N capture ranged between 57 to 100%; the NRC (11) assumed a capture efficiency of 90%. The alfalfa diet resulted in the lowest bacterial N capture efficiency (57%), and the triticale diet showed the highest value (100%). Because the NDF intake was similar for all diets, other factors might have accounted for the higher microbial efficiency of cows fed triticale silage. Rode et al. (20) concluded that the effect of diet on efficiency of microbial protein synthesis was primarily due to the physical nature of the diet rather than to its chemical composition. An increase in efficiency of microbial protein yield may require the use of additional dietary NAN because direct incorporation of peptide or AA may promote more efficient protein synthesis (5), but little direct evidence exists to support this view. However, the higher soluble fraction of triticale might contain a higher AA or peptide concentration because AA (9) and peptides (21) stimulate bacterial growth. The higher milk protein percentage of cows fed triticale silage also might have occurred as a result of higher microbial protein yield of cows fed the triticale silage diet. The barley and oat diets resulted in moderate bacterial N capture efficiency (73 and 90%, respectively).

Residual N was calculated by subtracting bacterial N and NH_3 N flow at the duodenum from the total N flow at the duodenum (Table 6). Thus, the residual N consisted of RUP, protozoa, and endogenous protein. The barley diet showed the lowest dietary residual N entering the duodenum, the alfalfa diet showed the highest, and the oat and triticale diets were intermediate. The higher dietary residual CP reaching the duodenum for cows fed alfalfa reflected the higher dietary CP and lower soluble protein content of alfalfa silage (7). The residual N as a percentage of dietary N intake for the alfalfa diet was 33.3%, which was lower than that observed for cows fed barley silage, but did not differ from that observed for cows fed oat or triticale silage. The residual N (in the TMR), measured using the in situ technique (7) with 10 to 24 h of incubation, was lower than the residual N calculated in this study. The in situ study also resulted in higher residual N for a TMR based on alfalfa silage compared with a TMR based on triticale silage; no differences existed among other treatments. However, in vivo, the residual N was lowest for the diet based on barley silage. No differences were observed among other dietary treatments. The lower residual N in the in situ study was expected because, in contrast to this in vivo study, endogenous N is removed when bags are washed as part of the in situ procedure.

For the in situ study (7), samples of fresh TMR were chopped three times before the samples were incubated in the rumen. Other factors, including particle size (10), also might have contributed to the differences in results between the in situ and in vivo studies.

Protein Balance

Based on NRC (11) requirements for 30 kg of milk yield and based on the calculated actual RUP in the present study (Table 6), both barley and oat silage diets were deficient in RUP. The diet based on alfalfa silage supplied extra RUP, and diets based on triticale silage were marginal in RUP supply (Figure 3). However, RDP appeared to have been marginal in cows fed the diets based on oat or triticale silage, but diets based on alfalfa or barley silage supplied excess RDP (Figure 3). Because NH_3 N was not deficient for microbial protein synthesis, the lower RUP from barley and oat silages might have been offset by increased bacterial protein supply to the intestine. Thus, the relative similarity among diets for cow performance might be indicative of the effects of both the degradability of N in the diet and microbial protein supplied to the duodenum. Because total protein intake of cows fed oat silage was lower than NRC (11) requirements, DMI could have been limited by a protein deficiency in cows fed oat silage, as was suggested by Small and Gordon (24). Judge and Gleeson (6) reported a response in silage DMI of 0.22 kg/100 g of supplementary CP intake, and, in a summary of four trials, Gordon et al. (4) reported a mean response that was equivalent to 0.05 kg/100 g of supplementary CP intake. However, a significant effect of dietary CP concentration on DMI for cows fed oat silage was unlikely because cows fed barley silage had similar DMI to those fed alfalfa silage even though dietary CP concentration was similar to that of the oat silage diet.

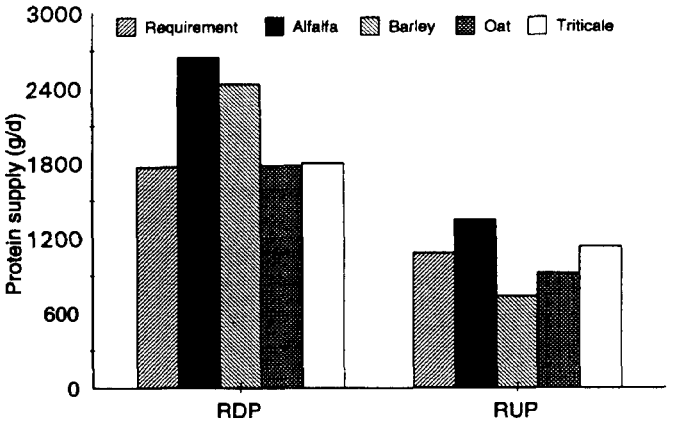

Figure 3. The RDP and RUP intakes relative to NRC (11) requirements of cows yielding 30 kg/d of milk.

Milk Yield and Milk Composition

The DMI expressed as kilograms per day or as a percentage of BW were higher for alfalfa and barley silage diets than for triticale and oat silage diets (Table 7), but BW of cows were not affected by dietary treatment. No differences existed among diets in yields of milk, 4% FCM, milk energy output, milk fat, protein, or lactose (Table 7). Milk from cows fed triticale silage contained a higher milk protein percentage than did milk from cows fed the other diets. Cows fed barley silage had a higher percentage of lactose in milk than did cows fed alfalfa silage; cows fed oat or triticale silage had intermediate percentages of lactose in milk. These results were in agreement with Christensen (2) and the production study (7), which showed that dietary silage source resulted in significant differences in DMI and CP intake but did not affect the milk yield of cows in early lactation.

TABLE 7. Influence of treatment on feed intake, milk yield, and milk composition.

	Diet				
	Alfalfa	Barley	Oat	Triticale	SEM
DMI					
kg/d	19.6[a]	18.6[a]	16.7[b]	17.2[b]	0.42
% of BW	3.29[a]	3.12[a]	2.83[b]	2.90[b]	0.06
Milk, kg/d					
Yield	31.6	31.5	30.1	30.2	0.51
4% FCM	29.1	27.7	27.3	26.6	0.78
Fat	1.10	1.01	1.01	0.97	0.05
Protein	0.95	0.96	0.90	0.94	0.02
Lactose	1.47	1.50	1.42	1.43	0.03
Milk composition, %					
Fat	3.50	3.23	3.45	3.21	0.14
Protein	3.01[b]	3.07[b]	3.04[b]	3.14[a]	0.03
Lactose	4.67[b]	4.80[a]	4.76[ab]	4.75[ab]	0.03
Milk energy,[1] Mcal/d	21.4	20.9	20.4	20.0	0.44
Gross efficiency, kg of milk/kg of DMI	1.61[c]	1.69[bc]	1.80[a]	1.76[ab]	0.03
BW, kg	596	596	590	591	4.9
BW Changes, g/d	-264	74	473	464	301

[a,b,c]Means in the same row with different superscripts differ ($P < 0.05$).

[1]Calculated according to Equation [1] of Tyrrell and Reid (26).

The lack of effect on milk yield, despite differences in DMI, CP intake, and lactate concentrations, and the higher concentration of total VFA for the cows fed alfalfa silage is intriguing. The theoretical calculated fermentation balance, as outlined by Owens and Goetsch (16) (data not shown), indicated that energy output from acetate, propionate, and butyrate averaged 27.2 ± 0.5 Mcal and did not differ among dietary treatments. In addition, calculated ATP per mole of glucose averaged 4.78 ± 0.01 and did not differ among treatments. Thus, despite differences in VFA concentrations, cows fed the various diets averaged similar amounts of energy and thus had similar milk yields.

CONCLUSIONS

Data for DMI and milk yield from this metabolic study were similar to those when these diets were fed in a production study (7), indicating that ruminal and duodenal cannulation did not influence performance. In general, the forestomach and whole-tract digestibilities for the oat and triticale silage diets were slightly lower than the forestomach and whole-tract digestibilities for the barley and alfalfa silage diets. Thus, the lower forestomach digestion of the oat diet reflected a lower true rate of NDF digestion, lower rate of passage, and higher ruminal turnover time. In the present study, as was reported previously (7), the correlation was negative between dietary NDF concentration and DMI ($P = 0.06$; $R^2 = 0.89$); for each percentage unit of NDF, the DMI was reduced by 0.94 kg/d. However, in addition to NDF concentration, rate of NDF digestion was also an important contributor to DMI. Source of silage influenced ruminal metabolites and concentrations; the N content of the triticale silage was probably used more efficiently for bacterial N yield than the N content of the other silages. We concluded that the source of silage did not significantly influence milk yield, although treatment differences were found for DMI, CP intake, VFA concentrations, lactate concentrations, and milk components. The absence of treatment differences in milk yield could reflect the fact that theoretical calculated fermentation balance indicated that energy output from various substrates did not differ among dietary treatments.

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