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# Low- and High-Quality Forage Utilization by Heifers and Mature Beef Cows<sup>1,2</sup>

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**ABSTRACT:** Eight cows (7 to 9 yr old, 522 kg) and six heifers (10 mo old, 169 kg) were fed either alfalfa hay (18.7% CP) or mature brome hay (5.1% CP) to determine the effect of cattle age on apparent forage utilization. Cattle were fitted with ruminal and duodenal cannulas and were individually fed once daily (ad libitum intake, 1000). The split-plot design consisted of age (whole-plot) and two sampling periods feeding alfalfa or brome hay (subplot). Each period consisted of 28 d: d 1 to 13 for adaptation, d 13 to 20 for feed intake determination, and d 20 to 28 for sampling. Nylon bags containing NDF substrate from alfalfa or brome hay were incubated ruminally for 0, 3, 6, 12, 24, 48, 96, and 192 h to determine the rate and extent of fiber degradation. Ruminal liquid dilution rate and fermentation characteristics were conducted on d 27. Ruminal

fill was determined by total evacuation at 0800 on d 28. Cows consumed more feed (BW<sup>.75</sup>;  $P < .01$ ) and had greater ruminal OM fill ( $P = .04$ ) but had similar fluid fill ( $P = .88$ ) compared with heifers. Ruminal liquid dilution rate was greater in cows than in heifers ( $P < .01$ ). The rate of in situ NDF degradation was 3 and .5% per hour greater in cows than in heifers when alfalfa and brome hay were fed, respectively (age  $\times$  hay,  $P < .01$ ). Ruminal NDF digestibility as a percentage of intake was greater in cows than in heifers ( $P < .01$ ). Numbers of ruminal cellulolytic bacteria were not affected by treatment ( $P > .21$ ). These data indicate that mature cows have a smaller ruminal fluid fill that turns over more rapidly, and this may be responsible for a faster rate of ruminal fiber degradation in cows than in young heifers.

Key Words: Beef Cows, Heifers, Forage, Intake, Digestibility

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## Introduction

When high-quality forage (21% CP; Moran, 1976) or forage plus concentrate diets are fed (Ledger et al., 1970; O'Donovan et al., 1978), *Bos taurus* cattle consume more feed relative to their maintenance requirement, thereby gaining faster and more efficiently than *Bos indicus* cattle. When low-quality forage is fed, the opposite occurs. While consuming low-quality forage, *Bos indicus* cattle have had greater total tract digestibility (Ashton, 1962) and ADG than *Bos taurus* cattle (Frisch and Vercoe, 1969; Thompson et al., 1981). Im-

proved utilization of low-quality forage by *Bos indicus* cattle has been attributed to their lower maintenance requirement (Frisch and Vercoe, 1977). Also, *Bos indicus* cattle have a faster rate of ruminal fiber degradation than do *Bos taurus* cattle (Hunter and Siebert, 1985a,b) when low-quality forage is fed (4.7% CP); this may be a consequence of higher ruminal ammonia concentration.

The effect of age on diet utilization has been studied less extensively. When diets of high-quality forage (> 16% CP) or forage plus concentrate were fed to sheep (Graham and Searle, 1972; Weston and Morgan, 1979; Graham, 1980) or cattle (Blaxter et al., 1966), age had no effect. Egan and Doyle (1982) reported that when high-quality forage was fed (17% CP) young lambs consumed more feed than aged wethers (per unit BW), but when low-quality forage was fed (4.3% CP) young lambs could not be sustained for long periods. This observation can be explained in part by the fact that young lambs have a greater energy requirement per unit of BW. Alternatively, aged wethers may be better able to utilize low-quality forage (greater intake and/or digestibility). Whether the ability to utilize low-quality forage in ruminants is a function of nutrient requirements or whether there are differences in ruminal digestive physiology has not been reported. Therefore, the objective of this study was to determine whether mature

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<sup>2</sup>Mention of a trade name or manufacturer does not constitute a guarantee or warranty of the product by the USDA or an endorsement over products not mentioned.

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Table 1. Diet composition

Ingredient	Percentage of diet
Alfalfa or brome hay <sup>a</sup>	99.4
Salt	.25
Chromic oxide	.25
Trace mineral premix <sup>b</sup>	.05
Vitamin ADE premix <sup>c</sup>	.05

<sup>a</sup>Alfalfa hay contained 93.9% OM, 18.7% CP, and 51.6% NDF, and brome hay contained 95.2% OM, 5.1% CP, and 72.6% NDF (DM basis).

<sup>b</sup>12% Ca, 12% Zn, 8% Mn, 10% Fe, 1.5% Cu, .2% I, and .1% Co.

<sup>c</sup>Each gram contained 8,800 IU of vitamin A, 880 IU of vitamin D, and .88 IU of vitamin E.

cows differ from heifers in their ruminal metabolism of low- and high-quality forage.

## Materials and Methods

*Animals, Diets, and Design.* Eight cows and six heifers were selected from the MARC III herd, gentled, and surgically fitted with ruminal and duodenal cannulas (Rupp et al., 1994). The experiment and the surgeries were approved by the U.S. Meat Animal Research Center's Animal Care and Use Committee. Gentling of the animals occurred in March, surgeries were conducted in April, and the experiment began May 15. At the start of the experiment, cows were 7 to 9 yr old and weighed 522 kg (SE = 9.8). The heifers were 10 mo old and weighed 168 kg (SE = 11.3).

After surgery, cattle were placed individually in open lot pens. Pens had concrete flooring, were 3.5 m wide and 20 m long, and a roof covered the front one-third of each pen. For digesta sampling, cattle were placed in individual stalls in a metabolism barn for 8 d. The stalls were 1 m wide, 2 m long, and fitted with rubber mats, and cattle were washed daily. The barn had continuous lighting and mechanical ventilation. Cattle were trained to this routine, and feed intake in the metabolism barn was similar to feed intake in the open lot pen.

The experiment consisted of a split-plot design. The whole-plot was completely randomized, and the comparison was cows vs heifers. The subplot consisted of two sampling periods similar to a crossover design. In Period 1, four cows and three heifers were fed chopped alfalfa hay (18.7% CP), and the other four cows and three heifers received chopped brome hay (5.1% CP; Table 1). Body weight was determined at the beginning and end of each period (d 0 and 29). Diets were consumed ad libitum and offered to achieve 15% orts, and during Period 2 dietary treatments were reversed. Daily orts were removed, weighed, and placed back in the feedbunk before feeding. Because of this feeding protocol, orts were not analyzed for chromium or nutrient content.

Bromegrass hay was harvested in September as first-cutting hay. It was baled and stored in the field for 8 mo before the experiment began. Alfalfa hay was second-

cutting, at early bloom, harvested, baled, and stored similar to the brome hay. Before the experiment began, hay was ground through a tub grinder that had a 13-cm screen. The ground hay was mixed with the other ingredients (Table 1) and stored under an open-front shed. Using plastic tubs, the mixed diet was transferred and fed to the animals daily. Chromic oxide was mixed with the complete diet to allow chromium to be used as a digesta flow marker (Varel and Kreikemeier, 1994). To determine chromium intake, we sampled hay in the bunk. The concentration of chromium in the mixed diet at the feedbunk compared with what was added to the diet was 85% for brome hay and 98% for alfalfa hay.

*Sampling and Laboratory Analysis.* On d 20 of each period, cattle were moved to the metabolism barn and placed in individual stalls described previously. Because of the bulkiness of feed and small feed pans, animals were fed at 0800, 1500, and 2100 daily so that feed was available at all times.

In situ fiber degradation measurements began on d 20. Dacron bags (Ankom Products, Fairport, NY; 5 × 10 cm; 53 ± 10 μm pore size) containing .5 g of NDF substrate from alfalfa or bromegrass hay were incubated in the rumen of each cow. The NDF substrates were prepared by grinding the hay to particles 1 mm in diameter in a Wiley mill and boiling them for 1 h with neutral detergent, followed by extensive washing of the insoluble residue to remove the detergent (Van Soest and Robertson, 1980). Alfalfa NDF was incubated when alfalfa was fed, and bromegrass NDF was incubated when bromegrass was fed. The bags were closed with a #4 rubber stopper and two size-12 rubber bands. These bags were placed in a large nylon-mesh bag (38 × 46 cm), that was inserted into the rumen. Bags were put into the rumen in reverse order, and all bags were removed from the rumen at 0700 on d 28, washed in cold tap water (including 0-h bags) until rinse water was clear, and frozen (−20°C) for later analysis. Incubation times were 0, 3, 6, 12, 24, 48, 96, and 192 h. Fiber loss from washing the 0-h bags was less than 1%; therefore, no mathematical adjustment was made for fiber disappearance from the other bags. Neutral detergent fiber, ADF, and ADL residues in the Dacron bags, feed, duodenal, and fecal samples were determined using the sequential detergent analysis system (Van Soest and Robertson, 1980; Van Soest et al., 1991). Duodenal, feed, and fecal samples were analyzed for DM, OM, ash, and N with standard procedures (AOAC, 1990). We calculated rate and extent of fiber degradation using nonlinear procedures of SAS (1989). The method was Marquardt, and the model was described in detail by Grant and Mertens (1992).

On d 26 at 0700, approximately 200 g of ruminal fluid was collected, blended for 1 min with a Waring blender at high speed, while gassing with CO<sub>2</sub>, and filtered through four layers of cheesecloth. Serial dilutions were made in an anaerobic buffer (Varel and Dehority, 1989). Total anaerobic and cellulolytic bacteria were enumerated using the Hungate anaerobic culture method de-

scribed by Bryant (1972). The medium used to determine total viable bacteria contained the following (per 100 mL): clarified ruminal fluid (filtered through eight layers of cheesecloth and centrifuged at  $20,000 \times g$  for 10 min), 30.0 mL; glucose, cellobiose, maltose, starch, xylose, and glycerol, .03 g each; Trypticase (BBL Microbiology Systems, Cockeysville, MD), .2 g; resazurin, .0001 g; mineral S2, 5 mL (Salanitro et al., 1974); and purified agar (BBL), 1.75 g. Sodium carbonate (.4%) and cysteine hydrochloride (.05%) were added as sterile anaerobic solutions after the medium was autoclaved (Bryant, 1972). Roll tubes (four replicates) were incubated at  $37^\circ\text{C}$ , and colonies were counted after 7 d. The composition of the cellulose agar roll tube medium was as follows (per 100 mL): clarified, preincubated ruminal fluid (Dehority and Grubb, 1976), 15 mL; Trypticase, .2 g; yeast extract, .05 g; mineral S2, 5 mL; cellulose (Whatman no. 1 filter paper ball milled with flint pebbles for 18 h), .2 g; resazurin, .0001 g;  $\text{Na}_2\text{CO}_3$ , .4 g; cysteine hydrochloride, .05 g; and purified agar, .7 g. Four replicates of these tubes were incubated for 2 wk before zones of clearing were counted. Fifteen cellulolytic isolates per ruminal fluid sample ( $10^7$  dilution) were identified with methods previously published (Varel and Dehority, 1989). Also on d 26, 1,200 g of ruminal fluid was collected to harvest bacterial cells by differential centrifugation. The ruminal fluid was combined with an equal amount of saline (.9% wt:wt) and frozen. Samples were thawed at room temperature, blended for 1 min in a Waring blender at maximum speed, passed through four layers of cheesecloth, and centrifuged at  $500 \times g$  for 5 min (two times) to remove feed particles and protozoa. Bacteria were then separated from the supernatant by centrifuging for 20 min at  $20,000 \times g$ . The pellet was washed with .9% NaCl (wt/vol), recentrifuged ( $20,000 \times g$ ), and rinsed with distilled water. The resulting bacterial suspension was freeze-dried, and purines were determined for these samples and for duodenal samples using the procedures of Ushida et al. (1985) and Zinn and Owens (1986).

Chromic oxide was used as a digesta flow marker. Duodenal digesta samples were collected (150 g) at 0700, 1400, and 2000 daily for three consecutive days (d 22 to 24). Fecal grab samples were collected (150 g) once daily for five consecutive days: d 21 at 1400, d 22 at 2000, d 23 at 0700, d 24 at 1400, and d 25 at 2000. Duodenal and fecal samples were stored frozen ( $-20^\circ\text{C}$ ), lyophilized, ground in a blender (60 s at maximum speed), composited within sampling site (weight basis), and analyzed for OM, N, and Cr as described below.

Cobalt EDTA was dosed intraruminally on d 26 at 0800, with 2 g of CoEDTA dissolved in 400 mL of distilled water for cows and 1 g dissolved in 200 mL for heifers to serve as a fluid-phase marker (Uden et al., 1980). Ruminal samples were collected at 0 (before dosing), 1, 3, 6, 9, 12, and 24 h after dosing and pH was determined. A subsample of the ruminal fluid was combined with 25% (wt/vol) metaphosphoric acid (4:1 ratio) for VFA analysis. Another subsample was combined

with .1 N HCl (1:1 ratio) for ammonia analysis. Subsamples were also retained for Co analysis to estimate ruminal fluid dilution rate.

Duodenal, fecal, and feed samples were prepared and analyzed for Cr with the method of Williams et al. (1962). Ruminal fluid samples were thawed and centrifuged at  $10,000 \times g$  for 10 min, and the supernate was analyzed for Co with atomic absorption spectroscopy. Liquid dilution rates were calculated as described by Jacques et al. (1986). The supernate was also analyzed for ammonia using automated procedures (Technicon Industrial Systems, 1974) and for VFA after it was passed through a membrane filter with .22- $\mu\text{m}$  pores (Millipore, New Bedford, MA). Volatile fatty acid samples were analyzed with a Hewlett-Packard model 5840A (Avondale, PA) gas chromatograph as described previously (Varel et al., 1980).

Ruminal and postruminal digestibilities were estimated using the marker ratio technique (Merchen, 1988). Duodenal bacterial N flows were determined using purines as a microbial marker (Zinn and Owens, 1986). Microbial efficiency was calculated by dividing duodenal microbial N flow (grams) by the quantity (kilograms) of OM truly fermented in the rumen.

All ruminal contents were manually evacuated on d 28 at 0700. Ruminal contents were weighed, subsampled (500 g), and returned to the rumen. The subsample was analyzed for DM and OM. Ruminal fill of fluid was calculated as total digesta weight times digesta moisture content. Organic matter fill was calculated as digesta weight  $\times$  dry matter  $\times$  organic matter, allowing us to calculate ruminal fill of fluid and OM.

*Statistical Analysis.* Data for feed intake, site and extent of digestion, microbial counts, ruminal fill, fluid passage rates, and rate and extent of in situ fiber degradation were analyzed as a split-plot design using GLM procedures of SAS (1989). The model included age, animal nested within age, period, hay, and the hay  $\times$  age interaction. Significance of age effects were tested using mean squares of animal within age as the error term (whole-plot). Significance of hay and the hay  $\times$  age interaction were tested using the residual mean squares as the error term (subplot).

Data on ruminal fermentation characteristics (VFA,  $\text{NH}_3$ , and pH) were analyzed using a split-split-plot analysis. The model included those terms of the split-plot model just described, and period  $\times$  hay  $\times$  animal nested within age, sampling time, sample time  $\times$  age, sampling time  $\times$  hay, and sampling time  $\times$  age  $\times$  hay. Mean squares due to period  $\times$  hay  $\times$  animal nested within age were used to test significance of hay and the hay  $\times$  age interaction. Significance of sampling time and its interactions were tested with residual mean squares of the split-split-plot model just described.

## Results and Discussion

*Feed Intake and Ruminal Fill.* Feed OM intake, expressed per kilogram of BW, did not differ between cows

Table 2. Feed intake and ruminal fill in cows and heifers consuming low- and high-quality forage

Item	Alfalfa hay		Brome hay		SE	Significance <sup>a</sup>		
	Cow	Heifer	Cow	Heifer		Age	Hay	X
No. of observations	8	6	8	6	—	—	—	—
BW, kg	533	171	510	167	4.5	.01	.01	.06
BW <sup>.75</sup> , kg	111	47	107	46	.73	.01	.01	.09
OM intake								
g/d	10,538	3,561	9,077	2,657	239	.01	.01	.27
g/kg BW	19.7	20.7	17.8	15.7	.9	.63	.01	.14
g/kg BW <sup>.75</sup>	94.9	74.8	84.7	56.6	3.5	.01	.01	.28
Ruminal OM fill								
g	7,278	2,210	7,938	2,680	310	.01	.09	.76
g/kg BW	13.5	12.9	15.5	16.0	.75	.97	.01	.53
g/kg BW <sup>.75</sup>	65	47	74	57	3.3	.04	.01	.76
Ruminal fluid fill								
kg	47.4	19.2	51.0	23.4	1.6	.01	.03	.84
g/kg BW	88	112	99	141	4.3	.01	.01	.08
g/kg BW <sup>.75</sup>	424	406	473	505	17	.88	.01	.16

<sup>a</sup>Probability that treatment effects were due to chance. The age × hay interaction is denoted as “X”.

and heifers ( $P = .63$ ), but cattle consumed more OM when alfalfa hay was fed than when brome hay was fed ( $P < .01$ ; Table 2). Ruminal fill of OM was similar between cows and heifers ( $P = .97$ ; g/kg BW), and ruminal fill was greater in cattle fed brome hay than in cattle fed alfalfa hay ( $P < .01$ ). Ruminal fluid fill (g/kg BW) was greater in heifers than in cows ( $P < .01$ ) and greater when brome hay was fed than when alfalfa hay was fed ( $P < .01$ ). When expressed per unit of metabolic body weight (BW<sup>.75</sup>), cows consumed more feed ( $P < .01$ ) and had greater ruminal OM fill ( $P = .04$ ) but had similar fluid fill ( $P = .88$ ) compared with heifers.

Based on feed intake and ruminal fill, mature cows seem to be able to utilize high- and low-quality forages better than young heifers, because mature cows consume more forage OM per unit of metabolic body weight

(BW<sup>.75</sup>). Per kilogram of BW, ruminal OM fill was similar in cows and heifers, but fluid fill was much greater in heifers. Per unit of metabolic body weight (BW<sup>.75</sup>), ruminal fluid fill was similar between cows and heifers.

*Ruminal Liquid Dilution Rate, Fiber Degradation, and Cellulolytic Bacterial Numbers.* Ruminal liquid dilution rate was greater in cows than in heifers ( $P < .01$ ) and greater when alfalfa hay was fed than when brome hay was fed ( $P < .01$ ; Table 3). The rate of in situ ruminal NDF degradation was 3% per hour greater in cows than in heifers when alfalfa hay was fed and .5% per hour greater in cows when brome hay was fed, resulting in an age × hay interaction ( $P < .01$ ). The extent of ruminal fiber degradation in situ was not affected by age ( $P = .91$ ) but was greater ( $P < .01$ ) for brome hay than for alfalfa hay. Number of ruminal cellulolytic bacteria was

Table 3. Ruminal liquid dilution rate, in situ NDF degradation, and ruminal cellulolytic bacterial counts in cows and heifers consuming low- or high-quality forage

Item	Alfalfa hay		Brome hay		SE	Significance <sup>a</sup>		
	Cow	Heifer	Cow	Heifer		Age	Hay	X
Ruminal liquid dilution rate, %/h	11.6	8.8	11.0	6.7	.44	.01	.01	.13
In situ NDF disappearance								
Rate, %/h	9.56	6.48	3.54	3.09	.25	.01	.01	.01
Extent, %	41.4	42.5	70.3	69.3	.58	.91	.01	.10
Ruminal bacteria								
Total ( $\times 10^9$ ) <sup>b</sup>	3.59	3.29	3.38	2.37	.61	.21	.38	.58
Cellulolytic ( $\times 10^7$ ) <sup>b</sup>								
<i>Butyrivibrio</i> spp.	58.4	46.7	47.5	53.3	6.8	.57	.76	.22
<i>R. flavefaciens</i>	15.8	27.8	25.0	22.2	6.1	.44	.77	.25
<i>R. albus</i>	13.3	17.8	15.8	11.1	3.5	.98	.56	.22
<i>Fibrobacter succinogenes</i>	0	2.2	0	1.1	.8	.02	.50	.50

<sup>a</sup>Probability that treatment effects were due to chance. The age × hay interaction is denoted as “X”.

<sup>b</sup>Expressed per milliliter of ruminal fluid.

not affected by treatment ( $P > .21$ ). *Butyrivibrio* spp. represented 51%, *Ruminococcus flavefaciens* 23%, and *Ruminococcus albus* 15% of the total cellulolytic bacteria, and their proportions were unaffected by treatment ( $P > .22$ ). The proportion of *Fibrobacter succinogenes* was greater in heifers than in cows ( $P = .02$ ), but these bacteria accounted for less than 2% of the cellulolytic population.

A more rapid rate in ruminal fiber degradation in cows may have been due to the increased turnover of the ruminal liquid pool, which would have influenced the removal of fermentation end products and the introduction of fresh fluid substrate (buffer and minerals). Number of ruminal cellulolytic bacteria is not a good indicator of fiber degradation. Recently, Dehority and Tirabasso (1998) concluded that the concentration of cellulolytic bacteria is not the limiting factor in digestion of cellulose in the rumen.

The ruminal liquid pool turned over more rapidly in cows than in heifers. It is interesting that the liquid pool was 27 to 42% smaller in cows (kg BW), and its turnover was 31 to 64% greater.

**Fermentation End Products.** Ruminal pH was higher in cows than in heifers ( $P < .02$ ), and it was not affected by hay (Table 4). There was an age  $\times$  hour after feeding interaction for ruminal pH and VFA ( $P < .01$ ; Figure 1). Before feeding (0 h) and at 1 h after feeding, ruminal pH was similar between cows and heifers ( $P > .05$ ), whereas at 3 to 24 h after feeding ruminal pH was greater in cows than in heifers ( $P < .01$ ). Ruminal  $\text{NH}_3\text{N}$  concentration was greater in cattle fed alfalfa hay than in cattle fed brome hay ( $P < .01$ ), and it was greater in heifers than in cows ( $P < .01$ ). Ruminal concentration of total VFA was numerically greater in cows than in heifers ( $P = .16$ ), and it was greater when alfalfa hay was fed than when brome hay was fed ( $P < .01$ ). There was also an age  $\times$  hour after feeding interaction ( $P < .01$ ) for total VFA concentration (Figure 1). At 6 h after feeding, VFA concentrations for cows and heifers were similar ( $P = .66$ ), and at all other times values for cows were greater than those for heifers ( $P < .05$ ). Although

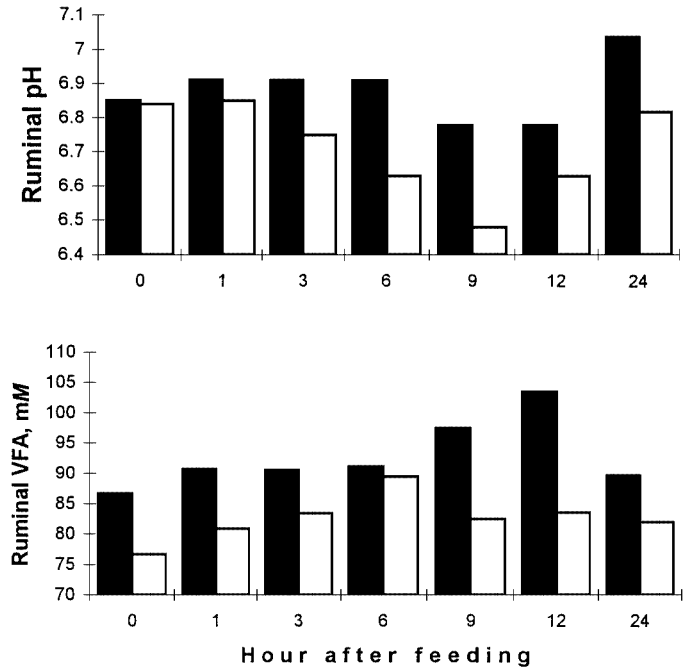


Figure 1. The effect of cows (solid bars) vs heifers (open bars) and hour after feeding on ruminal pH (upper graph) and total VFA concentration (lower graph). In each case the age  $\times$  hour after feeding interaction was significant ( $P < .01$ ). There are eight observations per data point (bar) for cows and six for heifers. For ruminal pH, the pooled SD = .141, and pH between cows and heifers was similar at 0 and 1 h after feeding ( $P > .30$ ) but different at 3 to 24 h after feeding ( $P < .01$ ). For ruminal concentration of total VFA, the pooled SD = 9.16, and VFA concentration between cows and heifers was similar at 6 h after feeding ( $P = .66$ ) but different at all other times ( $P < .05$ ).

there was an age  $\times$  hay interaction for the proportion of acetate ( $P = .08$ ), propionate ( $P = .04$ ), butyrate ( $P < .01$ ), and isovalerate ( $P < .01$ ), the numerical differences due to treatment were small. For isobutyrate and valer-

Table 4. Ruminal pH and  $\text{NH}_3\text{N}$  and VFA concentrations in cows and heifers consuming low- and high-quality forage

Item	Alfalfa hay		Brome hay		SE	Significance <sup>a</sup>		
	Cow	Heifer	Cow	Heifer		Age	Hay	X
Ruminal pH	6.93	6.65	6.84	6.78	.06	.02	.78	.11
Ruminal $\text{NH}_3\text{N}$ , mM	4.06	5.23	.31	1.13	.22	.01	.01	.43
Total VFA, mM	110	97	76	68	3.9	.16	.01	.52
VFA proportions, mol/100 mol								
Acetate	74.2	72.9	72.7	73.3	.48	.51	.23	.08
Propionate	15.5	15.3	18.5	17.1	.3	.01	.01	.04
Butyrate	5.5	7.5	6.8	7.6	.19	.02	.01	.01
Isobutyrate	1.5	1.4	.7	.7	.05	.97	.01	.23
Valerate	1.5	1.4	.7	.6	.03	.01	.01	.36
Isovalerate	1.8	1.5	.4	.6	.08	.37	.01	.01

<sup>a</sup>Probability that treatment effects were due to chance. The age  $\times$  hay interaction is denoted as "X".

Table 5. Body weight, feed intake, and site of nutrient digestion in cows and heifers consuming low- and high-quality forage

Item	Alfalfa hay		Brome hay		SE	Significance <sup>a</sup>		
	Cow	Heifer	Cow	Heifer		Age	Hay	X
OM intake, g/d	10,550	3,560	9,090	2,654	240	.01	.01	.27
Duodenal OM flow, g/d								
Microbial	1,070	400	820	255	58	.01	.01	.39
Nonmicrobial	5,373	2,014	5,260	1,709	155	.01	.20	.55
True ruminal OM digestion								
% of Intake	48.9	42.8	42.0	35.7	1.5	.02	.01	.97
% of Total tract digestion	79.5	72.7	79.7	70.8	2.8	.01	.77	.71
Fecal OM output, g/d	4,035	1,471	4,298	1,339	115	.01	.58	.11
Total tract OM digestion,								
% of Intake	61.6	58.6	52.3	51.2	1.7	.34	.01	.65
NDF intake, g/d	5,793	1,957	6,924	2,026	142	.01	.01	.01
NDF flow, g/d								
Duodenal	3,714	1,405	3,838	1,376	145	.01	.75	.61
Fecal	2,836	980	3,137	969	92	.01	.14	.12
Ruminal NDF digestion								
% of Intake	35.5	27.8	44.5	31.8	2.8	.01	.04	.39
% of Total tract digestion	70.1	55.0	81.6	60.1	5.8	.01	.18	.60
Total tract NDF digestion								
% of Intake	50.8	49.7	54.5	54.0	1.9	.78	.06	.89
N intake, g/d	359	121	125	37	9.4	.01	.01	.01
Duodenal N flow, g/d								
Microbial	107	35	63	20	5.1	.01	.01	.02
Nonmicrobial	127	52	70	22	3.3	.01	.01	.01
Microbial efficiency <sup>b</sup>	20.8	22.7	16.9	19.2	1.6	.39	.04	.89
Fecal N output, g/d	77	31	48	17	2.0	.01	.01	.01

<sup>a</sup>Probability that treatment effects were due to chance. The age × hay interaction is denoted as "X".

<sup>b</sup>Grams of microbial N synthesized in the rumen per kilogram of OM truly fermented in the rumen.

ate, the effect of hay was significant ( $P < .01$ ), their proportion was greater when alfalfa hay was fed.

Higher ruminal pH in cows than in heifers was likely due to the greater ruminal liquid dilution rate, thereby introducing more saliva buffering compounds. Lower concentration of ruminal ammonia and a greater concentration of VFA in ruminal fluid is consistent with an increased rate of fermentation and a smaller ruminal fluid pool.

*Site of Digestion.* Microbial OM flow at the duodenum was greater in cows than in heifers ( $P < .01$ ) and greater in cattle fed alfalfa ( $P < .01$ ) than in cattle fed brome hay (Table 5). Nonmicrobial OM flow was greater in cows than in heifers ( $P < .01$ ) and was unaffected ( $P = .20$ ) by hay. Ruminal fermentation of OM (true) expressed as a percentage of intake was greater in cows than in heifers ( $P = .02$ ) and greater when alfalfa hay was fed than when brome hay was fed ( $P < .01$ ). When ruminal OM fermentation was expressed as a percentage of total tract OM disappearance, only the effect of age was significant, being greater in cows than in heifers ( $P < .01$ ). Total tract OM digestibility for alfalfa hay was greater than for brome hay ( $P < .01$ ).

Duodenal and fecal NDF flows were greater in cows than in heifers ( $P < .01$ ) and unaffected ( $P > .10$ ) by hay

(Table 5). Ruminal NDF digestibility as a percentage of intake was greater in cows than in heifers ( $P < .01$ ) and greater when alfalfa hay was fed than when brome hay was fed ( $P = .04$ ). Expressed as a percentage of total tract NDF digestion, more NDF was fermented in the rumen of cows than in the rumen of heifers ( $P < .01$ ). Total tract NDF digestibility was greater for brome hay than for alfalfa hay ( $P = .06$ ). For N intake, duodenal microbial N flow, duodenal nonmicrobial N flow, and fecal N output, there was an age × hay interaction ( $P < .02$ ), whereas for microbial efficiency (microbial protein synthesis) there was only an effect of hay type ( $P = .04$ ); more microbial N was synthesized in the rumen when alfalfa hay was fed.

Total tract NDF digestibility was similar between cows and heifers (Table 5). However, the proportion of NDF digested in the total tract that was fermented in the rumen was much higher in cows than in heifers. This might be most easily explained by the more rapid rate of ruminal fiber degradation that occurred in cows compared with heifers.

In terms of ruminal microbial protein synthesis, the N economy of the cattle did not seem to be affected by age. Although there were no significant age effects for microbial efficiency ( $P = .39$ ), it was 9 to 13% greater

in heifers than in cows (Table 5). Conversely, total tract OM digestion was similar in cows and in heifers, but the proportion fermented ruminally was 14 to 17% greater in cows than in heifers. Therefore, within hay type, the proportion of N intake flowing at the duodenum as microbial N was similar in cows and heifers.

### Implications

Mature cows are able to consume 27 and 50% more alfalfa and brome hay, respectively, per unit of metabolic body weight than 10-mo-old heifers. Improved forage utilization in cows seems to be partially due to increased digestive function. Ruminal liquid dilution rate and the rate of ruminal fiber degradation seems faster in cows than in heifers. This information provides a rational explanation for how mature beef cows are able to utilize low-quality forages to a greater extent than do young growing cattle. Because cows derive more total energy from their ruminal fermentation and have a lower maintenance energy requirement than heifers, higher-quality diets will be required for heifers than for cows to achieve acceptable performance.

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