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Effects of sorghum grain processing and forage fiber source on milk production, digestibility and kinetics of passage in Holstein cows

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EFFECTS OF SORGHUM GRAIN PROCESSING AND FORAGE FIBER SOURCE ON MILK PRODUCTION, DIGESTIBILITY AND KINETICS OF PASSAGE IN HOLSTEIN COWS

by

Matthew Henry Poore

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As members of the Final Examination Committee, we certify that we have read the dissertation prepared by Matthew Henry Poore entitled EFFECTS OF SORGHUM GRAIN PROCESSING AND FORAGE FIBER SOURCE ON MILK PRODUCTION, DIGESTIBILITY AND KINETICS OF PASSAGE IN HOLSTEIN COWS

and recommend that it be accepted as fulfilling the dissertation requirement for the Degree of Doctor of Philosophy.

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Final approval and acceptance of this dissertation is contingent upon the candidate's submission of the final copy of the dissertation to the Graduate College.

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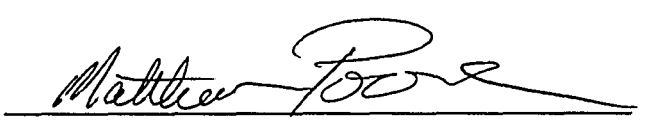
SIGNED: 

DEDICATION

This dissertation is dedicated to my parents, Dr. and Mrs. Henry W. Poore and the rest of my family. Their encouragement has seen me through a lot of tough times.

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ABSTRACT

Experiments were conducted to determine effects of source of forage and starch degradability on milk production, digestibility and passage in Holstein cows. A preliminary experiment showed that sampling site, dosing time and passage model had little influence on passage parameter estimates for grain in lactating cows. Mean retention times were 17 and 25 h for duodenal and fecal sampling, respectively, and 16 and 18 h at the duodenal site and 24 and 26 h at the fecal site for doses given before rather than after feeding, respectively.

In an 8 wk trial, cows in early lactation were fed diets with 30% neutral detergent fiber (NDF) with forage NDF from wheat straw or alfalfa hay in proportions of 0:3, 1:2, 2:1 or 3:0. Intake and milk yield were not influenced, milk fat percentage, acetate to propionate ratio (C2:C3) and persistence were decreased with increasing straw, and yield of FCM decreased on all straw. Ratio of forage NDF to ruminally degradable starch (FNDF:RDS) was 1.10, 1.01, .92 and .84 in 0:3, 1:2, 2:1 and 3:0 diets, respectively, and it was concluded that a ratio of <1:1 would result in low C2:C3, and poor persistence.

In another 8 wk trial, cows were fed diets formulated to contain equal forage NDF from wheat straw or alfalfa hay, and steam-flaked or dry-rolled sorghum grain in a 2 x 2 factorial arrangement of treatments.

All diets had a FNDF:RDS >1:1. Forage source did not influence any performance parameter nor did forage source interact with grain processing. Steam-flaking grain increased milk yield 12%, milk protein yield 14% and improved efficiency and persistence. Although milk fat percentage was decreased from 3.6 to 3.2, yield of milk fat was not influenced. It was concluded that increasing starch degradability may improve performance if the ratio of FNDF:RDS is maintained > 1:1.

In the last experiment, duodenally cannulated cows were fed diets similar to those in the second lactation trial, except straw was substituted for 2/3 of the alfalfa hay on an NDF basis. Substituting straw for alfalfa did not influence flow of OM, starch or any CP fraction, resulted in decreased (54 vs 47%) ruminal cellulose digestibility. Steam-flaking sorghum grain increased ruminal digestion of starch (74 vs 48%), increased flow of non-ammonia CP (120 vs 110% of intake) and bacterial CP (2.8 vs 2.2 kg/d), and decreased ruminal digestibility of cellulose (47 vs 53%), compared to dry-rolling. Response to steam-flaking in the lactation trial was probably due to both increased energy availability and improved duodenal flow of CP.

CHAPTER 1

INTRODUCTION

Cattle evolved consuming diets high in fiber and primarily consisting of forages. Current management schemes for intensive beef and dairy production consist of feeding diets with a high proportion of grain (concentrates), but fiber is still important to maintain normal rumen function.

Beef cattle fed diets low in fiber may suffer acidosis, liver abscesses, and rumen parakeratosis (Britton and Stock, 1986). However, beef cattle have a relatively low fiber requirement (relative to dairy cattle) and growing steers are sometimes successfully fed 100% concentrate diets (Stock et al., 1988) containing as little as 10% neutral detergent fiber (NDF). Lactating dairy cows require higher dietary levels of NDF (about 30%) to maintain normal milk composition, to maintain persistence of milk yield and to prevent displaced abomasum and ruminal acidosis.

Van Soest (1987) showed that 4% fat corrected milk was highest when cows were fed diets containing 36% NDF whether alfalfa hay, corn silage, or bermudagrass hay were the forage sources. However cows in this study were only producing about 20 kg FCM/d. Few studies evaluating optimum fiber levels are with high producing cows (>35 kg/d). High producing cows in early lactation may have difficulty consuming

enough high fiber feed to meet energy requirements, while a diet too low in fiber results in low milk fat production, poor persistence, displaced abomasum and excessive weight gain. The best estimate is that high producing cows require 28 to 32% NDF to maximize fat corrected milk production in early lactation (Woodford et al., 1986; Allen and Mertens, 1988; Chase, 1988).

Forages differ in both content and quality of NDF which complicates the study of fiber requirements. Maintenance of optimal milk production may be related to properties of both the digestible and indigestible NDF components of a diet. Digestible fiber may stimulate growth of cellulolytic bacteria which produce acetate:propionate ratios resulting in optimal energy metabolism for the lactating cow (Van Soest, 1982). Indigestible NDF helps maintain normal rumination, which in turn increases salivation which buffers the rumen, and helps maintain ruminal pH above levels (pH 6.0) known to negatively impact fiber digestion (Hoover, 1986). Indigestible bulk is also involved in formation of the raft in the dorsal rumen, which may influence the passage of particles and thereby site and extent of nutrient digestion (Ulyatt et al., 1986).

Not only do forages differ in level and fermentability of NDF, but their physical characteristics (particle size and specific gravity) vary. This may influence rate of passage from the rumen and impact rumen environment through extent of digestion, raft formation, and chewing activity. Forage ground to a small particle size loses the ability to promote optimal milk production (Shaver et al., 1986;

Woodford and Murphy, 1988). Concentrates contribute a substantial amount of fiber to lactation diets and this fiber has high potential digestibility, but also small particle size, high specific gravity and rapid passage rate. Changes in contribution of concentrate to total diet fiber may complicate comparison of forage fiber sources (Van Soest, 1982; Poore et al., 1990a).

"Functional fiber" was proposed to represent the ability of a feed to maintain chewing and milk fat percentage (Balch, 1971). Sudweeks et al. (1981) proposed a system for formulating diets based on a "roughage value index" based on NDF content and ability of the NDF to stimulate rumination. One recent study (Woodford and Murphy, 1988) showed maintenance of functional fiber levels in 28% NDF diets for high producing Holstein cows (>35 kg milk/d) influenced performance. Pelleting 1/3 of the alfalfa in the diets had no influence, but pelleting 2/3 decreased intake, chewing time and milk yield.

Another question related to fiber content of diets is how to substitute alternative feeds into diets as the price or availability of ingredients fluctuates. Substituting low quality forages for high quality forages can depress performance. Shaver et al. (1988) showed that when concentrate level was held constant at 40%, substitution of high quality alfalfa hay with lower quality forages decreased intake and production in high producing cows.

Data from Arizona (Khalaf, 1987; Brown et al., 1990) showed that substitution of chopped wheat straw for half the alfalfa hay increased

production of 3.5% FCM when diets were marginally deficient in fiber (<27% NDF). Thus, substitution of low quality forage for high quality forage will not always negatively impact lactational performance.

To date, research in which fiber sources have been compared at the same fiber level is limited (Mertens, 1982; Colenbrander et al., 1986; Woodford and Murphy, 1988; Allen and Mertens, 1988), and these studies did not include cereal straws.

Response of lactating cows to dietary fiber level may also be related to level and ruminal availability of starch (grain) in the diet (Beauchemin et al., 1989b; Kung et al., 1989). Poore et al. (1990a) showed that when concentrate level was increased in the diet of steers, ruminal digestibility was depressed more for straw than for alfalfa NDF. Thus, production responses with low quality forages may depend on level and degradability of grain (starch) in diets.

Several studies have studied interactions between starch and protein degradability using grain sources with different inherent starch degradability. A limitation of these studies, however, is that level of starch, and level and source of fiber confound starch degradability (McCarthy et al., 1989; Herrera-Saldana et al., 1990). No studies have evaluated the effects of ruminal starch degradability on ruminal fiber digestion by lactating cows when levels and sources of fiber and starch were not confounded, and no studies have evaluated starch by fiber source interactions.

The objectives of this dissertation are to investigate the effects of source of forage fiber in diets balanced for fiber level, the effects of increasing starch degradability by steam-flaking sorghum grain and to identify interactions between forage fiber source and starch degradability on lactational performance and nutrient digestion by Holstein cows.

CHAPTER 2

LITERATURE REVIEW

Interest in substituting low quality forages for alfalfa hay has increased because cost of alfalfa hay has increased relative to grain and other forages. This review will evaluate studies conducted to compare different forage fiber sources, focusing on those studies in which diets were formulated to contain equivalent fiber level, and in which the influence of starch sources (grains) varying in ruminal degradability on milk production and nutrient flow were investigated.

Low quality forages for lactating cows

Previous work at Arizona showed that substituting chopped wheat straw for half the alfalfa hay had little, if any negative effect on milk production by Holstein cows in early lactation (Khalaf, 1987). Response to substitution of straw was related to NDF level of the control diet. Diets usually contained 45% forage. Control diets contained from 23 to 29% NDF, depending on NDF of the alfalfa used (35 to 53%). Thus control diets were often deficient in fiber (<28% NDF), and 3.5% FCM production positively responded to wheat straw substitution. When alfalfa hay contained 53% NDF, diets had adequate NDF (>30 %) and substitution of wheat straw for alfalfa tended to decrease 3.5% FCM production.

Orskov et al. (1988) compared two varieties of chopped barley straw (Gerbel or Corgi) that were either untreated or ammoniated in complete mixed diets for lactating cows during the first 10 wk post-partum. Diets contained 48% straw and 14% CP. The two straw varieties varied in their degradability characteristics determined in sheep (Ramanzin et al., 1986). Untreated Gerbel, treated Gerbel, untreated Corgi and treated Corgi contained 89.6, 88.5, 88.4 and 84.3% NDF, respectively. Corgi straw had higher leaf to stem ratio then Gerbel, resulting in faster and greater potential degradation of dry matter. Ammoniation increased rate and potential extent of dry matter digestion for both straw types. Fat corrected milk production (4% FCM) was higher for the ammoniated Corgi straw (26.7 kg/d) than for the other three treatments (22.2 kg/d). This response was primarily due to higher DMI on that diet (17 kg/d) compared to an average of 13.5 kg/d on the other treatments. Milk fat percentage was higher for diets with Gerbel straw (4.2%) compared to Corgi straw (3.9%). Weight loss was higher for cows on untreated Gerbel straw (36 kg) compared to the other treatments (12 kg). Digestibility of organic matter was 63.2, 66.8, 67.8 and 68.4% for untreated Gerbel, treated Gerbel, untreated Corgi and treated Corgi, respectively, suggesting that the reason for the production was due primarily to stimulated intake rather than increased digestibility. Applicability of data to dairy production in our region is not known, because forage NDF (45%) was much higher than in diets normally fed here.

Shaver et al. (1988) showed that milk production was depressed when high fiber forages were substituted into 40% concentrate diets (table 1). The NDF content of diets increased when mid-bloom alfalfa, late-bloom alfalfa, or bromegrass hay was substituted for pre-bloom alfalfa, while NDF of the corn silage diet was intermediate. Intake and milk yield (fat percentage not reported) were decreased on the lower quality forages although efficiency of production was not affected. This is probably related to increasing level of diet NDF.

Table 1. Diet NDF, intake, and milk production when cows were fed 40% concentrate diets containing various forages[a].

	Forage					
Item	Corn Silage	Prebloom Alfalfa	Midbloom Alfalfa	Fullbloom Alfalfa	Brome-grass Hay	SE
Diet NDF, %	32.7	30.8	35.0	37.2	44.8	-
Milk, kg/day	36.5[b]	38.0[b]	32.6[c]	32.1[c]	29.7[c]	1.2
DMI kg/day	23.7[b]	23.3[b]	20.2[c]	20.0[c]	17.9[d]	.4
Kg milk/kg feed	1.54	1.63	1.60	1.60	1.68	-

[a]Shaver et al., 1988. 5 x 5 latin square with 5 ruminally cannulated Holstein cows, 15 day adaptation periods.

[b,c,d] $P<.05$.

The study is not a true comparison of fiber source because forage source and level of fiber were confounded.

Brown et al. (1990) substituted chopped wheat straw (untreated or ammoniated) for half the alfalfa hay in diets containing 45% forage. Concentrate was based on steam-flaked sorghum grain in both trials. In trial 1, ADF was increased from 23% on the diet with all alfalfa hay to 27% on the diets with half the forage as wheat straw. Milk production (27.5 kg/d) and DMI (19 kg/d) were not influenced by diet, but milk fat percentage and 3.5% FCM production were higher for the straw diets (3.2% and 26.3 kg/d) than for the all alfalfa diet (2.4% and 22.2 kg/d). No differences between ammoniated and non-ammoniated straw were observed. In trial 2, ADF was increased from 18.2% on the alfalfa hay diet to 23.5% on the diets with straw. Milk production (24.8 kg/d), DMI (17.7 kg/d), and production of 3.5% FCM (23.5 kg/d) were not influenced by forage, but milk fat percentage was higher on the treated straw (3.4%) than on alfalfa hay (2.9%) and was intermediate for untreated straw (3.3%).

Formulating lactation diets based on NDF

Mertens (1982) reported that when lactation diets were formulated to contain from 30 to 50% NDF, peak FCM yield was near 36% NDF whether the fiber source was alfalfa hay, corn silage or bermuda grass. Production was higher for alfalfa than corn silage or bermuda grass at 36% NDF (51, 44, and 40 lb/d, respectively), primarily due to differences in DMI on the corn silage (43 lb/d) and bermuda grass (42 lb/d) compared to alfalfa (52 lb/d). Cows in this study were relatively low in milk production, so data may not relate to high producing cows.

Nevertheless, this study has stimulated much interest in formulating lactation diets to an NDF specification. Woodford et al. (1986) showed optimal NDF level to be near 28% for high producing cows fed diets composed of high quality alfalfa hay and corn grain-soybean meal based concentrate. Current recommendations (Coppock 1987) are for 31% dietary NDF for cows producing 29 to 36 kg 4% FCM/d and 28% NDF for cows producing greater than 36 kg 4% FCM/d.

Although formulating diets to an NDF specification has received much attention, Briceno et al. (1987) suggested that the method may not be valid over a wide range of fiber sources. Based on regression analysis of a large data set containing numerous experiments with high and low quality fiber sources (alfalfa hay, corn silage, cottonseed hulls ground corrugated boxes and sugar cane bagasse), they found that optimal level of NDF varied depending on forage source. This conclusion should be viewed cautiously because cows were at a wide range of production levels, and different sources of fiber were not compared in any one experiment.

Comparison of fiber sources at near equivalent diet NDF

Woodford and Murphy (1988) substituted alfalfa hay pellets for one-third or two-thirds of the alfalfa haylage in 40% forage diets (28% NDF, concentrate based on corn and soybean meal) for early lactation cows. Milk production was 33.7, 35.5 and 31.8 kg/d ($P<.05$) for the control, one-third and two-thirds pellet diets, respectively. Milk fat percentage and DMI were decreased ($P<.05$) on the two-thirds pellet diet

(3.01, 2.93 and 2.59; and 23.2, 23.1 and 18.8, respectively). Depressed milk fat and intake were associated with decreased ruminal pH, decreased chewing time and decreased ruminal liquid turnover rate. This study demonstrates the importance of physical form of NDF on milk production. Diets with a large proportion of diet NDF as very fine particles may result in low intake, milk production and milk fat but some reduction in forage particle size may be beneficial.

Cleale and Bull (1986) compared mixed grass-legume silage at early and late maturity as forage sources for lactating cows. Diets were formulated to contain the same concentration of NE_l, which resulted in the diet with late maturity silage containing less NDF than the early maturity silage (31 compared to 35%). Milk yield tended to be higher (25.9 and 23.7 kg/d) but milk fat lower (3.05 and 3.25%) when late maturity silage was fed. Intake was also higher ($P<.05$) for the late maturity silage. Production responses suggest that the diet with late maturity silage was deficient in NDF. Thus NDF may have been more useful than NE_l as a specification for diet formulation. Nevertheless, this study shows that low quality forages might be useful in lactation diets if more concentrate is fed to maintain dietary energy level.

Colenbrander et al. (1986) fed lactating cows diets formulated to contain 32% NDF with corn silage, alfalfa haylage or a 50:50 mixture of the two silages as forage. Milk yield and milk fat percentage were not influenced by diet and averaged 33 kg/d and 3.4%, respectively. Intake was slightly lower for the corn silage based diet (19.8 kg/d)

than the alfalfa silage (21.1 kg/d) or the 50:50 mix (21.7 kg/d). This study demonstrates the value of formulating diets from various forage sources to a specified NDF level.

DePeters and Smith (1986) compared pre-bloom (40% NDF) to early-bloom (46% NDF) alfalfa hay as forage sources in diets with 70 or 50% hay. The 70% pre-bloom and 50% early-bloom diets contained similar levels of NDF (33.7 and 34.6%, respectively) and resulted in similar levels of milk production (27.0 and 27.2 kg/d), milk fat percentage (3.60 and 3.55%) and DMI (16.5 and 16.2 kg/d) during the first 14 weeks of lactation. This study further demonstrates that production responses can be maintained when diets with different qualities of forage are adjusted to similar fiber levels.

Beauchemin and Buchanan-Smith (1989b) fed cows diets containing forage as 37% alfalfa silage (dry basis) or with 22% alfalfa silage and 15% alfalfa hay. Substituting hay for haylage increased ($P<.05$) milk production (20.3 and 19.6 kg/d) and DMI (18.3 and 17.9 kg/d), but milk composition and chewing activities were not influenced.

Beauchemin and Buchanan-Smith (1990) substituted mixed hay (57% NDF) for alfalfa haylage (44% NDF) in the diets of 8 ruminally cannulated lactating Holstein cows. Hay substitution increased milk yield ($P<.05$, 17.3 and 18.6 kg/d), but DMI (16.4 and 16.8 kg/d) and milk fat percentage (3.59 and 3.64 %) were not affected.

Kaiser and Combs (1989) compared alfalfa hay cut at early vegetative, late-bud or full-bloom maturities in diets for lactating

cows. Diets were formulated to contain 29% total NDF and 22% NDF from forage. Because NDF of hay sampled during the trial was higher than that sampled initially, total NDF was higher for the diet with late bud (34.6%) than for diets with vegetative (31.8%) and full-bloom (30.6%) hays. Milk production (36.1, 37.7 and 37.3), milk fat percentage (3.3, 3.2 and 3.1%) and DMI (25.1, 24.9 and 25.9 kg/d) were not influenced by advancing maturities, but chewing time was greater for full-bloom than the vegetative hay.

Llamas-lamas and Combs (1990) evaluated the same hays and diets as Kaiser and Combs (1989) in six ruminally cannulated cows. Milk yield was 33.6, 33.1 and 33.8 kg/d as hay maturity advanced, and was slightly lower ($P<.05$) for the late-bud compared to the full-bloom, and DMI was higher ($P<.05$) for early vegetative (26.1 kg/d) than late bud (24.4 kg/d) or full bloom (24.8 kg/d). Digestibilities of NDF and cellulose were higher ($P<.05$) for the early vegetative as compared with the late-bud and full-bloom hays (55, 49 and 43%; 67, 60 and 54%, respectively). Ruminal passage rate, determined with ytterbium labeled hay, was faster for the early vegetative (5.2 %/h) than late-bud (4.8 %/h) or full-bloom (4.8 %/h). Faster passage of the early-vegetative hay could have been due to higher intake. Rate and potential extent of NDF digestion was higher ($P<.01$) for early vegetative than for hay cut at the two later maturities, and potential extent of digestion was higher ($P<.01$) for late-bud than for full-bloom hay . Rate and potential extent of digestion averaged 9.9, 6.5 and 6.4 %/h; and 64.7,

51.7 and 41.5 %, respectively for the advancing maturities. Although the late-bud hay was lower in quality than expected, results of these two studies demonstrate that within a species, over a wide range of forage quality, balancing diets for NDF may result in similar lactational performance.

Weiss et al. (1989) compared diets containing alfalfa haylage with concentrate from barley or corn. The barley based diet contained 48% alfalfa haylage and 31% NDF while the corn based diet contained 67% alfalfa haylage and 29% NDF. Milk production (22.9 and 23.3 kg/d), milk fat percentage (3.41 and 3.75%) and DMI (20.1 and 21.2 kg/d) were not influenced by the respective diets. Ruminal passage rate of forage (4.8 and 4.5 %/h), concentrate (4.3 and 4.2 %/h) and liquid (6.9 and 6.8 %/h) were not influenced by diet.

Influence of starch source on lactating cows

Tommervik and Waldern (1969) compared wheat, corn, barley, sorghum grain, oats and a complex concentrate for lactating cows. Concentrates were pelleted and contained 95.7% grain while the complex mixture contained 38% barley, 20% wheat millrun, 25% peas, 3.2% cottonseed meal and 9.5% molasses. Forage was alfalfa hay. In a lactation trial in which concentrate:forage ratio was maintained at 60:40, DMI was highest for oats (17.1 kg/d) and lowest for corn (16.5 kg/d). Milk yield was not influenced and averaged 23.5 kg/d, while milk fat percentage was highest for oats (4.1%) and lowest for sorghum grain (3.8%). In an acceptability trial, hay was offered at 1% BW and

concentrate was fed ad libitum. Voluntary concentrate intake was highest for sorghum grain (12.2 kg/d) and oats (12.1 kg/d) and lowest for corn (9.8 kg/d). Total DMI, milk fat percentage and milk yield were not influenced and averaged 16.5 kg/d, 2.8% and 25.3 kg/d, respectively. Yield of milk fat was highest for sorghum grain (770 g/d), and lowest for wheat (570 g/d).

Brown et al. (1970) compared grain mixtures in 45% concentrate diets for lactating cows. Concentrates contained either 54.4% sorghum grain and 17.4% barley or 54.4% barley and 17.4% sorghum grain. The grain mixtures were either steam-rolled or pelleted. Milk yield and fat percentage were not influenced by treatment and averaged 25 kg/d and 3.0% respectively. Dry matter intakes were not reported.

Bush et al. (1972) evaluated methods for processing sorghum grain to be used in diets for lactating dairy cows. Diets contained 50% concentrate and 50% alfalfa hay with concentrate containing 70% sorghum grain. In trial 1, grain was ground coarse, medium or fine. Dry matter intake and milk fat were not influenced by fineness of grind and averaged 18 kg/d and 3.3%, respectively. Milk yield was higher for fine grinding (21.4 kg/d) than coarse grinding (20.6 kg/d) and was intermediate for medium grinding (20.8 kg/d). In trial 2, grain was finely ground, finely ground and steamed, or finely ground, steamed and then dry heated. No production parameter was influenced by these processing methods. In trial 3, grain was finely ground; coarsely ground, cooked and pelleted (partially gelatinized); or finely ground,

cooked and pelleted (completely gelatinized). Intake and milk fat were not influenced and averaged 16.4 kg/d and 3.0%, respectively. Milk yield was higher for the finely ground (23.8 kg/d) than for either diet with gelatinized grain (23.1 kg/d).

Bade et al. (1973) compared dry-ground sorghum grain to sorghum grain reconstituted with either water or acetic acid for lactating cows. Diets contained 60% concentrates that contained 87% grain and 10% cottonseed meal and 40% forage (alfalfa and sorghum hay). Dry matter intake (percentage of BW) and milk yield were not influenced and averaged 3.25% and 25 kg/d. Milk fat percentage was lower for water reconstituted (3.3%) than for dry ground or acetic acid reconstituted grain (3.6%), but efficiency of milk production (kg milk/kg DMI over maintenance) was superior for water reconstituted grain (2.06) than for the other treatments (1.98). Starch digestibility was higher for water reconstituted grain (92.4%) than dry ground grain (85.7%) while acetic acid reconstituted grain was intermediate (88.5%). Molar proportion of acetate was slightly lower on the water reconstituted (66%) compared to the other treatments (69%) but acetate to propionate ratios were high (4.0) for all diets.

Bush et al. (1973) compared sorghum grain ground to three particle sizes (trial 1), and finely ground, steam-rolled or micronized sorghum grain (trial 2) in diets for lactating cows. Diets contained 50% concentrate (that was 70% sorghum grain) with alfalfa hay as forage. In trial 1, DMI and milk fat percentage were not influenced by

treatment, but medium or fine grinding resulted in higher milk production (19.7 kg/d) than coarse grinding (19.2 kg/d). In trial 2, DMI (16.9 kg/d) and milk production (26.9 kg/d) were not influenced by processing method, but fat percentage averaged 2.8, 3.0, and 2.6% for grinding, steam-rolling and micronizing, respectively.

Bush and Adams (1974) compared finely ground sorghum grain with sorghum grain micronized and rolled to 30 or 18 lb/bu for lactating cows. Diets contained 60% concentrate of which 70% was sorghum grain. Milk production, milk fat percentage, DMI and OM digestibility were not influenced by treatment and averaged 21.3 kg/d, 3.6%, 16.7 kg/d and 69%, respectively.

DePeters and Taylor (1985) compared corn and barley in complete cubed diets for lactating cows. Diets contained 50% alfalfa hay and either 32% corn or 40% barley, and had 17% CP and 34% NDF. Milk production (28 kg/d), milk fat (2.9%), DMI (18.5 kg/d) and digestibility of organic matter (68.5%) were not influenced by grain type, but digestibility of fiber components was lower on the barley based diets.

Moe and Tyrrell (1977) evaluated effects of processing method for dry corn on milk production and intake by cows 150 days in milk. Cows were fed diets containing 40% low quality timothy hay (70% NDF) and 45% dry corn. Corn was either whole, coarsly cracked or finely ground. Diets contained 36% NDF and 13% CP, and were fed ad lib.. Dry matter intake was higher for cracked and ground corn (17 kg/d) than for whole corn (16 kg/d) and averaged 2.9% of BW across treatments. Milk

production was greatly improved by fine grinding (18.1 kg/d) compared to whole corn (15.5 kg/d) and cracked corn was intermediate (16.3 kg/d). Milk fat percentage was lower for cracked and ground diets (3.8%) compared to whole (4.2%) but fat yield, which was 656 g/d, was not affected. Milk protein percentage was not influenced (3.5%), but protein yield was higher for diets with cracked or ground corn (569 g/d) compared to whole corn (493 g/d). Gross efficiency (milk/DMI) was .96 for whole and cracked diets and 1.06 for the ground diet. Digestibility of organic matter averaged 65, 59 and 56%, and digestibility of ADF averaged 29, 30, and 36% for diets with ground, cracked and whole corn, respectively. Authors concluded that whole and cracked corn had only 68 and 86% the energy value of ground corn, respectively.

Bush et al. (1979) compared diets containing either finely ground or reconstituted sorghum grain for early lactation cows. Diets contained 60% concentrate that contained 70% grain, and forage was alfalfa hay. Dry matter intake was not influenced and averaged 20 kg/d. Actual milk yield and milk fat percentage were not influenced and averaged 28.4 and 28.0 kg/d, and 3.4 and 3.3%, for ground and reconstituted, respectively. Ruminal volatile fatty acid proportions were not affected, and acetate to propionate ratio averaged 2.7. Digestibility of DM tended to be higher for reconstituted (63.4%) than ground (60.5%) grain.

Herrera-Saldana and Huber (1989) studied interactions between degradability of starch and protein sources for early lactation

Holsteins. Diets contained either barley or sorghum grain and either cottonseed meal or brewers grains in a 2x2 factorial arrangement of treatments. Milk yield (35.3 kg/d) and DMI (24.3 kg/d) were not influenced by grain source, but milk fat percentage was lower for barley than for sorghum grain diets (3.0 and 3.5%), resulting in .1 kg/d less fat yield for barley than for sorghum grain diets. Starch digestibility was higher for barley diets (90%) than sorghum grain diets (81%), but ADF digestibility was not influenced. There was an apparent interaction between grain and protein source, with cows fed barley supplemented with cottonseed meal yielding 3 kg more milk than the other treatments, and barley supplemented with brewers grains yielding 3 kg FCM less than the other treatments.

Faldet et al. (1989) compared wheat and corn as starch sources for lactating cows. Diets contained 29% corn, 10% corn:22% wheat or 33% wheat with the remainder sorghum silage and soybean meal. Milk yield decreased linearly (28.8, 28.0 and 27.3) and milk fat percentage increased linearly (3.68, 3.71 and 3.81%) but DMI was not influenced (25.2, 25.0 and 24.6 kg/d) as wheat increased in diets.

Casper and Schingoethe (1989) compared corn, barley and dried whey as energy sources in diets containing either soybean meal or urea as supplemental protein. Corn, barley and dried whey diets contained 28, 31 and 26% NDF, respectively. Cows fed corn based diets produced more milk (32.8 and 31.6 kg/d) and 4% FCM (30.0 and 27.8 kg/d), and had higher DMI (20.5 and 18.8 kg/d) than cows fed barley based diets. Milk

fat percentage was not different for the two grains (3.4%). Milk yield was similar for cows fed dried whey or barley (30.8 kg/d). Milk fat percentage was highest for dried whey (3.5%), so yield of 4% FCM was similar to corn (29.6 kg/d). No interactions between protein and energy source were observed.

McCarthy et al. (1989) used four early lactation Holstein cows fitted with ruminal and duodenal cannulae to compare corn and barley based diets with supplemental CP from either soybean or fish meal. Diets contained 45% corn or 49% barley and were based on mixed haylage and corn silage. Milk yield (35.6 and 32.5 kg/d) and DMI (23.8 and 20.7 kg/d) were higher ($P<.05$) for corn than barley, respectively, while milk fat percentage (2.73 and 2.97%) and 4% FCM (28.4 and 27.3 kg/d) were similar. Ruminal and total tract digestibilities for starch were lower ($P<.05$) for corn (49.3 and 93.2%) than for barley (77.1 and 96.8%). Ruminal and total tract digestibilities of NDF were higher ($P<.05$) for corn (30.3 and 42.4%) than barley (17.5 and 35.7%).

Herrera-Saldana et al. (1990) fed diets containing barley or sorghum grain, with supplemental CP from either cottonseed meal or brewers dried grains to duodenally cannulated lactating cows. Starch was 31.1% of the barley diets and 27.8% of sorghum grain diets. Ruminal and total tract digestibilities of starch were 80 and 94% for barley diets and 49 and 88% for sorghum grain diets. Ruminal digestion of feed CP and microbial efficiency were higher for barley diets than for sorghum grain diets.

Casper et al. (1990) compared corn and barley diets with supplemental CP from either urea or soybean meal. Grains comprised about 35% of the diets that were based on corn silage. Milk yield was not influenced by grain (32.2 and 31.7 kg/d), but milk fat percentage (3.38 and 3.23%), 4% FCM (29.1 and 27.4 kg/d) and DMI (20.7 and 19.3 kg/d) were higher for corn than for barley diets. In this study there were grain by supplemental CP interactions; performance was better for cows fed barley supplemented with soybean meal than with urea, while on corn, supplemental CP source had no influence on production parameters.

Summary

Low quality forages can be useful in diets for lactating cows. Production may be reduced if elevated fiber levels reduce intake. Positive responses were observed when addition of low quality roughage corrected marginal fiber levels in control diets, and diets contained a starch source of high ruminal degradability.

Formulating diets for lactating cows to an NDF specification has been of interest, but studies comparing NDF sources at the same NDF level are few. Most of these studies show forage NDF source has little influence on intake or production when diet NDF levels are equal.

Several studies compared sorghum grain processed by different methods for lactating cows. Milk yield was higher when grain was finely ground, compared to coarse grinding, but other processing methods (micronizing, reconstituting, gelatinizing and pelleting) did not improve milk yield compared to fine grinding. Milk production (<25

kg/d) and DMI (<18 kg/d) were low in these trials, so results may not apply to high yielding cows with high intake. In one study finely ground corn was superior to cracked or whole corn. No studies were found in which steam-flaked grain was evaluated in diets for lactating cows.

No clear effects of grain source on production were found. In trials from the midwest, corn was shown generally to be superior to barley, primarily due to higher DMI. However, other studies showed that barley was equivalent or superior to corn for lactating cows. Wheat and sorghum grain were nearly equal to corn or barley for lactating cows. Inclusion of barley usually resulted in reduced fiber digestibility, but improved starch digestibility compared to corn. No studies have evaluated interactions between starch degradability and forage source for lactating cows.

CHAPTER 3

INFLUENCE OF PASSAGE MODEL, SAMPLING SITE AND DOSING TIME ON PASSAGE OF RARE EARTH LABELED GRAIN THROUGH HOLSTEIN COWS

ABSTRACT

Three lactating Holstein cows with a T-cannula in the proximal duodenum were dosed with rare earth labeled grain to evaluate effects of passage model, sampling site and marker dosing time on passage parameters. Animals were fed twice daily ad libitum and rare earth labeled grain (applied by the 24 h immersion technique) was fed before (Dy) or 2 h after (Yb) the a.m. feeding, and duodenal digesta and feces were sequentially sampled. Marker excretion curves were fitted to a two-compartment bi-exponential model using curve peeling, or to two-compartment models, with one to six orders of gamma time-dependency in the fast compartment using non-linear regression. Best fit of the non-linear models was with three orders of gamma time dependency (G3G1). Passage parameters from the G3G1 model were similar to those from the curve-peeled bi-exponential model, but differed from parameters for the bi-exponential model fit using non-linear regression. Estimates of the slow rate (K_2, /h), the fast rate (K_1, /h, corrected for time dependency), time to first appearance (tau, h) and mean retention time (MRT, h) were .0808, .270, .30 and 16.5; .0772, .335, 1.21 and 17.3 for duodenal sampling and .0763, .231, 7.18 and 24.8; .0735, .316, 8.30 and

25.1 for fecal sampling for the G3G1 and bi-exponential curve-peeling models, respectively. Sampling site influenced only estimates of tau and MRT, which were 7 h longer for the fecal than for duodenal sampling. Dosing time did not influence any of the parameters. The conclusions from this study are that both curve peeled, bi-exponential and best fit time-dependent, time-independent non-linear regression methods yield similar estimates of passage parameters for marked grain fed to lactating Holstein cows, that fecal sampling can be used to reliably estimate ruminal K_2 for grain, and that the time of dosing marker has little effect on passage parameter estimates for grain.

INTRODUCTION

Two modeling approaches have been commonly used to evaluate particulate passage in ruminants. Grovum and Williams (1973) described a model with two sequential time-independent compartments (bi-exponential) and a time delay, fit using a linear regression technique (curve peeling). Non-linear regression has also been used to fit data to the bi-exponential model or to a series of time-dependent, time-independent two compartment models with time delay (Pond et al., 1988; Ellis et al., 1979; Ellis et al., 1988; Matis, 1972). Choice of passage model can affect passage parameter estimates (Pond et al., 1988; Coleman et al., 1984; Goetsch and Owens, 1985; Snyder et al., 1984), but did not influence parameters in one study (Prange et al., 1982) with passage of grain through lactating dairy cows.

Some studies have reported that ruminal passage rate could be accurately predicted from fecal sampling (Prange et al, 1982;, Pond et al., 1988), while others (Robinson and Sniffen, 1983; Goetsch and Owens, 1985) have questioned the validity of fecal sampling for determining ruminal passage rates. Fecal sampling is advantageous because surgically altered animals are not required.

It has also been suggested that marker dosed before a meal of forage may have different passage characteristics than that dosed after (Pond et al., 1989) or with the meal (Leonard et al., 1989), which would compromise the value of passage rate estimates derived using pulse dosed markers.

Differences in methods and models for fitting passage curves, differences in sampling sites and concerns about validity of dosing regimes complicate interpretation of rate of passage data and make comparison of results from various laboratories difficult.

This experiment evaluated methods of fitting two compartment passage models, and the influence of sampling site and dosing time on estimates of passage of grain through lactating Holstein cows.

MATERIALS AND METHODS

Animals and diets.

Three Holstein cows (643 kg) in late lactation (220 days in milk, 15 kg milk/d), each fitted with a gutter-t-type cannula (2.5 cm internal diameter) in the proximal duodenum, were fed twice daily a 45% concentrate total mixed diet (table 2). Cows were fed to ad libitum

consumption, and had access to water and trace mineralized salt blocks at all times. Cows were individually housed in 4 x 8 m pens that had dirt floors and were partially shaded.

Marker preparation and dosing.

Sorghum grain that had been steamed 1 h and then flaked to a test wt of 360 g/l (28 lb/bu) was marked with Dy or Yb by the immersion technique described by Poore et al. (1990a). Briefly, grain (200 g/l) was soaked for 24 h in a 2.5 g/l solution of Yb or Dy chloride (hydrated), rinsed extensively with distilled water and then dried at 50°C for 48 h. Cows were offered 350 g of labeled grain mixed with 350 g of mixed diet either before (Dy, 2.21 mg/g of grain) or 2-h after (Yb, 2.26 mg/g of grain) the normal a.m. feeding. Five grams of Co-EDTA (Uden et al., 1980) was included with the pre-feeding marker in order to evaluate liquid turnover rate.

Sampling and marker analysis.

Samples of duodenal digesta were obtained at 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 16, 20, 24, 28, 32, 36, 42, 48, 54, 60 and 72 h after the initial dose, and fecal grab samples were obtained at 0, 4, 8, 12, 16, 20, 24, 28, 32, 36, 42, 48, 54, 60 and 72 h after the pre-feeding dose. Samples were dried at 100°C, ground to pass a 2-mm screen (Wiley mill), ashed at 500°C, extracted with a mixture of 3N HNO_3 and 3N HCl and analyzed for Yb and Dy using atomic absorption spectrophotometry as reported by Poore et al. (1990a). Cobalt concentrations in extracts were determined using atomic absorption spectrophotometry as described

by Moore et al. (1990a). Marker concentrations were expressed as mg/g of OM.

Particle size and specific gravity.

Particle size of marked and unmarked grain was determined by sieving 50 g samples for 5 min with a Ro-Tap sieve shaker (C-E Tyler Combustion Engineering, Inc., Bessemer City, NC), and functional specific gravity was determined as described by Hooper and Welch (1985).

Passage models.

Ruminal passage rate of Co-EDTA (Co) was determined by regressing the natural log of Co concentration against time from 2 to 20 h post-dosing for duodenal samples, and from 12 to 28 h for fecal samples. It was not possible to fit a two compartment model because there was only one point on the rising portion of the Co excretion curve for both duodenal and fecal sampling.

Excretion curves for rare earths were fitted to a two compartment time independent-time independent (bi-exponential) model described by Grovum and Williams (1973, GW) using linear regression (curve peeling), or to the series of two-compartment models (emerging) with increasing orders of gamma time dependency in the first compartment (G1G1-G6G1) using non-linear procedures of SAS (1985) as described by Pond et al. (1988). Both modeling approaches estimate passage from two sequential compartments (fast and slow) with a time delay (tau). Because excretion curves for both markers (Yb and Dy) were fit relative to time of dosing for the first marker (Dy), tau for the second marker

(Yb) was calculated as tau minus 2 h. Grovum and Williams (1973) called the slow rate K_1 and the fast rate K_2, whereas Pond et al. (1988) use opposite designations for the rate parameters. In this paper K_2 is designated as the passage rate from the slow compartment, and K_1 the rate parameter from the fast compartment divided by the order of gamma time-dependency. As discussed by Pond et al. (1988) and Ellis et al. (1979), passage from the fast compartment is time-dependent for G2G1 or higher, so it must be divided by the order of time dependency for direct comparison to the time-independent rate. Mean retention time (MRT) for all models was calculated as $(1/K_1) + (1/K_2) + \text{tau}$. The method of Pond et al. (1988) results in an error mean square for over-all model fit (RE) and initial concentration of marker in the slow compartment (C_2). Initial concentration in the slow compartment for Grovum and Williams (1973) was calculated as the concentration on the regression line described by K_2 at time = tau + $(1/K_1)$.

Statistical analysis.

Passage parameters were compared using the GLM procedures of SAS (1985). The model included effects of cow, treatment (site, dosing time or model) and residual. Passage parameters for both Yb and Dy were pooled for comparison of sampling site and passage model. Means were separated using the Least Significant Difference test following a significant F-test.

RESULTS

Dry matter intake averaged 23.6 kg/d (3.7% BW). Cows consumed 7.2 kg (or about 30% of their daily intake) between the time of the first and second marker feeding. Particle size distribution and functional specific gravity of marked and unmarked grain are in table 3. The marking procedure caused a decrease ($P<.05$) in large particles (>4.0 mm) and an increase ($P<.05$) in small particles (.85-2.0 mm), but did not influence the proportion of medium (2.0-4.0 mm) or very fine (<.85 mm) particles. Particle size distribution of Dy- and Yb-labeled grain was not different. Functional specific gravity of grain particles after 2 h of incubation was not influenced by marking, and functional specific gravity did not change over the 24-h of incubation, as is the case with forages (Hooper and Welch, 1985).

Actual excretion of Dy and Yb for both sampling sites, averaged across the three cows are presented in Figure 1. Passage rate of Co averaged .125/h when estimated from duodenal sampling and .121/h from fecal sampling (SEM=.51). Excretion of rare earths peaked later and declined slower than Co, evidence that the rare earths remained bound to particulate matter rather than disassociating from the particles and passing from the rumen with the liquid phase.

Influence of passage model on passage parameters.

Passage parameters determined using the methods of Grovum and Williams (1973) and Pond et al. (1988) are presented in tables 4 (duodenal sampling) and 5 (fecal sampling). Passage rate for the slow

compartment (K_2) was not influenced by model, except that the G1G1 (non-linear regression fit, time-independent, time-independent) model resulted in a faster rate ($P<.05$) at the duodenum than did the other models. Estimates of K_1 and tau tended to decrease at both sampling sites as the order of gamma time dependency was increased for the models of Pond et al. (1988). As a consequence, retention time was shifted from tau to the fast compartment, without influencing MRT. Tau from duodenal sampling became negative with more than three orders of gamma time dependency because curves were fit relative to dosing time for Dy, and tau for Yb was corrected for the 2 h delay in dosing time. Thus, although tau for Dy was restricted to be $\geq$0 h, tau for Yb was restricted to $\geq$-2 h. With more than three orders of time-dependency, tau for Dy was 0 h while tau for Yb reached a minimum of -1.1 h for the G6G1 model. Estimates of K_1 and tau from the Grovum and Williams (1973) method were most similar to G2G1, and were the closest to actual first appearance of marker at the duodenum (1 h for one cow and 2 h for the other cows). Estimates of MRT were similar regardless of model at both sampling sites. Initial marker concentration was similar for all models at both sampling sites, except it was about 10% higher when estimated from duodenal sampling using the G1G1 model. Based on the criteria of Pond et al. (1988) the best fit of the non-linear regression models was with G3G1; residual error was reduced by more than 5% up through three orders of time-dependency, with little reduction occurring by further increasing the order of time dependency. The method of Grovum and

Williams (1973) and the G3G1 model of Pond et al. (1988) were used to compare sampling site and dosing time.

Influence of sampling site on passage parameters.

Effects of sampling site on passage parameters are in table 6. For both GW and G3G1, K_2 and K_1 were not influenced by sampling site. Ruminal events accounted for 85% (G3G1) or 95% (GW) of retention time in the fast compartment estimated from fecal sampling. For both models, tau and MRT were 7 h longer for fecal than duodenal sampling for both models.

Influence of dosing time on passage parameters.

Effects of dosing time are presented in table 7. Dosing time did not influence K_2, K_1, tau or MRT for either model at either sampling site. Estimates of MRT tended to be about 1 h longer ($P<.10$) for the marker administered after feeding at both sites and for both models.

DISCUSSION

Based on functional specific gravity and particle size, marked particles used in this study differed little from unmarked particles. Particle size and specific gravity were the same for the Dy and Yb marked particles, and this is important because particle size and specific gravity are the two most important physical factors influencing passage of particles from the rumen (Welch, 1986).

Influence of passage model on passage parameters.

In theory, passage of particles from the rumen should be a time-dependent process. As retention time increases, particle size becomes smaller and specific gravity increases, which should increase the liklihood that particles will pass from the rumen (Welch, 1986; Ellis et al., 1988). Nevertheless, Grovum and Williams (1973) showed that a model with two sequential, time-independent compartments adequately described passage of liquid and particles through the gastro-intestinal tract of sheep. Several studies compared passage parameters estimated using a two-compartment model with time-dependency in the fast compartment to those from the bi-exponential model, but only two comparisons have been made with lactating Holstein cows (Snyder et al., 1984; Prange et al., 1982). Only Grovum and Williams (1973) compared the linear regression (curve peeling) technique with a non-linear regression technique for fitting the bi-exponential model; both methods resulted in similar parameter estimates. Beauchemin and Buchanan-Smith (1989a) reported that determining K_2 by hand before using non-linear

regression to fit other parameters improved the fit of the bi-exponential model for labeled forages fed to lactating Holstein cows.

In the present study, estimates of passage parameters were similar when estimated using the curve peeling method of Grovum and Williams (1973) or the models of Pond et al. (1988) with two or three orders of time dependency in the fast compartment (G2G1 and G3G1). The G2G1 and GW models estimated first appearance of marker for both duodenal and fecal sampling closest to actual observation of first marker appearance. Estimates of tau were substantially shorter than actual first appearance when order of time-dependency was greater than three. The G1G1 model and GW are conceptually the same (bi-exponential), but parameter estimates differed due to the method by which data were fit. Thus, the inability of the G1G1 model to resolve the fast and slow rate parameters noted by Pond et al. (1988) and Coleman et al. (1984) may be due to the method by which data were fit rather than to invalidity of the model.

Our fit of G1G1 was different than either GW or G3G1, but estimates of K_1 and K_2 were not equal, as reported by Coleman et al. (1984) and Pond et al. (1988). This could be due to higher feed intake in this study (3.7% of BW) compared with those of Pond et al. (1988, 1% of BW) and Coleman et al. (1984, 1.3% BW). In other studies with lactating dairy cows, G1G1 gave similar parameter estimates as G2G1 (Prange et al., 1982; Snyder et al., 1984). Thus, model comparisons

made at low intake may not be applicable when DMI is high, as in lactating dairy cattle.

Goetsch and Owens (1985) compared G1G1 with G2G1 for fitting particulate flow through calves fed forage or concentrate diets at 2% BW. Estimates of K_2 were similar for both models, but K_1 estimated by G2G1 was consistently twice that estimated by G1G1. This discrepancy could have been due to the time-dependent K_1 not being corrected for the order of time dependency, e.g., $[(K_1)/2]$. Failure to correct for the order of time-dependency in G2G1 would also explain the shorter MRT for the G2G1, compared to the G1G1 model.

Worrell et al. (1986) fed meadow hay to yearling beef steers (DMI averaged 2.2% of BW), and compared different models for estimating passage rate of three forage particle sizes within three forage maturities. The one compartment time-dependent model, the G2G1 model and a graphical-fit one compartment time independent-model (peak decay, log scale) gave different estimates of passage rate, but with all three models rate of passage was faster for smallest particles and for the least mature forage.

Only two studies have compared models for fitting passage of marked grain through lactating cows. Prange et al. (1982) reported that G1G1 and G2G1 gave similar estimates for K2 and K_1 (DMI not reported). Snyder et al. (1984) fed silage based diets at 3% BW to lactating cows, and used non-linear regression to fit passage data to G2G1 and G1G1. Estimates of K_2 were similar for both models but standard errors were

greater for G2G1. Estimates of "postruminal retention time" apparently calculated as tau + ($1/K_1$) were reported. This estimate was consistently shorter for G2G1, again, possibly because retention time in the fast compartment was calculated as $1/K_1$ rather than $2/K_1$.

Influence of sampling site on passage parameters.

Fecal sampling has been widely used to determine ruminal passage rate (K_2), but validity of this technique has been questioned (Goetsch and Owens, 1985). Theoretically, ruminal sampling would be most appropriate, but because it is difficult if not impossible to obtain a representative rumen sample without disturbing the rumen environment (Goetsch and Owens, 1985; Beauchemin and Buchanan-Smith, 1989a), duodenal sampling should result in the most reliable measurement of ruminal outflow (W.C. Ellis, personal communication). In addition, fecal sampling from non-surgically altered animals would be especially advantageous when maximal intakes, high levels of production or large numbers of animals are desired. Because interpretation of ruminal sampling data is difficult, this discussion will consider only comparisons between duodenal and fecal sampling.

In the present study duodenal and fecal sampling resulted in similar estimates of K_2 and K_1 for both GW and G3G1. This suggests that when grain is fed to lactating dairy cows with high DMI, most (if not all) of the retention time for both compartments occurs in the rumen. In contrast, Pond et al. (1982), Prange et al. (1982), and Pond et al. (1988) reported that K_2 was similar when determined from duodenal or

fecal sampling, but only about 60% of the retention time for the fast compartment occurred in the rumen. Goetsch and Owens (1985) reported that K_2 was slower when determined from fecal rather than from duodenal samples for the G2G1 model, but not the G1G1 model.

In a recent study at the AZ station with lactating cows fed alfalfa based diets at 3% BW, Moore et al. (1989) showed that K_2 (GW) for grain and hay were similar when estimated from fecal or duodenal samples. Estimates did tend to be about 10% slower when estimated from fecal samples, and this is consistent with the trend seen in our data. However, ruminal liquid passage was slower when determined from fecal sampling (7.9 %/h) as compared to duodenal sampling (10.2 %/h), which was not observed in the present study.

Robinson and Sniffen (1983) reported that in Holstein cows fed 3.2% BW, K_2 for both chromium-mordant (Cr, 2.3 vs 2.0 %/h) and $YbCl_3$ (infused, 4.3 vs 3.6 %/h) were significantly slower for fecal compared to duodenal sampling, but liquid passage (Co-EDTA) was not influenced. The slow passage of Cr (possibly due to high density; Ehle, 1984) and questionable validity of infused rare earth salts as passage markers (non-specific labeling) limit interpretation of these data.

The observation in the present study that tau was 7 h longer when estimated from fecal sampling compared with duodenal sampling is consistent with results from other studies which showed differences of 7 to 10 h (Prange et al., 1982; Goetsch and Owens, 1985; Pond et al., 1988).

Influence of marker dosing time.

Pond et al. (1989) reported passage parameter estimates for coastal-bermudagrass hay were dramatically different when labeled forage was administered before rather than after a meal. Estimated K_2 was 42% faster, K_1 was 71% faster, tau was 4.5 h longer and MRT was 11.9 h shorter when marker (in gelatin capsules) was dosed before (^{160}Tb), compared to after (cold Tb), feeding. Authors concluded that passage of marker dosed before a meal, as is done in most studies, may not be representative of particles dosed after the meal. Interpretation of these data are, however, complicated by several factors: 1) Marker dosed in gelatin capsules may not have the same ruminal mixing characteristics as feed particles actually consumed by the animal; 2) Cold Tb was applied to the forage at a concentration 200x higher than the ^{160}Tb, which could influence passage estimates, as concentration of rare earth influences digestion of marked particles (Coleman et al, 1984); and 3) Feed intakes were only reported to be "near ad libitum", and are assumed to be low, because of the low quality of the hay. Because DMI were not reported, effects of DMI on magnitude of the results could not be evaluated. Pond et al. (1989) suggested that differences in passage estimates were due to gelatin capsules stratifying at different ruminal locations. However, Cochran et al. (1986) showed that in beef steers fed 1.9 % of BW, passage rate was not influenced when marked forage was placed on top of, or stratified within the ruminal raft.

Leonard et al. (1989) reported MRT was slightly shorter and marked whole corn kernels in the feces were more abundant when dyed whole corn was fed after- rather than with- hay. This effect is opposite to the effect seen by Pond (1989) and the trend in the present study. The effect seen for marked forage (Pond et al., 1988) was more dramatic than effects on marked grain in the present study, and that of Leonard et al. (1989). This could indicate that grain and forage may respond differently to time of dosing. Moore et al. (1989), however, reported estimates of K_2 for alfalfa hay were the same whether marker was dosed before or 2-h after feeding in Holstein cows fed 3% BW of a diet similar to the one used in this study.

In the present study and that of Moore et al. (1989), Dy was dosed before feeding and Yb after feeding; thus marker and dosing time could have been confounded. Allen (1982) concluded that binding characteristics of rare earth elements were too dissimilar to allow their use in the type of multiple marker system used in this study. However, Goetsch and Galyean (1983) showed that Dy and Yb applied to alfalfa hay by the method used in our studies gave nearly identical estimates of passage parameters. Moore et al. (1986) labeled alfalfa hay and steam-flaked milo with Yb and Dy as described for this study, and showed that marker solubilization (19% for alfalfa hay and 11% for sorghum grain) was similar and marker migration to unmarked stems (1% for both hay and sorghum grain) was minimal for both elements during a

24 h in-vitro digestion. In addition, Poore et al. (1990) rotated Dy, Yb and Eu as markers for milo, alfalfa hay and wheat straw, and found that ruminal passage rate (K_2) for the various feeds was not influenced by the rare earth used. Because of this evidence, we conclude the use of Yb and Dy as in this study is appropriate.

In conclusion, increasing order of gamma time-dependency to three (G3G1) minimized residual error of passage curves fit to a two-compartment model using non-linear regression. Fitting the two-compartment, time-independent model using linear regression (GW) resulted in essentially the same passage parameter estimates as G3G1. However, parameters were different when the two-compartment, time-independent, time-independent model was fit using non-linear regression. Estimates of K_1 and K_2 were not influenced by sampling site, suggesting that fecal sampling is appropriate for evaluating ruminal events under the conditions of this study. Dosing marked grain before or after a meal did not influence passage parameters, and therefore it is suggested that marked grain be offered to cows at the beginning of a meal in order to encourage rapid and complete consumption.

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Table 2. Ingredient composition and analysis of the total mixed diet (exp. 1)

Item	% of DM
Ingredient	
Dairy concentrate[1]	38
Whole cottonseed	7
Alfalfa hay	34
Alfalfa hay cubes	14
Cottonseed hulls	7
Analysis	
Dry matter (% as fed)	94.2
Crude protein	14.7
Calcium	1.3
Phosphorus	.6

[1] 44% steam-rolled corn, 35% malt pellet, 10% almond hulls, 5% wheat millrun, 2.5% molasses, .5% salt, .6% limestone, 1.7% dicalcium phosphate and 1% urea.

Table 3. Particle size distribution[1] and functional specific gravity of labeled and unlabeled steam-flaked sorghum grain.

	Sieve Size, mm				
Sorghum Grain	4.0	2.0	.85	<.85	FSG[2]
	% retained				g/ml
Unlabeled	18.8[a]	54.6	17.3[a]	8.2	1.53
Dy-labeled	7.7[b]	51.8	33.7[b]	6.7	1.50
Yb-labeled	7.5[b]	53.5	32.9[b]	6.1	1.49
SEM	1.2	1.1	.6	1.2	.02

[1]Mean from 5 observations/grain.

[2]Functional specific gravity at 2 h incubation (Hooper and Welch, 1985), Mean from 2 observations/grain.

[a,b]Means in the same column with unlike superscript letters differ ($P<.05$).

Table 4. Influence of passage model on passage parameters determined from duodenal sampling[1]

	Passage Parameter[2]					
Model[3]	K_2	K_1	Tau	C_2	MRT	RE
GW	.0772[a]	.335[a]	1.21[ab]	99.8	17.3	---
G1G1	.0921[b]	.305[ab]	1.44[a]	109.8	15.9	779
G2G1	.0821[a]	.326[a]	.97[b]	99.8	16.5	671
G3G1	.0808[a]	.270[bc]	.30[c]	98.8	16.5	631
G4G1	.0791[a]	.252[c]	-.08[cd]	97.3	16.7	620
G5G1	.0815[a]	.227[c]	-.33[de]	98.9	16.8	612
G6G1	.0763[a]	.230[c]	-.54[e]	94.2	17.2	615
SEM	.0025	.018	.14	4.4	.4	125

[1]Averages include parameters for both Dy and Yb.

[2]K_2 = passage rate (/h) for the slow (second) compartment; K_1 = passage rate (/h) for the fast (first) compartment, corrected for the order of gamma-time dependency; Tau = time delay (h); C_2 = initial concentration (ppm) in the slow compartment; MRT = $(1/K_1) + (1/K_2)$ + Tau; RE = Error mean square for overall model fit.

[3]GW is the model of Grovum and Williams (1973) fit using linear regression and G1G1-G6G1 are the models of Pond et al. (1988) fit using non-linear regression.

[a,b,c,d,e]Means in the same column with different superscript letters differ ($P<.05$).

Table 5. Influence of passage model on passage parameters determined from fecal sampling[1]

	Passage Parameter[2]					
Model[3]	K_2	K_1	Tau	C_2	MRT	RE
GW	.0735	.316	8.3^{ab}	145.8	25.1	---
G1G1	.0766	.934	10.1^{a}	144.2	25.3	370
G2G1	.0763	.560	8.8^{ab}	143.7	25.1	349
G3G1	.0763	.231	7.2^{cd}	146.8	24.8	233
G4G1	.0757	.208	6.6^{d}	145.8	24.9	230
G5G1	.0753	.191	6.1^{d}	145.2	24.9	233
G6G1	.0751	.178	5.7^{d}	144.7	24.9	227
SEM	.0013	.190	.6	5.9	.4	62

[1]Averages include parameters for both Dy and Yb.

[2]Parameters defined in table 4.

[3]GW is the model of Grovum and Williams (1973) fit using linear regression and G1G1-G6G1 are the models of Pond et al. (1988) fit using non-linear regression.

^{a,b,c,d}Means in the same column with different superscript letters differ ($P<.05$).

Table 6. Influence of sampling site on passage parameters[1].

Site	K_2	K_1	Tau	MRT
	Grovum and Williams (1973) Model			
Duodenum	.0772	.335	.9[a]	17.3[a]
Feces	.0735	.316	8.0[b]	25.1[b]
SEM	.0017	.017	.4	.5
	Pond et al. (1988) G3G1 Model			
Site	K2	K1	Tau	MRT
Duodenum	.0808	.270	.3[a]	16.5[a]
Feces	.0763	.231	7.2[b]	24.8[b]
SEM	.0017	.014	.2	.4

[1]Passage parameters defined in table 4.

[a,b]Means within column and model with different superscript letters differ ($P<.05$).

Table 7. Influence of marker dosing time on passage parameters[1].

Site	K2	K1	Tau	MRT
	Grovum and Williams (1973) Model			
Duodenum				
Before feeding[2]	.0778	.360	1.2	16.9
After feeding[3]	.0776	.309	1.2	17.7
SEM	.0023	.014	.1	.5
Feces				
Before feeding	.0749	.306	7.6	24.2
After feeding	.0721	.326	9.0	26.0
SEM	.0007	.012	.4	.4
	Pond et al. (1988) G3G1 Model			
Site	K2	K1	Tau	MRT
Duodenum				
Before feeding	.0839	.288	.36	15.8
After feeding	.0777	.253	.24	17.2
SEM	.0022	.007	.06	.3
Feces				
Before feeding	.0774	.256	7.20	24.2
After feeding	.0782	.205	7.17	25.4
SEM	.0021	.021	.46	.3

[1]Passage parameters defined in table 4.

[2]Dy marked steam-flaked sorghum grain dosed prior to the morning feeding.

[3]Yb marked steam-flaked sorghum grain dosed 2 h after the morning feeding.

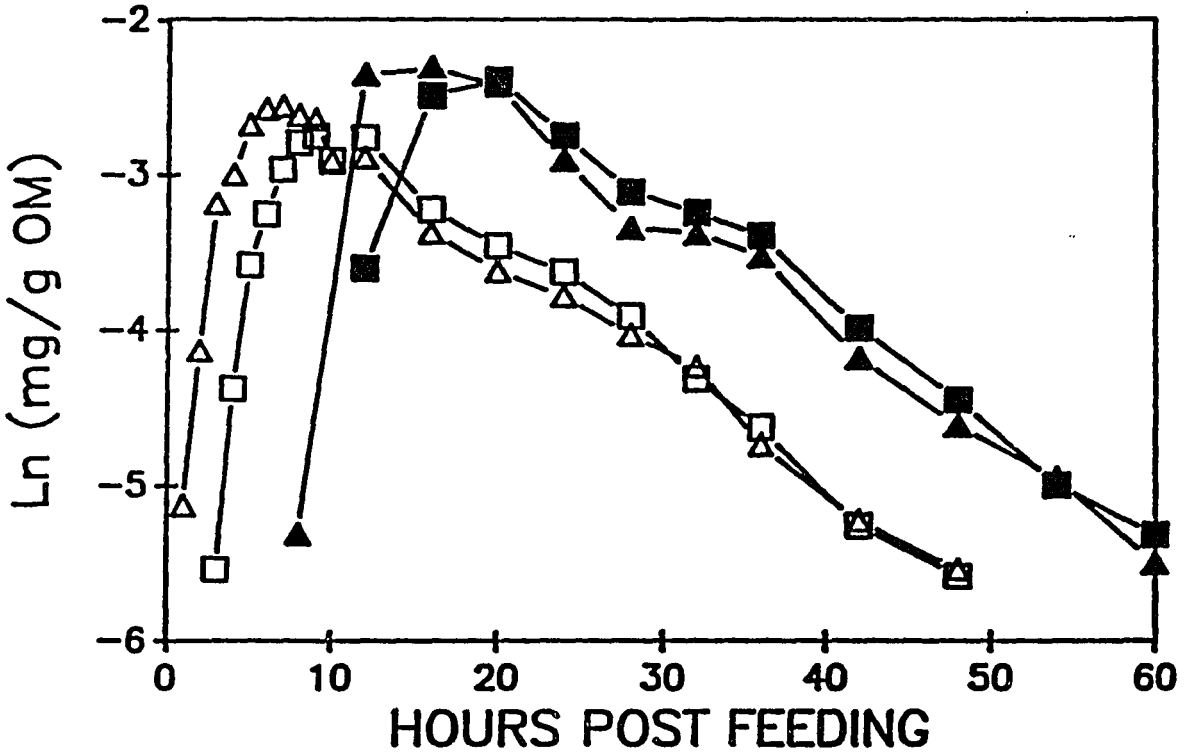

Figure 1. Duodenal (open figures) and fecal (closed figures) excretion of dysprosium (pre-feeding marker, triangles) and ytterbium (post-feeding marker, squares) by lactating Holstein cows.

CHAPTER 4

INFLUENCE OF SUBSTITUTING WHEAT STRAW FOR ALFALFA HAY IN DIETS FORMULATED TO CONTAIN 30% NDF ON MILK PRODUCTION OF EARLY-LACTATION HOLSTEIN COWS

ABSTRACT

Twenty-four Holstein cows in early lactation were fed diets formulated to contain 30% NDF with forage NDF from chopped alfalfa hay or chopped wheat straw in proportions of 3:0, 2:1, 1:2, and 0:3 in an 8 wk trial in order to evaluate effects of fiber source on lactational performance. Digestibility of diet components, ruminal passage rates for diet ingredients and molar proportions of VFA in ruminal fluid were determined following the lactation trial. Forage NDF decreased from 21 to 19% and ruminally degradable starch increased from 19 to 22% with increasing forage NDF from WS and the consequential increase in grain. Actual milk production (38.4 kg/d) and DMI (23.1 kg/d) were not influenced by forage NDF source, while FCM and fat production (kg/d) were reduced only on 0:3 AH:WS (linear and quadratic, $P<.05$). Protein production (kg/d) was highest for the 1:2 AH:WS diet (quadratic, $P<.05$). Milk fat percentage decreased linearly and milk protein percentage increased linearly with increasing straw level. Digestibility of NDF averaged 43.5, 45.4, 40.7 and 31.2% with increasing levels of WS (linear and quadratic, $P<.05$). Acetate to propionate ratio was 3.0, 2.4, 2.2 and 1.9 with increasing levels of straw (linear $P<.05$). Passage of diet

ingredients was not influenced by diet, and averaged 9.3, 7.6, 6.1 and 4.7 %/h for fluid, sorghum grain, alfalfa hay and wheat straw, respectively. Due to increased ruminally degradable starch from grain and decreased NDF from forage, diets with low quality forage may need to be higher in total NDF than diets with high quality forage. Based on these data we suggest that the ratio of forage NDF to ruminally degradable starch be maintained $\geq$1:1 when diets based on low quality forage are fed to lactating cows.

INTRODUCTION

It has been proposed that formulating diets to an NDF specification may be the most practical means of adjusting lactation diets for differences in forage quality (Mertens, 1982).

Some recent lactation studies support this concept. Colenbrander et al. (1986) reported cows fed corn silage or alfalfa haylage diets formulated to contain 32% NDF had similar production. Kaiser and Combs (1989) reported production was similar when cows were fed alfalfa hay at three maturities in diets formulated to contain 29% NDF. Briceno et al. (1987), however, suggested that formulating diets on NDF may not be applicable across a wide range of fiber sources. It is also believed (Van Soest, 1987) that differences in buffering capacity, cation exchange capacity and density among forage sources will lead to large differences in lactational performance, even when diets are formulated to contain equal NDF.

Cereal straw is a low quality forage available in large amounts in many regions of the world. There has been considerable interest recently in using chopped straw in diets for lactating cows (Orskov et al., 1988; Khalaf, 1987; Brown et al., 1990), but when diets are high in straw (48%, Orskov et al., 1988) cows cannot consume adequate feed to support high milk yield. Production responses when chopped wheat straw was substituted for some of the alfalfa hay in diets at the AZ station have been variable, depending on levels of NDF and starch in the diets, and the production potential of the cows. Brown et al. (1990) reported that substituting chopped straw for half the alfalfa hay in diets marginally deficient in fiber and high in ruminally degradable starch increased feed intake and yield of FCM by moderately producing cows. Khalaf (1987) reported responses to straw that were similar to Brown et al. (1990) when high yielding cows were fed diets that were moderately fiber deficient; however, when fiber levels were adequate, intake and yield of FCM was slightly reduced by substituting straw for alfalfa hay.

The present study was designed to evaluate the influence of substituting wheat straw for alfalfa hay on an NDF basis in diets formulated to contain near optimum levels of dietary NDF (30%) on production responses by high-yielding Holstein cows in early lactation.

MATERIALS AND METHODS

Animals and diets

Twenty-four Holstein cows (20 multiparous, 4 primiparous; 62 d in milk) from the University of Arizona Dairy were fed four diets containing forage NDF from wheat straw or chopped alfalfa hay in the proportions 0:3, 1:2, 2:1 or 3:0 (table 8). Diets were formulated to contain 17% CP and to meet or exceed requirements of early lactation cows (NRC, 1989) for Ca, P and Mg. Sorghum grain was steamed 1 h and then flaked to 360 g/l (28 lb/bu). Wheat straw was chopped using a miller rotary-hay mill (United Farm Tools, Inc., Turlock, CA) equipped with a 5-cm screen. Total mixed diets were prepared weekly in a truck equipped with a mixing box (Kirby Manufacturing Inc, Merced, CA). Baled alfalfa hay was placed in the box and allowed to mix until stems were approximately 7.5 cm in length. Concentrate mixes were then added and allowed to mix until well dispersed and maximum hay stem length was about 5 cm. This method of mixing resulted in diets of similar physical form. During the last 10 d of the lactation trial, and during the fecal collection period Cr_2O_3 (.1% in diet DM) was included as a digestibility marker.

Cows were fed a common diet during a 2 wk pretrial covariate period, followed by an eight wk lactation trial and a 5 d fecal sampling period. Cows were blocked based on d in milk, production and parity, and randomly assigned within blocks to one of the four treatments. Cows were housed in dry lots (12 cows each) with shades, and had free access

to water and trace mineralized salt blocks. The experiment was conducted during February through April. Cows were fed ad libitum (5% refusal) through Calan gates (American Calan, Inc., Northwood, NH) with feed offered twice daily.

Production data and sample collection.

Milk yield was recorded twice daily, and milk samples were obtained bi-weekly and analyzed for fat, protein and lactose using infra-red analysis by Arizona DHIA.

Cows were weighed following the a.m. milking on two consecutive days, and body condition scored once (1 being very thin and 5 very fat) before and following the trial.

Diet samples were obtained weekly during the lactation trial Daily samples of feed offered and orts were composited over the 5-day fecal sampling period. One portion of each sample was dried at 100°C to determine DMI, and a remainder was dried at 50°C for laboratory analyses.

For determination of passage rates, alfalfa hay, wheat straw and flaked sorghum grain were labeled with Dy, Eu or Yb, respectively, using the immersion method (Poore et al. 1990a). An acetate buffer (.1M, pH 5.0) was used as the final rinse. After Cr_2O_3 had been fed for 10 d, cows were fed 5 g Co-EDTA, 280 g Yb-sorghum grain, 150 g Dy-alfalfa and 100 g Eu-straw mixed with a small portion of the morning feeding. Fecal grab samples were obtained before dosing and at 6, 12, 18, 24, 30, 36,

42, 48, 60, 72, 84, 96, 108 and 120 h post-dosing. Fecal samples were immediately placed in a freezer. Samples were later thawed and dried at 50°C for 48 h. Feed, orts and fecal samples were ground to pass a 2 mm screen in a Wiley mill before compositing.

Three hours post-feeding on the day following the last day of fecal collection, ruminal fluid samples were obtained by suction using a stomach tube. Fluid was strained through 3 layers of cheesecloth, placed immediately on ice and then frozen until analyzed for VFA.

Sample analysis.

Feed, orts and feces were analyzed for CP using a N autoanalyzer (Technicon, Terrytown, NY), Cr using atomic absorption spectrophotometry, and starch by glucose determination following enzymatic hydrolysis. Samples for CP were wet ashed with 10 ml concentrated sulfuric acid, .5 g Mg sulfate and .1 g Na selenite. Samples for Cr analysis were ashed as for CP, and then ten ml water and .4 g periodic acid were added, and samples were boiled another 3 h. Samples for starch analysis were gelatinized by autoclaving, hydrolyzed with amyloglucosidase (Diazyme L-200, Miles, Inc., Elkhart, IN), and glucose release was then determined with immobilized glucose oxidase-peroxidase (Model 27 glucose analyzer, Yellow Springs Instruments, Inc., Yellow Springs, OH) as described by Poore et al. (1989a). Neutral detergent fiber was determined using Bacillus sp. type-XIA alpha-amylase (Sigma Chemical Co., St. Louis, MO) as described by Robertson and Van

Soest (1977), and organic matter and dry matter were determined according to AOAC (1980).

Fecal samples were analyzed for rare earths as described by Poore et al. (1990a) and for cobalt as described by Moore et al. (1990a) using atomic absorption spectrophotometry after 4 g samples were dry ashed at 500°C and solubilized with a mixture of 3 N HCl and HNO_3. Natural log of marker concentrations during the post-peak portion of the passage curve were regressed against time to determine ruminal passage rate (Grovum and Williams, 1973).

Ruminal VFA were measured using gas-liquid chromatography (Erwin et al., 1961) with tri-methyl acetic acid as an internal standard.

Statistical analysis.

Data were analyzed with the General Linear Model procedure of SAS (1985), using single degree of freedom linear and quadratic contrasts to test effects of straw substitution. Pre-trial data for milk yield (kg/d), DMI, milk fat percentage and yield (kg/d) and gross efficiency were used as covariates for those variables. Milk yield (kg/d) during the pre-trial was used as the covariate for protein and lactose yield (kg/d) because pre-trial samples were not analyzed for protein and lactose. Least square means are presented for all variables analyzed using covariance.

RESULTS

Diet composition.

As wheat straw (WS) was substituted for alfalfa hay (AH) on an NDF basis (table 8), total forage decreased from 49 to 28% and forage NDF decreased from 21 to 19%. Because of increased grain, starch increased from 26 to 30%, and soybean meal increased from 8 to 20% of diet DM. Diets contained nearly equivalent NDF, ADF and CP.

Production responses.

Dry matter intake (kg/d and % of BW) and actual milk yield were not influenced by forage NDF source and averaged 23.1 kg/d, 3.6% and 38.4 kg/d (table 9). Yield of 3.5% FCM increased slightly from 0:3 to 2:1 WS:AH, but then decreased sharply at 3:0 WS:AH (linear and quadratic, $P<.05$). Milk fat yield showed a similar effect as FCM (linear and quadratic, $P<.05$), with 1.2 kg/d produced on 0:3 through 2:1 WS:AH and a decrease to .95 kg/d for 3:0 WS:AH. Protein yield showed a quadratic effect ($P<.05$) with the highest protein yield on 2:1 WS:AH and similar production for 0:3 and 3:0 WS:AH.

Milk composition was influenced by forage source. Milk fat percentage decreased linearly ($P<.05$) from 3.2% to 2.6% as wheat straw in diets was increased, and milk protein percentage increased linearly ($P<.05$) from 2.8% to 3.0% as straw was increased. Lactose percentage of milk was not influenced by forage source.

Gross efficiency of milk production (kg FCM/kg DMI) and persistence (FCM wk 8/FCM wk 1) decreased linearly ($P<.05$) with

increasing level of WS. Gross efficiency and persistence were only slightly reduced through 2:1 WS:AH, with a large decrease at 3:0 WS. Neither weight gain or body condition score change was influenced by forage NDF source, but cows fed 2:1 and 3:0 WS:AH tended to gain more weight (.9 kg/d) than cows fed 0:3 or 1:2 WS:AH (.5 kg/d).

Diet digestibility and ruminal VFA.

Digestibility of dietary components is in table 10. Organic matter digestibility was similar for the 0:3, 1:2 and 2:1 WS:AH, but decreased sharply at 3:0 WS:AH (linear and quadratic effects, $P<.05$). Digestibility of NDF was 43.5% on 0:3, 45.4% on 1:2, decreased to 40.7% on 2:1 and then dropped sharply to 31.2% at 3:0 WS:AH (linear and quadratic effects, $P<.05$). Source of forage did not influence digestibility of starch or CP with averages of 96% and 65% for starch and CP, respectively.

Total VFA concentration in rumen fluid was not influenced by fiber source and averaged 58 mM. Molar proportions of acetate, butyrate and valerate decreased linearly ($P<.05$) while molar proportion of propionate and 2-methyl butyrate increased linearly ($P<.05$) with increasing WS. Acetate to propionate ratio decreased linearly ($P<.05$) from 3.0 on 0:3 WS:AH to 1.9 on 3:0 WS:AH.

Rate of passage of liquid and diet ingredients.

Passage of diet ingredients and liquid were not influenced by forage fiber source (table 11). Passage rate of liquid (Co-EDTA)

averaged 9.3 %/h while ingredient passage rates averaged 7.6, 6.1 and 4.7%/h, for sorghum grain, alfalfa hay and wheat straw, respectively.

DISCUSSION

In this study actual milk yield and intake of DM were not influenced by forage fiber source in diets formulated to the same total NDF, supporting the concept of using NDF in diet formulation. There was, however, a tendency for increased DMI and milk yield when chopped straw was substituted for part of the alfalfa hay on an NDF basis, and this is consistent with intake and performance responses observed with beef cattle (Swingle et al., 1990). Milk composition, persistence, diet digestibility and ruminal VFAs were influenced by diet, showing that factors other than total diet NDF are important to lactational performance. It is well known that reducing forage particle size can result in reduced intake and chewing time in diets for lactating cows (Woodford and Murphy, 1988). The forages in this study were similar in particle size, and resulted in similar chewing times in another study (Poore et al. 1989b) with similar forages, so effects in the present study are probably due to factors other than physical form of forage.

Because diets were formulated to contain 30% NDF from three sources (alfalfa hay, chopped straw and concentrate), proportion of NDF from forage (calculated from forage analysis), decreased from 23% on all alfalfa to 20% on all WS. Estimated NDF in AH and WS in our laboratory is about 9% lower when samples are ground to pass a 1-mm screen in a Udy cyclone mill compared to a 2-mm screen in a Wiley mill, so to allow

comparison with future studies, forage NDF estimates were decreased 9%, resulting in estimates of 20.8, 20.3, 19.3 and 18.6 for 0:3, 1:2, 2:1 and 3:0 WS:AH, respectively. Concentrate NDF or NDF from finely processed forages is not as functional in stimulating rumination as is coarse forage NDF (Sudweeks et al., 1981), so it is recommended (Mertens, 1982) that to maintain a normal rumen environment, 75% of the total NDF should be from coarse forages (or 21% coarse forage NDF). Because diets in the current study were marginal in forage NDF, and forage NDF decreased as WS was substituted for AH, it is likely that this played a role in the changes in milk composition and persistence.

Estimates for ruminally degradable starch in sorghum grain steam-flaked to 360 g/l (28 lb/bu) are 74% (Poore et al., 1990b) so it is a starch source with high ruminal availability, similar to starch in barley (McCarthy et al., 1989; Herrera-Saldana et al., 1990). Increasing ruminal degradation of starch decreases acetate to propionate ratio, reduces ruminal pH and may depress fiber digestion (Hoover, 1986), and influence milk composition. Nocek and Russell (1988) suggested that performance should be optimal when diets are formulated with an optimal ratio of structural to non-structural carbohydrates. This concept, although a possible advance over formulating to total NDF, ignores possible differences in functional characteristics of NDF (e.g. concentrate vs forage sources), and ruminal degradability and differences in fermentation end-products for different sources of non-structural carbohydrates. Van Soest (1990) showed that in vitro

fermentation of non-starch, non-structural carbohydrates (pectins) resulted in fermentation end products similar to structural carbohydrates (high acetate) while in vitro fermentation of starch resulted in end products with a high proportion of propionate and some lactate. In the current study, although the balance between structural (NDF) and non-structural carbohydrates [100-(NDF - CP - ash - fat)] should the same in all four diets, increased concentrations of ruminally degradable starch may have altered the ruminal environment enough to impact fiber digestion and milk composition as WS was substituted for AH.

Because both the level of forage NDF and of ruminally available starch may influence the rumen environment, a balance between the two may be necessary to maintain normal milk production. This would be especially critical when diets contain low quality forage and the main energy source in diets is grain, because grain level must be relatively high to meet energy requirements of the cow. In the current study, the ratio of forage NDF to ruminally available starch (FNDF:RDS) was 1.10, 1.02, .92 and .84 for 0:3, 1:2, 2:1 and 3:0 WS:AH, respectively (table 8). Davis (1979) reported that when molar proportion of propionate (C3) in ruminal fluid exceeded 25 moles/100 moles or acetate to propionate ratio (C2:C3) was lower than 2.2, milk fat production was reduced. Based on those criteria, the 1:2 WS:AH diet was acceptable (25 molar% C3 and 2.4 C2:C3), the 2:1 WS:AH was marginal (27 molar% C3 and 2.2 C2:C3) and the 3:0 WS:AH was unacceptable (30 molar% C3 and 1.9 C2:C3),

suggesting that the critical FNDF:RAS is between .9 and 1.0. Based on these considerations we suggest that to maintain normal milk production, and to prevent acidosis and poor persistence in lactating cows, the ratio of forage NDF to ruminally available starch be maintained above 1:1.

This concept incorporates differences in ruminal degradability of starch sources, differences in fermentation end-products between starch and non-starch carbohydrates and differences in functionality of concentrate vs forage NDF. Assumptions are that ruminal fermentation of structural and non-starch-non-structural carbohydrates will have a relatively minor effects on rumen environment, and that NDF from concentrates will have little impact on chewing activities. The concept does not include functionality of different forage NDF sources, so diets formulated this way with finely processed forage may need adjustments to maintain chewing times. Formulation of diets based on this concept will require additional information on total starch and ruminal availability of starch from various sources of concentrate.

In conclusion, feeding early lactation cows diets with 30% NDF with forage NDF from varying proportions of wheat straw and alfalfa hay resulted in similar levels of intake and actual milk yield, but yield of FCM, milk composition, fiber digestibility, ruminal VFA and persistence were all influenced by diet. This study demonstrates that when very low quality forages are substituted for alfalfa hay on an NDF basis in grain based diets formulated to near optimal NDF for early lactation cows,

forage NDF decreases, ruminally available starch increases, and the altered balance between the two may negatively impact performance. Whether low quality forage can be entirely substituted for alfalfa hay when FNDF:RDS is maintained above 1:1, and whether adding ruminally degradable starch to diets is beneficial when FNDF:RDS is greater than 1:1 are important questions for future research.

Table 8. Diet composition and nutrient analysis (exp. 2).

Item	Forage NDF, WS:AH 0:3	1:2	2:1	3:0
Ingredient composition, % of DM[1]				
Alfalfa hay[2]	49.0	31.4	15.1	-
Wheat straw, chopped[3]	-	10.1	19.4	28.0
Flaked Sorghum grain[4]	32.8	36.2	39.2	41.0
Soybean Meal[5]	7.6	12.0	16.0	19.7
Dicalcium phosphate	1.15	1.07	.99	.92
Limestone	-	-	-	1.05
Chemical composition				
DM %	89.2	87.6	87.7	88.1
Composition of DM, %				
Ash	7.7	7.8	8.1	8.4
CP	17.6	17.6	17.2	17.4
Starch	25.6	26.7	28.3	29.9
RDStarch[6]	18.9	19.8	20.9	22.1
NDF	30.4	31.3	31.9	30.2
ADF	22.0	22.8	21.2	20.4
Forage NDF[7]	20.8	20.1	19.3	18.6
FNDF:RDS[8]	1.10	1.02	.92	.84
NE_l, Mcal/kg[9]	1.70	1.71	1.72	1.72

[1]All diets contained 4% molasses, 4% animal fat, .5% salt and .35% Magnesium oxide.

[2]Mid-bloom. Analysis: DM, 92.9%; CP, 17.4%; NDF, 46.8%; ADF, 35.4%; P, .12%; Ca, 2.16%; Starch, 3.5%.

[3]Analysis: DM, 93.1%; CP, 3.9%; NDF, 73.0%; ADF, 47.6%; P, .04%; Ca, .36%; Starch, 2.8%.

[4]Analysis: DM, 86.0%; CP, 9.5%; Starch, 75.7%.

[5]Analysis: DM, 92.6%; CP, 54.1%; Starch, 7.4%.

[6]Calculated based on data of Poore et al. (1990b).

[7]Percent NDF in diet from forage, calculated from ingredient analysis.

[8]Ratio of forage NDF to ruminally degradable starch.

[9]Calculated from NRC, 1989.

Table 9. Intake and production[1] by cows fed diets containing various proportions of forage NDF from alfalfa hay or wheat straw.

Item	Forage NDF, WS:AH 0:3	1:2	2:1	3:0	SEM
Dry matter intake					
Kg/d	22.5	23.3	23.9	22.5	.87
% of BW	3.61	3.63	3.72	3.52	.12
Yield, kg/d					
Actual milk	38.4	39.5	39.4	36.2	1.13
3.5% FCM[ab]	35.8	36.0	36.6	31.3	1.22
Milk fat[ab]	1.20	1.18	1.19	.95	.05
Milk protein[b]	1.07	1.13	1.15	1.07	.029
Lactose	1.86	1.91	1.87	1.73	.067
Milk composition, %					
Milk fat[a]	3.22	3.00	2.94	2.60	.10
Milk protein[2a]	2.81	2.87	2.93	3.00	.061
Lactose[2]	4.88	4.89	4.77	4.89	.060
Efficiency, FCM/DMI[a]	1.60	1.54	1.53	1.39	.065
Persistence[23a]	1.03	.95	.92	.78	.038
Weight gain, kg/d2	.46	.56	.89	.88	.163
Change in condition[24]	.08	-.04	.00	.13	.079

[1]Least squares means.

[2]Actual means.

[3]FCM week 8/FCM week 1.

[4]Initial condition score averaged 2.8 on a 1 to 5 scale (1 is very thin and 5 very fat).

[a]Linear effect, $P < .05$.

[b]Quadratic effect, $P < .05$.

Table 10. Digestibility and ruminal volatile fatty acid concentrations in cows fed diets containing various proportions of forage NDF from alfalfa hay or wheat straw.

	Forage NDF, WS:AH				
Item	0:3	1:2	2:1	3:0	SEM
Diet Digestibility, %					
Organic matter[ab]	67.2	69.1	68.0	63.5	.75
NDF[ab]	43.5	45.4	40.7	31.2	1.88
Starch	95.4	95.0	95.5	96.2	.49
CP	65.4	66.6	64.6	63.6	.97
Ruminal fluid VFA[1]					
mMolar	63.9	55.0	64.7	48.2	6.20
mole/100 mole					
C2[a]	64.1	59.9	59.3	57.3	1.12
C3[a]	21.7	25.1	27.1	29.8	1.08
C4[a]	11.7	12.2	10.7	10.1	.50
Isobutyrate	.59	.64	.72	.65	.051
Valerate[a]	1.37	1.33	1.12	1.14	.058
Isovalerate	.35	.41	.45	.41	.048
2-methyl butyrate[a]	.32	.42	.61	.57	.076
C2:C3[2a]	2.99	2.43	2.21	1.94	.140

[1]Taken 3 h post-feeding via stomach tube.

[2]C2=acetate, C3=propionate and C4=butyrate.

[a]Linear effect, P <.05.

[b]Quadratic effect, P <.05.

Table 11. Ruminal passage rates for liquid and diet ingredients in cows fed diets containing various proportions of forage NDF from alfalfa hay or wheat straw[1].

Item	Forage NDF, WS:AH 0:3	1:2	2:1	3:0	SEM
Ruminal passage rate, %/h					
Liquid	9.5	10.1	8.2	9.3	.65
Sorghum grain	7.8	8.2	6.8	7.5	.45
Alfalfa hay	6.4	6.7	5.4	5.8	.50
Wheat straw	4.7	5.1	4.1	4.9	.33
Relative passage rate[2]					
Sorghum grain	84.7	83.2	82.8	81.5	6.0
Alfalfa hay	69.7	67.7	67.2	63.2	7.2
Wheat straw	50.8	52.3	50.3	53.5	4.4

[1]Calculated according to Grovum and Williams, 1973.

[2]Particulate passage rate as a percentage of liquid passage rate.

CHAPTER 5

INFLUENCE OF ALTERING FORAGE FIBER SOURCE AND RUMINAL STARCH DEGRADABILITY ON MILK PRODUCTION BY EARLY-LACTATION HOLSTEIN COWS FED DIETS FORMULATED TO CONTAIN EQUAL FORAGE FIBER

ABSTRACT

Twenty-four Holstein cows (12 multiparous, 12 primiparous) that averaged 52 d in milk were used to study effects of forage fiber source and method of sorghum grain processing on lactational performance. Diets contained high quality (alfalfa hay) or low quality (wheat straw) forage, and low (dry-rolled sorghum grain) or high (steam-flaked sorghum grain) ruminal starch degradability in a 2 x 2 factorial arrangement of treatments. The experiment included a 2 wk covariate period followed by 8 wk of treatment. Diets contained 30% total NDF and 16.5% CP. Forages were included to provide 22% NDF; consequently, straw diets had lower forage:concentrate (31:69) than alfalfa diets (52:48). Substituting low quality forage for high quality forage did not influence DMI or any production parameter. Ruminal passage rates for liquid and all diet ingredients were slower with low than with high quality forage, but NDF digestibility and chewing time were not influenced. Diets with high starch degradability resulted in higher daily yield of milk (+3.4 kg) and milk protein (+110 g/d), milk protein percentage (+.08%) and improved efficiency and persistence. Milk fat percentage decreased from 3.6 to 3.2%, but yield of milk fat was not decreased when grain was

steam-flaked. Total tract digestibility of starch increased from 80 to 97% when sorghum grain was steam-flaked, but digestibility of NDF (38%) was not influenced. Few interactions between forage quality and starch source were observed. This study shows that low quality forages can be substituted for alfalfa hay if diets contain a level and form of NDF such that DMI and chewing time are maintained, and the ratio between forage NDF and ruminally degradable starch is greater than 1:1. Also, increasing ruminal degradability of starch is beneficial when forage NDF:ruminally degradable starch is maintained greater than 1:1.

INTRODUCTION

Low quality forages, such as cereal straws, are abundant and usually available at much lower cost than high quality forages. It would be desirable in some situations to increase use of low quality forages in diets for productive ruminants, but it is commonly believed that performance will suffer if high producing cows are fed low quality forage (Van Soest, 1987). In several trials at the AZ station, substitution of chopped wheat straw for alfalfa hay (Brown et al., 1990) increased diet NDF, and improved performance when control diets were low in fiber and high in ruminally degradable starch. However, when diets contained adequate NDF, substitution with straw tended to decrease milk yield (Khalaf, 1987). If lactation diets contain too much chopped straw, intake and milk yield are low (Orskov et al., 1988).

It has been proposed that formulating diets for lactating cows to a specified level of NDF may be the most practical means of adjusting

for differences in forage quality (Mertens, 1982; Chase, 1988). Validity of the concept has been supported by results of recent lactation trials (Colenbrander et al, 1986; Kaiser and Combs, 1989) but has been questioned by some researchers (Briceno et al., 1987). However, when forages vary widely in NDF, resulting isofibrous diets have differences in forage NDF and starch which will influence performance (Poore et al., 1989b).

Poore et al. (1990a) showed that ruminal digestibility of wheat straw was depressed more than alfalfa hay when concentrate in diets for beef steers was increased from 60 to 90%. Thus it is possible that level of ruminally degradable starch in diets could interact with forage quality, and influence lactational performance. Earlier experiments (chapter 4) suggested that milk composition and performance could be maintained when the ratio of forage NDF:ruminally degradable starch was 1:1 or greater. Steam-flaking sorghum grain dramatically increases ruminal degradability of starch compared to dry processing, and provides an interesting mechanism for studying starch degradability, because degradability can be altered without changing other dietary parameters.

This experiment was designed to evaluate the main effects of forage NDF source (alfalfa hay or wheat straw), ruminal starch degradability (steam-flaked or dry-rolled sorghum grain) and forage by starch source interactions on lactational performance by early lactation Holstein cows.

MATERIALS AND METHODS

Animals and diets

Twenty-four Holstein cows (12 multiparous, 12 primiparous; 52 d in milk) from the University of Arizona Dairy were fed four diets with forage NDF from alfalfa hay or chopped wheat straw with concentrate based either on dry-rolled or steam-flaked sorghum grain, in a 2 x 2 factorial arrangement (6 cows per diet). Cows were fed a common diet during a 2 wk covariate period, followed by an eight wk lactation trial. Cows were blocked on d in milk, production and parity, and randomly assigned from within blocks to one of the four treatments. One cow was removed from each steam-flaked diet for reasons not related to treatment; one was off feed during the pretrial and never recovered to her previous level of production, and one suffered a severe foot injury in week 4 of the treatment period. Cows were housed in dry lots (28 m^2/cow) with shades (4.5 m^2/cow) equipped with evaporative coolers (Korral Kool, Inc., Mesa, AZ). Pens were equipped with Calan gates (American Calan Co., Northwood, NH) for measuring individual feed intakes, and the experiment was conducted from September to November. Cows were fed ad libitum (10% refusal) with feed offered twice daily, and had free access to water and trace mineralized salt blocks.

Milk yield during the pretrial and treatment periods was recorded twice daily. Milk was sampled bi-weekly and analyzed for fat,

protein, lactose and solids not fat using infrared analysis (Arizona DHIA).

Cows were weighed following the morning milking on two consecutive days and were body condition scored once (1 being very thin and 5 very fat) before and following the trial.

Diet ingredient composition is given in table 12. Diets were formulated to contain 25% forage NDF from either wheat straw (78% NDF) or alfalfa hay (46% NDF), 17% CP and to meet or exceed requirements (NRC, 1989) for Ca, P and Mg.

Steam-flaked sorghum grain (SF) was prepared by steaming whole grain for one h and then flaking through a 50 x 80 cm roller-mill with rolls adjusted to give bulk density of 360 g/l (28 lb/bu). Dry rolled grain (DR) was prepared in the same mill with rolls adjusted to coarsely crack grain. Wheat straw (WS) was chopped through a Miller rotary hay mill (United Farm Tools, Inc., Turlock, CA) with a 5 cm screen, resulting in maximum stem length of approximately 5 cm. Wheat straw based diets were blended in a stationary horizontal mixer.

Alfalfa hay based diets were prepared in a truck equipped with a mixing box (Kirby Manufacturing Inc., Merced, CA). Baled AH was placed in the truck and allowed to mix until stems were approximately 7.5 cm in length. Concentrate mixtures were then added, and allowed to mix until all ingredients were well dispersed and maximum stem length was reduced to 5 cm. These methods resulted in a similar physical form for both AH and WS based diets. Moisture content of diets (89%) was equalized by

adding water to diets containing DR. Chromium oxide was included (.1% of diet DM) 10 d prior to and during the fecal collection period as a digestibility marker.

Sample collection.

Diets and ingredients were sampled weekly during the lactation trial. Diets were sampled daily during the fecal collection period. Orts were collected daily during the fecal sampling period, composited by cow, and an aliquot taken for analysis. A portion of each sample was dried at 100°C to determine absolute DM and the remainder dried at 50°C in preparation for subsequent analysis. On d 1 of the fecal sampling period, cows were dosed with rare earth labeled feed ingredients to determine rates of passage. Forages were labeled with Dy, grain with Yb and soybean meal (SBM) with Eu using the immersion method (Poore et al. 1990a). Briefly, feeds were soaked for 24 h in 2.5 g/l solutions of rare earth chlorides, followed by five hourly rinses and drying at 50°C. Concentration of rare earths were 4.12, 9.17, .76, 1.03 and 3.27 mg/g for WS, AH, DR, SF and SBM, respectively. Labeled feeds (175 g WS or 145 g AH, 207 g DR or 175 g SF, and 140 g SBM) and 9 g Co-EDTA (to monitor fluid kinetics; Uden et al., 1980) were mixed with a small portion of the a.m. feeding and offered to the cows immediately as they returned from the milking parlor. The remainder of the meal was offered when that containing marker had been consumed (within one h).

Fecal samples were obtained from the rectum before dosing and at 10, 16, 22, 28, 34, 46, 58, 70, 82, 94, 106 and 118 h post-dosing.

Fecal samples were frozen immediately after collection. Prior to analysis, samples were thawed and dried at 50°C. Feed, orts and fecal samples were ground to pass a 2 mm screen in a Wiley mill before compositing on an equal DM basis. All composite samples were reground to pass a 1-mm screen in a cyclone mill (UDY Corporation, Fort Collins, Co).

On the last day of the experiment, rumen fluid samples were obtained with a stomach tube 3 h post-feeding. Samples were strained through 3 layers of cheesecloth, placed immediately on ice and then frozen until analyzed for VFA concentrations.

Behavioral observation.

During wk 6 and 7 cows were observed to quantitate rumination and eating time. Each cow was observed each 5 min over a 24-h period, and behavior recorded as ruminating, eating, drinking or resting (Woodford and Murphy, 1988). Rumination and eating times were averaged across the two days of observation.

Sample analysis.

Feed, orts and fecal samples were analyzed for CP using a N autoanalyzer (Technicon, Terrytown, NY), starch using amyloglucosidase hydrolysis and immobilized glucose oxidase-peroxidase (Poore et al., 1989a), NDF (Robertson and Van Soest, 1977) using alpha-amylase (type XI-B from bacillus sp, product # A 3051, Sigma Chemical Co., St. Louis, MO) as described by Poore et al. (1990a), and DM and organic matter (OM) according to AOAC (1980). Samples for Cr analysis (.5 g) were wet ashed

by boiling in concentrated sulfuric acid (10 ml) with .4 g Mg sulfate and .1 g Na selenite. Then .4 g periodic acid and 10 ml water were added and solutions were heated 3 h, which resulted in complete oxidation of chromium. Chromium was then determined using an atomic absorption spectrophotometer with an air-acetylene flame (Hitachi, Ltd., Tokyo, Japan).

Fecal samples (3.0 g) were dry ashed at 500°C, then solubilized by boiling in 20 ml of a mixture of 3 N HCl and 3 N HNO_3. Samples were diluted to 50 ml and KCl was added (1,500 ppm K in final solutions). Concentrations of rare earths and cobalt (Moore et al., 1990a) were measured using atomic absorption spectrophotometry. Ruminal passage rate was the absolute value of the slope obtained when the natural log of marker concentration during the post-peak portion of the passage curve was regressed against time (Grovum and Williams, 1973).

Ruminal volatile fatty acids were measured using gas-liquid chromatography (Erwin et al., 1961) with tri-methyl acetic acid as an internal standard.

Statistical analysis.

Data were analyzed with the GLM procedure of SAS (1985) for main effects of forage fiber source and grain source, and forage by grain interaction. Pre-trial data were used as covariates in analysis of intake and production variables, and covariate adjusted means are reported. Least square means are presented for all variables because two cows were removed from the study.

RESULTS

Diet analysis.

Although diets were formulated to contain 25% forage NDF, actual level was about 22%. Concentrations of total NDF% (30%) and ADF% (19-23%) as well as NE_1 (1.65 Mcal/kg) and CP (16.5%) were near recommendations for cows at this level of production (Coppock, 1987; NRC, 1989).

Production responses.

Least squares means for production parameters are in table 13. Intake of dry matter was not influenced either by forage source or degree of starch degradability, and averaged 20.5 kg/d (3.5%) of BW. Daily milk yield was 3.4 kg higher ($P<.01$) for steam-flake (SF) than dry-roll (DR) diets but was not influenced by forage source. Yield of 3.5% FCM tended to be higher ($P<.09$) for SF than DR diets, and there was a tendency ($P<.11$) for a grain x forage interaction. FCM yield was nearly equal for SF and DR based diets with AH as forage, but was 3 kg/d higher for SF than DR with WS as the forage. Daily yield of milk fat was not influenced by either grain processing or forage source, but there was a tendency for a grain x forage interaction ($P<.12$); fat yield was 60 g/d lower for SF than DR with AH as forage, and 80 g/d higher for SF than DR when WS was the forage. Yield of protein, lactose and solids

not fat (SNF) followed actual milk yield, were higher for SF than DR diets (P<.01) and were not influenced by forage source.

Milk composition was altered by grain processing, but not by forage source. Percentage of milk fat was lower (P<.05), and percentages of milk protein (P<.07), lactose (P<.04) and SNF were higher (P<.05) for SF than DR.

Gross efficiency (kg FCM/kg DMI) was higher (P<.08) for SF than DR diets, and tended to be higher (P<.16) for WS than AH diets. There was also a tendency for a grain x forage interaction (P<.19) with efficiencies being similar for DR (1.38) and SF (1.40) when AH was forage, but lower for DR (1.38) than SF (1.57) when WS was forage. Gross efficiency based on actual milk yield was higher (P<.01) for SF than DR diets.

Milk yield was more persistent with SF (P<.10) than DR diets. Neither grain or forage source influenced body weight gain (P>.20), but cows fed SF tended (P<.12) to lose less body condition than cows fed DR. There was also a tendency (P<.18) for a grain x forage interaction on body condition loss; cows fed SF and DR had similar loss of condition (.15 and .17 units, respectively) when AH was the forage, while cows fed SF lost less condition than cows fed DR (.0 and .21 units, respectively) when WS was the forage.

Diet digestibility and ruminal volatile fatty acids.

Digestibility of OM, NDF and starch were not affected by source of forage, but digestibility of CP was higher (P<.01) for WS (67%) than

for AH (63%) based diets (table 14). Diets with SF had higher (P<.01) digestion coefficients for OM and starch, and a tendency for higher digestibility of CP (P<.19) compared with DR. Steam-flaking sorghum grain did not affect digestibility of NDF.

Total VFA (mM) in ruminal fluid was not influenced by starch degradability, but tended to be higher (P<.13) for AH than WS. Molar proportions of acetate were lower (P<.01), and propionate higher (P<.01) for SF compared with DR. Molar proportion of acetate tended to be higher (P<.11), propionate lower (P<.01) and butyrate higher (P<.01) when AH, rather than WS was the forage. Molar proportions of isobutyrate (P<.08), valerate (P<.15) and isovalerate (P<.12) tended to be higher on AH than on WS. Acetate to propionate ratio was higher (P<.05) for DR than for SF, and was higher (P<.01) for AH than for WS.

Chewing behavior.

Total chewing and rumination time, whether expressed as total min/d or min/kg DMI, was not influenced by either forage source or grain processing (table 15). There was a tendency (P<.12) for cows fed SF to spend less time eating than cows fed DR.

Rate of passage of liquid and diet ingredients.

Ruminal passage rates for liquid, SBM, grain and forage averaged 8.9, 7.5, 6.8 and 5.6 %/h, across all diets (table 15). Ruminal passage of liquid, soybean meal, grain and forage was slower (P<.05) when WS rather than AH was the forage. When expressed relative to liquid passage rate, passage of WS was still slower (P<.01) than AH, but

relative rates for grain and SBM were not influenced by forage source. Relative to liquid DR tended to pass slower (P<.16) than SF, but grain processing did not influence forage or SBM. Passage rates for SBM, SF, DR, AH and WS were 85, 80, 74, 71 and 55 % of the liquid passage rate, respectively.

DISCUSSION

Low intake and altered ruminal environment and milk composition are problems that may limit the use of low quality forages in diets for high producing cows (Van Soest, 1987).

Substituting low quality forage on an equal weight basis for high quality alfalfa hay usually reduces intake and milk yield, because total diet NDF is excessive (Shaver and Satter, 1988). Using chopped straw as the only forage for lactating cows may result in low intake when diet NDF is too high (Orskov et al., 1988). Diets based on WS in the current study were low enough in total NDF (30%) so that DMI was not reduced, compared to AH.

Functional forage NDF is needed to maintain chewing activity and normal milk yield by dairy cattle. Finely grinding and pelleting forages (Woodford and Murphy, 1988) or decreasing forage NDF relative to concentrate NDF (Sudweeks et al., 1981) results in reduced chewing time and milk yield. In the present study, substituting chopped WS for AH on an equal NDF basis did not alter chewing times, so the similarity of performance was in part due to maintaining the level of coarse forage (functional) NDF in the diets.

Grasses have lower cation exchange capacity and buffering capacity than legumes (Van Soest, 1987), and this might result in lower fiber digestion, reduced acetate to propionate ratio (C2:C3) and possibly acidosis, especially when diets are high in ruminally degradable starch (Van Soest, 1987; Poore et al., 1990a). Alfalfa hay is high in non-starch, non-structural carbohydrates (pectin), so when low quality forage is substituted for alfalfa on an equal NDF basis, diets normally will contain more grain (starch), and this can influence lactational performance. Because grains differ in ruminally degradable starch, and only starch digested in the rumen influences the ruminal environment and fiber digestion, forage source and degradability of starch might interact to influence lactational performance. In the current study, however, we observed few interactions between forage source and starch degradability, probably because intake and fiber digestion were similar for AH and WS diets, and C2:C3 was maintained in the desirable range for milk production (Davis, 1979).

Poore et al. (1989b) showed that DMI and milk yield were not altered when chopped WS was substituted for AH in diets with 30% total NDF. However, milk fat percentage and yield were decreased as WS replaced AH. This effect was apparently due to decreased forage NDF and increased ruminally degradable starch in the diets. It was postulated that maintaining a ratio of forage fiber to ruminally degradable starch (FNDF:RDS) greater than 1:1 might be necessary for maintaining lactational performance, because milk fat percentage, fiber digestion

and C2:C3 were slightly decreased when FNDF:RDS decreased from 1:1 to .9:1, and severely depressed when the ratio was further reduced to .8:1. In the current study the minimum ratio was 1:1 for the WSSF diet, and C2:C3 (2.54) and molar proportion of C3 (25 moles/100moles) were close to levels known to negatively impact lactational performance (Davis, 1979; Van Soest, 1982) on that diet. There was a tendency for an interaction between forage source and starch degradability on FCM and fat yield in the current study because milk fat percentage was reduced less by SF in diets based on WS than AH. This is opposite from the interaction expected based on traditional ideas about fiber quality, and the effects are apparently due to factors other than chewing time, fiber digestion and C2:C3.

Steam-flaking sorghum grain improves performance of beef cattle (Theurer, 1986) but has not been widely used for feeding lactating dairy cattle partly because of the concern that increasing ruminal degradability of starch would cause acidosis and reduce ruminal fiber digestion (Hoover, 1986). Increasing ruminal starch degradability can, however, result in increased flow of bacterial CP from the rumen of lactating cows (Herrera-Saldana et al., 1990; Poore et al., 1990b). Steam-flaking sorghum grain is interesting not only from an applied nutrition standpoint, but also as a model for studying the effects of altered ruminal starch degradability. By steam-flaking sorghum grain, ruminal degradability of starch can be manipulated without altering level and source of fiber or grain in diets. This is not the case in

the most common model used for studying effects of ruminal starch degradability, which is to substitute or mix grains having different inherent starch degradability. In the study of McCarthy et al. (1989) for example, fiber digestion was depressed when barley replaced corn in diets for lactating cows, but it is not known if this effect was due to the greater availability of starch in barley, or due its high content of indigestible fiber. Another advantage of the processing model is that the degree of steam-flaking can be controlled to produce a wide range in ruminal starch availability within a single grain (Poore et al., 1989a; Moore et al., 1990b).

In studies comparing corn to barley in diets for lactating cows (Casper and Schingoethe, 1989; Casper et al., 1990; McCarthy et al., 1989) yield of FCM has generally been lower on barley, an effect usually due to lower feed intake and milk fat percentage on barley based diets. In these studies, however, FNDF:RDS (calculated from McCarthy et al., 1989 and NRC, 1989) was reduced from about 1:1 on corn diets to about .8:1 on the barley diets. In contrast, in studies where FNDF:RDS of barley diets was maintained above 1:1 (DePeters and Taylor, 1985; Weiss et al., 1989), milk fat and milk yield were not reduced. In another study, when barley replaced sorghum grain, (Herrera-Saldana et al., 1990) FNDF:RDS fell from about 1.3 to .85, and C2:C3 was decreased from 3.1 to 1.9. This resulted in decreased milk fat percentage and yield in a lactation study with similar diets. Increasing ruminal degradability of starch by flaking sorghum grain did not negatively affect milk yield

or intake in our study, possibly because FNDF:RDS was maintained greater than 1:1 in the SF diets.

Steam-flaking sorghum grain increased milk yield by about 3.4 kg/d (12%). Steam-flaking grain decreased milk fat percentage but daily yield of milk fat was not altered, compared to dry-rolling. Milk protein concentration was increased, so daily yield of protein was improved 14% by steam-flaking the sorghum grain. Because starch digestibility was increased on SF, without a decrease in NDF digestibility or DMI, digestible organic matter intake was about 10% higher for SF than DR, and this explains part of the improved milk yields. Poore et al. (1990b) reported that steam-flaking sorghum grain increased duodenal flow of CP by promoting greater ruminal microbial protein synthesis, which may also be involved in production responses seen in the current study.

Chopped straw as a forage results in a more dense ruminal raft than alfalfa hay (Moore et al., 1990a) which may impede the passage of small particles from the rumen and impact ruminal fiber digestion (Poore et al., 1990a). Ruminal passage of all ingredients was slower for WS diets in the current study, and this may in part explain why NDF digestibility was not lower for WS than AH based diets. Slower passage rate would offset slower digestion rate of WS, and slower passage of the concentrates could increase their NDF digestibility. This effect of WS has been reported previously for beef cattle (Moore et al., 1990a). Because passage rates were slower, ruminal fill should be greater on WS

diets. Apparently however, rumen fill was not increased enough to stimulate rumination or decrease DMI.

Expressing particulate passage rate as a percentage of the liquid passage rate separates effects due to ruminal changes that affect all particles due to inherent differences in the particles themselves. It is apparent from this analysis (table 15) that decreased passage of SBM and sorghum grain was closely related to the decreased liquid turnover, while some of the differences between forages were due to characteristics of the forage particles themselves. From this it may be concluded that WS passed slower than AH, and this caused slower passage of liquid, SBM and grain. Steam-flaked sorghum grain also passed faster than DR, when expressed relative to liquid, possibly due to increased fragility of the particles resulting from processing. Because there was a tendency for slower liquid passage for AHSF than AHDR, individual animal variation obscured inherent differences in the grain particles, and expressing passage rates relative to liquid uncovered this effect. Faster passage for the flaked grain is opposite to the effect reported by Turnbull and Thomas (1987), who showed a slower passage for steam-flaked compared to dry-rolled corn.

CONCLUSIONS

Substituting chopped wheat straw for alfalfa hay in this study resulted in no differences in dry matter intake, milk yield or milk composition. Factors involved in successful substitution of low quality for high quality forages include 1) total NDF near 30% so DMI is

adequate, 2) sufficient functional forage NDF to maintain chewing time, and 3) a ratio of forage NDF to ruminally degradable starch of at least 1:1. This study also shows that increasing ruminal degradability of starch, by steam-flaking sorghum grain, is beneficial when ratio of forage NDF to ruminally degradable starch is maintained above 1:1.

Table 12. Diet composition and nutrient analysis (exp. 3)[1].

	Diet			
Ingredient, % of DM	AHDR	AHSF	WSDR	WSSF
Alfalfa hay[2]	52.3	52.3	-	-
Wheat straw, chopped[3]	-	-	30.6	30.6
Flaked Sorghum grain[4]	-	34.2	-	40.5
Dry-rolled sorghum grain[5]	34.2	-	40.5	-
Soybean Meal[6]	4.1	4.1	18.5	18.5
Dicalcium phosphate	1.1	1.1	.9	.9
Limestone	-	-	1.0	1.0
Diet DM %, as fed	89.3	87.9	88.7	87.8
Analysis, % of DM				
Ash	9.1	9.2	9.3	9.4
CP	16.4	16.5	16.5	16.3
Starch	25.0	24.7	29.4	29.2
RDS[7]	12.0	18.3	14.1	21.6
NDF	29.2	29.7	29.8	30.7
ADF	23.6	22.8	18.6	19.4
FNDF[8]	21.8	21.8	22.4	22.4
FNDF:RDS	1.82	1.19	1.58	1.04
NE_l, Mcal/kg[9]	1.66	1.66	1.65	1.65

[1]All diets contained 4% molasses, 3% animal fat, .3% salt and .4% magnesium oxide.

[2]Early-bloom. Analysis: DM, 92.0%; CP, 18.0%; NDF, 41.7%; ADF, 35.1%; lignin, 6.8%; cellulose, 28.3%; hemicellulose, 6.6%; P, .18%; Ca, 1.4%; starch, 2.7%.

[3]Analysis: DM, 93.6%; CP, 4.2%; NDF, 73.2%; ADF, 49.5%; lignin, 5.7; cellulose, 43.8; hemicellulose, 23.7; P, .04%; Ca, .18%; starch, 1.8%.

[4]Steam-flaked to 360 g/l. Analysis: DM, 83.0%; CP, 9.6%; starch, 76.0%; NDF, 9.7; ADF, 6.8; lignin, 1.4; cellulose, 5.4; hemicellulose, 2.9%.

[5]Analysis: DM, 88.0%; CP, 9.6%; starch, 74.9%; NDF, 9.3; ADF, 5.8; lignin, 1.5; cellulose, 4.4; hemicellulose, 3.5%.

[6]Analysis: DM, 92.6%; CP, 54.1%; starch, 7.5%; NDF, 9.0%; ADF, 6.0%; lignin, 0.9%; cellulose, 5.1%; hemicellulose, 3.0%.

[7]Ruminally degradable starch (calculated from Poore et al, 1990b).

[8]Percent forage NDF, calculated from ingredient analysis.

[9]Calculated from NRC, 1989.

Table 13. Intake and milk production[1] by cows fed isofibrous diets containing steam-flaked or dry-rolled sorghum grain with forage NDF from alfalfa hay or wheat straw.

	Diet					Significance of effect (P)		
Item	AHDR	AHSF	WSDR	WSSF	SEM[2]	G	F	G*F
Dry matter intake								
kg/d	21.1	20.6	20.2	20.0	.67	NS[3]	NS	NS
% of BW	3.58	3.56	3.47	3.38	.112	NS	NS	NS
Yield, kg/d								
milk	28.6	31.3	27.6	31.6	.82	.01	NS	NS
3.5% FCM	28.7	28.8	27.8	30.8	.85	.09	NS	.11
milk fat	1.00	.94	.98	1.06	.044	NS	NS	.12
protein	.83	.92	.80	.93	.026	.01	NS	NS
lactose	1.37	1.52	1.37	1.59	.039	.01	NS	NS
SNF	2.38	2.64	2.29	2.65	.067	.01	NS	NS
Milk composition, %								
fat	3.53	3.02	3.60	3.37	.169	.04	NS	NS
protein	2.91	2.97	2.88	2.99	.039	.07	NS	NS
lactose	4.79	4.85	4.76	4.85	.045	.12	NS	NS
SNF	8.33	8.47	8.29	8.41	.061	.05	NS	NS
Gross efficiency								
FCM[4]	1.38	1.40	1.38	1.57	.059	.08	.16	.19
milk[5]	1.37	1.54	1.37	1.57	.048	.01	NS	NS
Persistence[6]	.82	.92	.82	.85	.040	.10	NS	NS
BW gain, kg/d	.96	1.21	.95	1.12	.208	NS	NS	NS
Change in body condition[7]	-.17	-.15	-.21	.00	.072	.12	NS	.18

[1]Covariate adjusted least squares means.
[2]Standard error for individual diet means.
[3]P>.20.
[4]Kg FCM/kg DMI.
[5]Kg actual milk/kg DMI
[6]FCM week 8/FCM week 1.
[7]Condition score averaged 2.72 where 1 is very thin and 5 very fat.

Table 14. Digestibility and ruminal volatile fatty acid concentrations in cows fed isofibrous diets containing dry-rolled or steam-flaked sorghum grain with forage NDF from alfalfa hay or wheat straw.

	Diet					Significance[1] of effect (P)	
Item	AHDR	AHSF	WSDR	WSSF	SEM	G	F
Digestibility, %							
Organic matter	59.6	65.7	58.7	66.1	1.05	.01	NS
NDF	39.2	37.5	38.0	37.0	2.13	NS	NS
Starch	79.4	96.9	81.4	96.6	1.34	.01	NS
CP	61.9	63.6	65.8	67.4	1.20	.19	.01
Ruminal VFA[2]							
mMolar	77.0	68.0	57.2	62.4	7.88	NS	.13
mole/100 mole							
acetate	68.5	64.9	68.0	62.9	.78	.01	.11
propionate	17.5	20.7	20.0	25.0	.75	.01	.01
butyrate	11.0	11.4	9.3	9.6	.50	NS	.01
isobutyrate	.89	.84	.74	.68	.081	NS	.08
valerate	.92	1.11	.83	.86	.114	NS	.15
isovalerate	.61	.55	.49	.45	.065	NS	.12
2-methyl butyrate	.62	.59	.70	.68	.081	NS	NS
C2:C3[3]	3.94	3.17	3.41	2.54	.150	.01	.01

[1]Grain x forage interactions not significant (P>.20).

[2]Taken 3 h post-feeding via stomach tube.

[3]C2=acetate, C3=propionate.

Table 15. Chewing activity[1] and ruminal passage rates[2] for liquid and diet ingredients in cows fed isofibrous diets containing dry-rolled or steam-flaked sorghum grain with forage NDF from alfalfa hay or wheat straw.

	Diet					Significance[3] of effect (P)	
Item	AHDR	AHSF	WSDR	WSSF	SEM	G	F
Chewing, min/d							
Ruminating	376.3	392.5	362.9	340.0	23.32	NS	NS
Eating	285.8	262.0	295.8	258.5	18.63	.12	NS
Total	662.1	654.4	658.8	598.5	32.05	NS	NS
Chewing, min/kg DMI							
Ruminating	18.5	19.2	17.9	18.1	1.92	NS	NS
Eating	13.9	12.7	14.5	13.9	1.20	NS	NS
Total	32.3	31.9	32.3	32.0	2.72	NS	NS
Passage rate, %/h							
Forage	6.93	6.66	4.32	4.44	.361	NS	.01
Sorghum grain	7.62	7.58	5.73	6.32	.551	NS	.01
Soybean meal	8.53	7.84	6.82	6.80	.628	NS	.04
Co-EDTA	10.09	9.28	8.11	8.10	.642	NS	.02
Relative passage rate[4]							
Forage	.69	.72	.54	.55	.031	NS	.01
Sorghum grain	.75	.81	.72	.78	.039	.16	NS
Soybean meal	.84	.85	.85	.84	.036	NS	NS

[1]Mean of two 24-h observations.

[2]Calculated according to Grovum and Williams, 1973.

[3]Grain by forage interactions not significant (P>.20).

[4]Particulate passage rate as a fraction of liquid passage rate.

CHAPTER 6

INFLUENCE OF ALTERING FORAGE FIBER SOURCE AND RUMINAL STARCH DEGRADABILITY ON SITE AND EXTENT OF DIGESTION IN HOLSTEIN COWS FED DIETS FORMULATED TO CONTAIN 21% FORAGE FIBER

ABSTRACT

Four Holstein cows (166 d in milk), each fitted with a t-type cannula in the proximal duodenum were used in a 4 x 4 Latin square with a 2 x 2 factorial arrangement of treatments to study effects of forage fiber source and ruminal degradability of starch on digestion events. High quality (alfalfa hay) or low quality (1:2 alfalfa hay:chopped wheat straw) forage was included to provide 21% forage NDF, and sorghum grain was steam flaked or dry-rolled to achieve high or low ruminal starch degradability. Dry matter intake averaged 21 kg/d and was not influenced by treatment. Ruminal and total tract digestibilities of feed OM, CP, NDF and ADF, and flow of CP fractions to the duodenum were not affected by source of forage NDF. Digestibilities for cellulose were lower, both in the rumen (47 vs 53%), and total tract (45 vs 51%) when wheat straw was a source of forage. Diets with steam-flaked grain had higher ($P<.01$) ruminal (74 vs 48%) and total tract (98 vs 83%) starch digestibilities than those with dry-rolled grain. Digestibilities of OM and CP, and flow of non-ammonia CP (% of intake) and bacterial CP (kg/d) to the duodenum were also higher ($P<.02$), but ruminal cellulose digestibility was lower (53 vs 47%) for diets with steam-flaked grain

compared to dry-rolled grain. No interactions between forage quality and ruminal starch degradability were observed. Increased availability of energy, because of enhanced digestibility of starch and OM, and increased flow of CP to the duodenum, because of improved bacterial protein synthesis, explain the improved yield of milk and milk protein by cows fed steam-flaked sorghum grain in previous lactation studies.

INTRODUCTION

Formulating diets to contain equal NDF may be the most practical means of adjusting lactation diets for changes in forage quality (Mertens, 1982) but the value of this method over a wide range of forage types has been questioned (Briceno et al., 1987). Ruminal starch degradability has been altered by substituting barley for corn (Casper and Schingoethe, 1989; McCarthy et al., 1989: Weiss et al., 1989; Casper et al., 1990) or dry-rolled sorghum grain (Herrera-Saldana and Huber, 1989; Herrera-Saldana et al., 1990), or by steam-flaking sorghum grain (Poore et al., 1989c; Oliveira et al., 1990; Moore et al., 1990b). Increasing ruminal degradability of starch may improve microbial yield efficiency (Oldham et al., 1979; Sniffen and Robinson, 1987; Herrera-Saldana et al., 1990) and microbial yield (Sniffen and Robinson, 1987; McCarthy et al., 1989; Herrera-Saldana et al., 1990), but may result in reduced fiber digestion (McCarthy et al., 1989; DePeters and Taylor, 1985). Because ruminal digestion is depressed more for low than high quality forages by low ruminal pH (Poore et al., 1990a), ruminal starch

degradability may interact with forage quality and influence productivity of lactating cows.

In a previous trial Poore et al. (1989c) reported that yields of milk and milk protein were increased by 12 and 14%, respectively when steam-flaked, rather than dry rolled sorghum grain was used in diets for early lactation Holstein cows. Forage source (wheat straw vs alfalfa hay) did not alter performance, and interactions between source of forage and ruminal starch degradability were few.

This study was conducted to evaluate influences of steam-flaking sorghum grain in diets with high or low quality forage on site and extent of nutrient digestion by lactating Holstein cows.

MATERIALS AND METHODS

Animals and diets.

Four Holstein cows (673 kg, 166 d in milk) each fitted with a single t-type cannula (2.5 cm internal diameter) in the proximal duodenum (anterior to the bile and pancreatic ducts) were used. Cannulae had a gutter-type flange similar to those described by Wanderley et al. (1985), and were installed under general anesthesia. During the experiment, which was conducted from March through May, cows were housed in individual pens (4 x 8 m) which had dirt floors and were partially shaded ($12m^2$). Cows were fed twice daily to ad libitum (10% refusal) consumption, and had free access to water and trace mineralized salt blocks.

Diet ingredient composition is in table 16. Chemical composition of ingredients and diets are in tables 17 and 18, respectively. Diets were formulated to contain 21% forage NDF either from alfalfa hay (AH) or from a mixture of AH and wheat straw (WS) in which WS provided 2/3 of the NDF, and to contain 16% CP and meet or exceed NRC (1989) requirements for Ca, P and Mg. Sorghum grain was either steam-flaked or dry rolled to give diets high or low ruminal starch degradability. Based on a review of studies with beef cattle (Theurer, 1986) starch in dry-roll is expected to be 57% ruminally degradable, and starch in steam-flake 76% ruminally degradable. For this experiment, sorghum grain was either coarsely dry-rolled or steamed for one h and then flaked to a bulk density of 360 g/l (28 lb/bu).

Wheat straw (WS) was chopped through a Miller rotary hay mill (United farm tools, Inc., Turlock, CA) with a 5 cm screen, resulting in a maximum stem length of approximately 5 cm. Complete diets were prepared in a truck equipped with a feed mixing box (Kirby Manufacturing, Inc., Merced, CA). The appropriate amount of alfalfa hay was placed in the box and allowed to mix until stems were approximately 7.5 cm in length. Mixtures containing concentrate ingredients, and chopped straw when appropriate, were then added and diets were allowed to mix until ingredients were well dispersed and maximum hay stem length was about 5 cm. This method resulted in similar physical form (table 18) for all the diets. Dry matter content was equalized by spraying on water while mixing the diets with DR. Chromium oxide (.1% of DM) was

included in diets as an external marker for determination of ruminal and total tract digestion coefficients.

Sample collection.

Feces and duodenal digesta were sampled four times daily for 3 d. Sampling time was advanced by 2 h each day, so that samples obtained represented each 2 h of a 24 h cycle. Duodenal samples were collected in complete gushes until at least 500 ml was obtained, after digesta present in the cannulae tube or intestinal lumen near the cannula was discarded. Digesta samples were frozen and then later thawed and dried at 50°C. Fecal (250 g rectal grab samples) were immediately dried in a forced air oven at 50°C. Diet samples were obtained daily starting one day before collection, and orts were composited during the 3 d of collection. A portion of each sample was dried at 100°C to determine DMI, and the remainder was dried at 50°C for chemical analysis. All samples were ground to pass a 2 mm screen in a Wiley mill, and then composited on an equal wieght basis.

Rumen bacteria were isolated using differential centrifugation according to Zinn and Owens (1986) from mixed rumen contents obtained from four ruminally cannulated cows fed each of the experimental diets.

Sample analysis.

Particle size of feed ingredients and diets was determined by sieving duplicate 50 g samples for 10 min using a Ro-Tap sieve shaker (C-E Tyler Combustion Engineering, Inc., Bessemer City, NC).

Composite samples were re-ground to pass a 1-mm screen in a cyclone mill (UDY Corporation, Fort Collins, CO) prior to analysis. Dry matter and organic matter were determined according to AOAC (1980). Starch was determined by quantitating glucose released (model 27 glucose analyzer, Yellow Springs Instruments, Inc., Yellow Springs, OH) from samples that had been autoclaved and hydrolyzed with amyloglucosidase (Diazyme L-200, Miles, Inc., Elkhart, IN)as described by Poore et al. (1989a). Nitrogen was determined using a N autoanalyzer (Technicon, Terrytown, NY) and Cr was determined by atomic absorption spectrophotometry (Hitachi, Ltd., Tokyo, Japan). Samples (.5 g) for N analysis were wet ashed in 10 ml concentrated sulfuric acid with .5 g Mg sulfate and .1 g Na selenite and then diluted to 100 ml. Samples for Cr analysis were wet ashed as described for N analysis, and then heated another 3 h after adding .4 g periodic acid and 10 ml water. Ammonia CP content of duodenal digesta was determined by extracting 2 g samples for with 50 ml of water for 1 h at room temperature, and determining N in the extract using the N autoanalyzer.

Neutral detergent fiber was determined using alpha-amylase (Robertson and Van Soest, 1977) from Bacillus sp. (Type XIB, Sigma, Inc., St. Louis, MO) as described by Poore et al. (1990a). Acid detergent fiber (not sequential with NDF) and 72% sulfuric acid lignin were determined, and cellulose and hemicellulose calculated, according to Goering and Van Soest (1970).

Nutrient flow to the duodenum and fecal output were determined with both chromium and 72% sulfuric acid lignin, assuming 100% recovery of both markers. Bacterial content of duodenal digesta was determined by measuring purines in digesta and bacterial organic matter as described by Zinn and Owens (1986), and bacterial contribution to duodenal non-ammonia CP was determined from CP content of bacterial OM (53%).

Milking management and behavioral observation.

Milk yield was measured twice daily, and milk samples were obtained bi-weekly and analyzed by infrared analysis (Arizona DHIA, Chandler) for milk fat and protein throughout the trial (table 19). After the last day of fecal and duodenal sampling, cows were observed every 5 min for 24 h to determine eating, ruminating and total chewing times (Woodford and Murphy, 1988).

Statistical analysis.

The experiment consisted of a 4x4 Latin square design with a 2x2 factorial arrangement of treatments. Experimental periods were 21 d with 15 d allowed for adaptation to diets and 6 d of collecting samples. Data were analyzed using the General Linear Model procedure of SAS (1985). Single degree of freedom contrasts were for main effect of forage fiber source, main effect of grain source, and forage by grain interaction.

RESULTS

Site and extent of digestion.

Data on site and extent of digestion calculated either with Cr or lignin as flow markers appear in tables 20-24. The results were quite comparable for the two flow markers, although standard errors were about 20% higher when flow was calculated using lignin ratio rather than Cr ratio. Results that follow were calculated using Cr as the flow marker.

Organic matter. Intake and duodenal flow of total OM were not influenced by either grain or forage source (table 20). Flow of bacterial OM to the duodenum ($P<.01$) was greater and flow of feed OM ($P<.02$) less on SF than on DR diets. Feed OM fermented in the rumen was about 2 kg/d greater ($P<.05$) for the SF than the DR diets, and fecal flow of OM tended ($P<.09$) to be lower for SF than DR. Ruminal digestibility of OM, after correcting for bacterial OM flow, was higher ($P<.01$) for SF (63%) than DR (51%) diets, and total tract digestibility of OM was higher ($P<.01$) for SF (68%) than DR (63%) diets. Organic matter flow, and digestibilities were not influenced by forage source.

Starch. Data on starch flow are in table 21. Intake of starch was about .8 kg/d higher ($P<.10$) for WS diets than AH diets, but was not different for DR and SF diets. Duodenal starch flow was greater ($P<.01$) on DR (3.4 kg/d) than SF (1.7 kg/d) diets. Fecal starch was also higher ($P<.01$) for DR (1.2 kg/d) than SF (.14 kg/d). Ruminal and total tract digestibilities of starch were 74 and 98%, respectively for SF and 48

and 83%, respectively for DR diets. Digestibility of starch entering the intestines was also higher (P<.01) for SF (92%) than DR (63%). Flow and digestibility of starch was not influenced by forage source.

Crude protein. Site and extent of CP digestion is presented in table 22. Intake of CP was not influenced by forage or grain source. Duodenal flow of bacterial CP was higher (P<.01) and flow of feed CP was lower (P<.03) for SF (2.8 and 1.3 kg/d) compared with DR (2.2 and 1.7 kg/d) diets, but flow of total non-ammonia CP and efficiency of bacterial CP synthesis were not influenced by method of grain processing. Duodenal flow of non-ammonia CP, as a percentage of CP intake, was higher (P<.03) for SF (120%) than for DR (110%) based diets. Ruminal digestibility of feed CP was higher for SF (61%) than DR (53%), but total tract digestibility of CP was not different for SF and DR diets. The CP variables were not influenced by forage source.

Fiber components. Data on intake and digestibility of fiber components are in tables 23 and 24. Intake of NDF and ADF was not influenced by forage source or starch degradability. Ruminal and total tract digestibility of NDF and ADF were not influenced by forage NDF source. Ruminal digestibility of NDF (P<.13) and ADF (P<.08), and total tract digestibility of NDF (P<.12) and ADF (P<.16), however, tended to be lower for SF than DR diets.

Intake of hemicellulose was higher (P<.01) and lignin was lower (P<.01) on WS diets than AH diets, but intake of cellulose was not influenced. Intake of cellulose, hemicellulose and lignin were not

influenced by method of grain processing. Ruminal digestibility of cellulose was lower for WS than AH ($P<.02$) and was lower when sorghum grain was SF rather than DR ($P<.03$). Total tract digestibility of cellulose was also lower ($P<.02$) for WS than AH, but only tended to be lower ($P<.15$) for SF than DR. Ruminal and total tract digestibilities of hemicellulose and lignin were not influenced by forage or starch source. Ruminal digestibility of lignin averaged 7% and total tract digestibility averaged -1%.

Milk yield and chewing times.

Yield of actual milk and 3.5% FCM were not influenced by treatment although milk yield tended to be greater for SF than DR diets (table 19). Protein yield ($P<.08$) and protein percentage in milk ($P<.04$) were higher for SF than DR based diets, while milk fat yield and fat percentage were not influenced by either forage or grain source. Rumination and total chewing time were not influenced by forage source or starch degradability, but ruminating and chewing time were higher for SF than DR when AH was the forage, but lower for SF than DR when WS was the forage (forage x grain, $P<.10$). Eating time was shorter for SF than DR diets ($P<.03$) and there was a grain by forage interaction ($P<.10$); cows fed the SF and the DR diets spent similar time eating when alfalfa was the forage, while cows fed SF spent less time eating than cows fed the DR when WS was the forage.

DISCUSSION

As expected, digestion of organic matter and starch in the rumen and total tract were greater when sorghum grain was SF rather than DR (Theurer, 1986). Other researchers have altered ruminal starch degradability in diets for lactating cows by substituting barley for corn (McCarthy et al., 1989) or for dry-rolled sorghum grain (Herrera-Saldana et al., 1990). McCarthy et al. (1989) reported that ruminal and total tract starch digestibilities were higher for steam-rolled barley (77 and 97%) than for ground corn (49 and 93%), while Herrera-Saldana et al. (1990) showed that ruminal and total tract digestibilities were higher for dry-rolled barley (80 and 94%) than for dry-rolled sorghum grain (50 and 88%). In the present study, ruminal and total tract digestibility of starch was higher for SF (74 and 98%) than for DR (48 and 83%).

In the studies of McCarthy et al. (1989) and Herrera-Saldana et al. (1990), digestibility of starch entering the intestine was slightly higher for diets with low ruminal availability, in conflict with expectation. This is in contrast to the current study, in which the starch source with higher rumen availability (SF) was also by far the most digestible post-ruminally. The possibility that barley starch may be less digestible than starch from steam-flaked sorghum grain in the intestine despite similar ruminal availability may be important. If barley starch is poorly utilized post ruminally, it may be desirable to maximize digestion in the rumen. Because starch from SF entering the

intestine is almost completely digested, improving bypass of this starch may be more beneficial.

It is usually accepted that starch digested in the small intestine is utilized more efficiently than that digested in the rumen (Owens et al., 1986). However, efficiency of weight gain by beef cattle is positively related to ruminal digestion of starch (Theurer, 1986). This may also be the case with sorghum grain for dairy cattle. Lactational efficiency of Holstein cows (Poore et al., 1989c; Oliveira et al., 1990; Moore et al., 1990b) can be improved when sorghum grain is processed in such a manner that ruminal digestion of starch is also improved. Altering the degree of steam-flaking (bulk density) can also influence lactational performance (Moore et al., 1990b).

In this study, duodenal flow of non-ammonia CP (% of intake) and bacterial CP increased, and flow of feed CP decreased when sorghum grain was processed to give high ruminal starch degradability. These results are consistent with those of McCarthy et al. (1989) and Herrera-Saldana et al. (1990) which showed increased flow of bacterial CP and decreased flow of feed CP to the duodenum when starch with high rumen degradability was fed. All three studies show that growth of rumen bacteria is stimulated when ruminal starch degradability is increased which is consistent with other studies (Sniffen and Robinson, 1987). Efficiency of microbial growth, however, was not influenced by differences in ruminal starch degradability in the present study or in that of McCarthy et al. (1989). In contrast, Herrera-Saldana et al.

(1990) showed production of microbial CP was more efficient with dry-rolled barley than with dry-rolled sorghum grain.

A possible consequence of increasing ruminal starch availability could be depressed digestion of fiber resulting from decreased ruminal pH (Hoover, 1986). McCarthy et al. (1989) showed ruminal digestibility of NDF was lower, and digestibility of ADF tended to be lower, when ruminal starch degradability was increased (barley vs corn). However, Herrera-Saldana et al. (1990) reported that NDF digestibility was higher in diets with increased ruminal starch degradability (barley vs sorghum grain), although ADF digestibility was not influenced. Interpretation of these results is complicated because ruminal starch degradability was confounded by factors such as level and source of fiber, level of starch and DMI. In the study by McCarthy et al. (1989) dietary starch was extremely high for barley (41%) and corn diets (45%), which resulted in abnormally low ruminal pH (5.76) and ruminal digestibility of ADF (15%) and NDF (23%), acetate:propionate (2.16) and milk fat percentage (2.85%). In the data of Herrera-Saldana et al. (1990) diet content and digestibility of NDF were unusually high, and there was a large discrepancy between ruminal digestibility of NDF (60%) and ADF (24%). This could have been the result of incomplete extraction of starch (apparently no alpha-amylase was used in NDF analysis), which would cause over estimation of NDF intake and digestibility.

In the current study, which avoided complicating factors present in the studies of McCarthy et al. (1989) and Herrera-Saldana et al.

(1990), ruminal digestibility of ADF and NDF were reduced only slightly when ruminal starch degradability was increased by steam-flaking sorghum grain, and milk fat percentage was not affected. The effect on fiber digestion was attributable primarily to decreased digestion of the cellulose fraction.

There was a tendency for ruminal and total tract digestibility of NDF and ADF to be lower for WS compared to AH diets, and this could also be attributed to the cellulose rather than to the hemicellulose fraction. This reduction in fiber digestion could have been due either to the increased ruminal digestion of starch (4.5 vs 3.5 kg/d) on WS or simply to the cellulose in WS having a lower potential for digestion than the AH. In an earlier lactation trial (Poore et al., 1989c), NDF digestibility was the same for diets based entirely on early-bloom AH or WS as forages. This is somewhat different than the results in the current trial, possibly because alfalfa hay was of much higher quality and starch content of the diets was slightly higher than in the previous trial. The minimal effect on fiber digestion, coupled with no effect on flow of CP or starch, indicates that WS can be substituted on an NDF basis for at least 2/3 of AH in diets for lactating cows, even when AH is of very high quality.

Theurer (1979, 1982) reported that that estimates of ruminal output of OM and CP in steers with abomasal cannulae were dramatically affected by the flow marker used. When chromium oxide was the marker, flow of OM and especially CP was overestimated relative to lignin as the

marker, resulting in much higher estimates of microbial yield efficiency. Chromium and lignin result in similar estimates of flow with re-entrant duodenal cannulae (Wanderley et al., 1985; Wanderley et al., 1987), but use of re-entrant cannulae is not practical with dairy cattle because of severely depressed performance (Robinson and Kennelly, 1990). However, accuracy of sampling from simple gutter-t-type cannulae has been questioned (Robinson and Kennelly, 1990). Since chromium oxide behaves as a heavy liquid and lignin flows with the particulate phase of digesta (Van Soest, 1982), discrepancies between markers can be expected if proportions of liquid and particulates are not representative of the intestinal digesta.

In the current study duodenal flow of nutrient fractions was similar when Cr or lignin was the flow marker. Flows based on lignin tended to be 20% more variable than flows based on Cr, possibly due to greater analytical precision with Cr analysis. The agreement between Cr and lignin in this study is possibly due to the sampling techniques used. It is important that digesta already in the cannula or in the intestinal lumen near the cannula be discarded and that digesta be collected in complete gushes. Flow through the proximal duodenum is vertical in most animals, causing particles to settle between gushes from the pyloris. Consequently, digesta that initially drains from the cannula often contains a high proportion of liquid relative to particles. Conversely, digesta that settles in the cannula tube is enriched with particles. Both situations are exaggerated if only small

samples are collected. Also, there are diurnal patterns in digesta flow and composition (Wanderley et al., 1987) so an advancing sampling schedule is advisable. Because sampling technique may have a profound effect on results, sampling should be frequent, samples should be large, and the methods used should be completely described.

Although measurements of production responses to forage source and grain processing were not the objective of this study, effects on milk yield and composition were similar to those reported earlier (Poore et al, 1989). Dhiman and Satter (1990) showed by abomasal infusion of protein, glucose or both that protein flow to the duodenum, not energy availability, was first limiting for milk production in early lactation cows. The greatest response, however was to infusion of both glucose (energy) and protein. Because of this, we conclude that the increase in milk and milk protein yield when sorghum grain is steam-flaked rather than dry-rolled, is due to both increased availability of energy (starch) and increased flow of CP to the duodenum.

CONCLUSIONS

Steam-flaking sorghum grain improves ruminal and total tract starch digestion by lactating cows, and increases the flow of non-ammonia CP and bacterial CP to the duodenum. These factors explain the increased milk yield and protein percentage when lactating cows are fed diets containing steam-flaked sorghum grain. When sorghum grain was SF, there was a small, but significant, depressing effect on ruminal and total tract digestibility of cellulose. Ruminal digestibility and

duodenal flow of OM, starch and CP were not affected by substituting WS for 2/3 of the NDF from AH, but ruminal and total tract digestibility of cellulose was slightly reduced.

Table 16. Ingredient composition of diets (exp. 4).

	Diet[1]			
Ingredient, % of DM	AHDR	AHSF	WSDR	WSSF
Alfalfa hay, chopped	52.5	52.5	17.5	17.5
Wheat straw, chopped	-	-	18.4	18.4
Sorghum grain[2]	37.7	37.7	42.5	42.5
Soybean Meal	3.0	3.0	14.3	14.3
Dicalcium phosphate	1.3	1.3	1.3	1.3
Limestone	-	-	.3	.3

[1] AHDR = alfalfa hay, dry-rolled grain; AHSF = alfalfa hay, steam-flaked grain; WSDR = alfalfa hay + wheat straw, dry-rolled grain; WSSF = alfalfa hay + wheat straw, steam-flaked grain. All diets contained 3% molasses, 2% animal fat, .3% salt, .25% magnesium oxide, 5000 IU vitamin A/kg and .1% Cr_2O_3.

[2]Dry-rolled or steam-flaked to a bulk density of 360 g/l (28 lb/bu).

Table 17. Nutrient and particle size analysis of ingredients (exp. 4).

Item	Ingredient				
	Wheat straw	Alfalfa hay	Sorghum grain		Soybean meal
			Dry-rolled	Flaked	
Dry matter %	93.0	92.2	87.2	85.0	91.5
% of dry matter					
NDF[1]	68.84	36.52	10.68	10.32	7.97
ADF[1]	46.62	29.04	5.29	6.90	4.86
Lignin[2]	5.51	6.04	1.33	1.44	.62
Cellulose[3]	41.11	23.00	3.96	5.46	4.24
Hemicellulose[4]	22.22	7.48	5.39	3.42	3.11
Crude protein[5]	3.76	19.84	10.12	9.80	51.03
Starch	1.03	4.44	75.78	76.56	6.55
30 min hydrolysis[6]	-	-	17.58	72.77	-
Particle size					
4.0 mm	9.7	-	-	-	-
2.8 mm	15.9	-	3.6	52.2	.4
2.0 mm	17.5	-	3.2	22.3	3.9
1.0 mm	27.4	-	67.2	15.9	42.3
.425 mm	18.1	-	16.9	6.1	38.7
.25 mm	8.5	-	3.4	1.7	9.6
<.25 mm	3.7	-	5.6	1.7	5.1

[1] Ash free basis.

[2] 72% sulfuric acid lignin.

[3] ADF - lignin.

[4] NDF - ADF.

[5] N*6.25.

[6] Percent of total starch hydrolyzed after 30 min incubation with Diazyme (Miles laboratories).

Table 18. Nutrient and particle size analysis of diets (exp. 4).

Item	Diet				SEM
	AHDR	AHSF	WSDR	WSSF	
Diet DM, % as fed	90.5	89.8	90.4	89.8	--
Analysis, % of DM					
Organic matter	91.4	91.4	91.2	91.2	.10
CP	16.7	16.4	16.8	16.8	.13
Starch	29.6	29.3	33.2	32.1	.55
NDF	24.9	26.0	26.1	27.2	.47
ADF	18.2	18.9	17.3	17.7	.35
Lignin	3.63	3.90	2.90	3.07	.15
Cellulose	14.58	15.02	14.37	14.65	.23
Hemicellulose	6.69	7.11	8.73	9.45	.53
Forage NDF[1]	19.2	19.2	19.1	19.1	--
Forage NDF[2]	20.7	21.8	20.4	21.5	--
FNDF:RDS[3]	1.43	1.00	1.28	.91	--
NE_l, Mcal/kg[4]	1.71	1.71	1.67	1.67	--
Particle size distribution[5]					
2.8 mm[ab]	17.2	23.7	10.4	17.6	1.7
2.0 mm[a]	8.6	19.3	7.7	18.8	.7
1.0 mm[a]	41.8	29.6	43.2	33.8	2.5
.425 mm[a]	23.0	19.0	27.4	20.0	1.7
.25 mm	5.6	5.4	6.7	5.5	.5
<.25 mm	3.7	3.2	4.6	4.4	.8

[1] Forage NDF%, calculated from forage analysis.
[2] Forage NDF%, calculated by difference based on diet NDF analysis and concentrate NDF analysis.
[3] Ratio of forage NDF to ruminally degradable starch (calculated from main effects of grain processing in this study).
[4] Calculated based on NRC 1989.
[5] Percent of diet particles retained on the given screen sizes.
[a] Grain effect ($P<.05$).
[b] Forage effect ($P<.05$).

Table 19. Intake, milk production and chewing activities by cows fed diets containing steam-flaked or dry-rolled sorghum grain with forage NDF from alfalfa hay or wheat straw.

Item	Diet					Significance of effect(P)	
	AHDR	AHSF	WSDR	WSSF	SEM[1]	G	F
Dry matter intake							
kg/d	20.7	20.7	21.3	20.7	1.0	NS[2]	NS
% of BW	3.15	3.11	3.10	3.27	.13	NS	NS
Yield, kg/d							
actual milk	18.2	19.2	18.6	19.6	.73	NS	NS
3.5% FCM	18.4	19.7	19.3	19.5	.83	NS	NS
milk fat	.65	.70	.69	.68	.034	NS	NS
protein	.56	.64	.58	.63	.029	.08	NS
Milk composition, %							
fat	3.54	3.57	3.75	3.47	.083	NS	NS
protein	3.08	3.30	3.11	3.17	.056	.04	NS
Chewing activity, min/d[3]							
rumination	378.8	443.8	406.3	378.8	23.9	NS	NS
eating	233.8	230.0	256.3	223.8	6.4	.03	NS
total	612.5	673.8	662.5	602.5	25.4	NS	NS

[1] Standard error for individual diet means.

[2] P>.10.

3 Grain by forage interaction (P<.10).

Table 20. Intake, and ruminal and total tract digestibility of organic matter in cows fed diets containing dry-rolled or steam-flaked sorghum grain with forage NDF from alfalfa hay or wheat straw.

	Diet					Significance[1] of effect (P)	
Item	AHDR	AHSF	WSDR	WSSF	SEM	G	F
OM Intake, kg/d	18.96	18.93	19.40	18.87	1.00	NS	NS
Based on Cr_2O_3[2]							
OM flow, kg/d							
Duodenal OM	13.73	12.48	13.42	12.26	.92	NS	NS
Bacterial	4.17	5.12	4.29	5.40	.33	.01	NS
Feed	9.57	7.37	9.13	6.87	.85	.02	NS
RFOM[3]	9.40	11.56	10.27	12.00	.90	.05	NS
Fecal OM	6.77	6.05	7.35	6.15	.51	.09	NS
Digestibility, %							
Ruminal							
apparent	27.7	34.3	30.7	34.9	3.28	.13	NS
corrected[4]	49.8	61.3	52.7	63.7	3.81	.01	NS
Total tract	64.3	68.2	62.4	67.3	1.46	.01	NS
Based on ADL[5]							
OM flow, kg/d							
Duodenal OM	15.09	12.77	14.66	13.92	1.11	NS	NS
Bacterial	4.19	4.61	4.20	5.43	.55	.16	NS
Feed	10.90	8.16	10.47	8.50	.75	.01	NS
RFOM	8.65	10.76	8.94	10.37	1.06	.08	NS
Fecal OM	6.52	5.83	8.18	6.01	.75	.08	NS
Digestibility, %							
Ruminal							
apparent	20.6	32.7	24.3	24.7	5.49	NS	NS
corrected	42.8	56.9	45.9	54.1	3.73	.01	NS
Total tract	65.7	69.2	58.2	68.0	2.79	.03	.14

[1] Grain by forage interaction not significant (P>.20).
[2] Flow marker = chromium oxide.
[3] RFOM = organic matter truly fermented in the rumen.
[4] Corrected for bacterial organic matter.
[5] Flow marker = 72% sulfuric acid lignin.

Table 21. Intake, and ruminal and total tract digestibility of starch in cows fed diets containing dry-rolled or steam-flaked sorghum grain with forage NDF from alfalfa hay or wheat straw.

	Diet					Significance[1] of effect (P)	
Item	AHDR	AHSF	WSDR	WSSF	SEM	G	F
Starch intake, kg/d	6.19	6.13	7.18	6.76	.44	NS	.10
Based on Cr_2O_3[2]							
Starch flow, kg/d							
Duodenal	3.57	1.83	3.28	1.60	.40	.01	NS
Fecal	.96	.14	1.44	.13	.24	.01	NS
Digestibility, %							
Ruminal	42.6	71.1	53.5	76.3	6.13	.01	NS
Entering intestines[3]	69.1	92.1	56.5	91.5	7.50	.01	NS
Total tract	84.6	97.8	80.9	98.0	2.51	.01	NS
Based on ADL[4]							
Starch flow, kg/d							
Duodenal	3.84	1.83	3.57	1.81	.34	.01	NS
Fecal	.94	.13	1.66	.13	.32	.01	NS
Digestibility, %							
Ruminal	38.3	70.9	49.4	72.6	5.27	.01	NS
Entering intestines	74.8	92.6	54.2	92.7	8.08	.01	NS
Total tract	84.9	97.9	78.1	98.0	3.45	.01	NS

[1] Grain by forage interaction was not significant (P>.20).

[2] Flow marker = chromium oxide.

[3] Digestibility of starch entering the duodenum.

[4] Flow marker = 72% sulfuric acid lignin.

Table 22. Intake, and ruminal and total tract digestibility of crude protein in cows fed diets containing dry-rolled or steam-flaked sorghum grain with forage NDF from alfalfa hay or wheat straw.

Item	Diet					Significance[1] of effect (P)	
	AHDR	AHSF	WSDR	WSSF	SEM	G	F
CP intake, kg/d	3.46	3.39	3.60	3.49	.21	NS	NS
Based on Cr_2O_3[2]							
Duodenal CP, kg/d							
Ammonia CP	.32	.26	.36	.30	.04	NS	NS
Non-ammonia CP	3.87	4.11	3.85	4.10	.22	NS	NS
Bacterial	2.18	2.80	2.23	2.76	.18	.01	NS
Feed	1.70	1.31	1.62	1.35	.13	.03	NS
BCP/RFOM[3]	23.7	24.2	21.9	23.1	1.52	NS	NS
Digestibility, %							
Ruminal							
apparent	-12.0	-21.0	-7.4	-18.4	4.12	.03	NS
corrected[4]	51.1	61.3	54.6	61.4	3.27	.02	NS
Total tract	61.0	61.9	63.9	64.4	2.10	NS	NS
Based on ADL[5]							
Duodenal CP, kg/d							
Ammonia CP	.34	.27	.39	.34	.05	.18	NS
Non-ammonia CP	4.30	4.21	4.21	4.71	.41	NS	NS
Bacterial	2.46	2.87	2.44	3.19	.34	.11	NS
Feed	1.84	1.34	1.77	1.52	.12	.01	NS
BCP/RFOM	26.01	24.79	23.91	26.97	2.40	NS	NS
Digestibility, %							
Ruminal							
apparent	-24.3	-24.5	-17.4	-38.8	13.15	NS	NS
corrected	47.0	60.3	50.3	55.5	3.74	.03	NS
Total tract	62.6	60.1	63.1	65.2	2.96	NS	NS

[1] Grain by forage interaction was not significant (P>.20).
[2] Flow marker = chromium oxide.
[3] Grams bacterial crude protein/100 g truly ruminally fermented organic matter.
[4] Corrected for bacterial CP. Ruminal digestibilities calculated based on flow of non-ammonia CP.
[5] Flow marker = 72% sulfuric acid lignin.

Table 23. Intake, and ruminal and total tract digestibility of NDF and ADF in cows fed diets containing dry-rolled or steam-flaked sorghum grain with forage NDF from alfalfa hay or wheat straw.

	Diet					Significance[1] of effect (P)	
Item	AHDR	AHSF	WSDR	WSSF	SEM	G	F
Intake, kg/d							
NDF	5.14	5.35	5.45	5.51	.27	NS	NS
ADF	3.75	3.87	3.61	3.56	.17	NS	NS
Digestibility, %							
Based on Cr_2O_3[2]							
Ruminal							
NDF	46.4	39.8	44.7	40.4	3.32	.13	NS
ADF	47.7	39.9	42.7	38.1	3.29	.08	NS
Total tract							
NDF	41.9	40.0	42.0	36.7	2.12	.12	NS
ADF	40.4	39.5	41.7	34.9	2.51	.16	NS
Based on ADL[3]							
Ruminal							
NDF	41.4	38.4	39.7	32.4	3.72	.19	NS
ADF	42.7	38.7	37.5	30.0	3.32	.11	.06
Total tract							
NDF	44.4	41.8	36.2	38.4	3.04	NS	.06
ADF	43.2	41.4	35.9	36.7	2.76	NS	.05

[1] Grain by forage interaction was not significant (P>.20).

[2] Flow marker = chromium oxide.

[3] Flow marker = 72% sulfuric acid lignin.

Table 24. Intake, and ruminal and total tract digestibility of cellulose, hemicellulose and lignin in cows fed diets containing dry-rolled or steam-flaked sorghum grain with forage NDF from alfalfa hay or wheat straw.

	Diet					Significance[1] of effect (P)	
Item	AHDR	AHSF	WSDR	WSSF	SEM	G	F
Intake, kg/d							
Cellulose	3.00	3.07	2.99	2.95	.15	NS	NS
Hemicellulose	1.39	1.48	1.84	1.96	.15	NS	.01
Lignin	.75	.80	.60	.61	.04	NS	.01
Digestibility, %							
Based on Cr_2O_3[2]							
Ruminal							
Cellulose	57.3	49.9	49.3	43.9	2.59	.03	.02
Hemicellulose	42.0	39.2	48.6	44.7	4.74	NS	NS
Lignin	8.3	1.5	8.1	8.4	8.81	NS	NS
Total tract							
Cellulose	51.7	50.6	48.1	42.8	2.09	.15	.02
Hemicellulose	44.4	40.7	42.5	40.0	3.44	NS	NS
Lignin	-6.0	-3.4	7.8	-3.3	7.16	NS	NS
Based on ADL[3]							
Ruminal							
Cellulose	53.2	48.7	44.7	36.0	3.77	.11	.02
Hemicellulose	37.0	44.0	37.5	36.9	5.40	NS	NS
Total tract							
Cellulose	53.8	52.1	42.7	44.2	3.08	NS	.01
Hemicellulose	46.0	42.6	36.6	41.6	4.97	NS	NS

[1] Grain by forage interaction was not significant (P>.20).

[2] Flow marker = chromium oxide.

[3] Flow marker = 72% sulfuric acid lignin.

CHAPTER 7

SUMMARY

Three experiments were conducted to evaluate digestion characteristics and lactational performance as influenced by forage fiber source and sorghum grain processing.

An initial study was conducted to evaluate methodology used to evaluate particulate passage rates for lactating cows. Neither dosing time (before or after feeding) nor sampling site (duodenal or fecal) influenced passage rate estimates for rare earth labeled grain or Co-EDTA, and choice of passage model had little influence on interpretation of the data.

A lactation trial was conducted to evaluate forage fiber source in diets formulated to 30% NDF and containing forage NDF from chopped wheat straw or alfalfa hay in proportions of 0:3, 1:2, 2:1 and 3:0. Milk yield and intake were not influenced by forage source, but yield of FCM and fat were lower when wheat straw was the only source of forage. Milk fat percentage and acetate to propionate ratio (C2:C3) decreased linearly with increasing straw. This was attributed to increased ruminally degradable starch and decreased forage NDF, and diets with a ratio of forage NDF to ruminally degradable starch (FNDF:RDS) less than 1:1 led to undesirable changes in milk composition and C2:C3.

A second lactation trial was conducted to evaluate effects of forage source and starch degradability on lactational performance. Forage NDF (22% of diets) was either chopped wheat straw or alfalfa hay, and sorghum grain was either steam-flaked or dry-rolled. Forage source did not influence any production parameter, chewing time or digestibility of diet components, but ruminal passage rate for liquid and all diet ingredients was slower in wheat straw diets. Increasing ruminal starch degradability by steam-flaking sorghum grain increased starch digestibility without decreasing fiber digestibility. Milk yield and milk protein yield were increased by 12 and 14%, respectively, but yield of milk fat was unchanged when sorghum grain was steam-flaked rather than dry rolled. Increasing starch degradability was beneficial to early lactation cows, and forage by starch source interactions were few, probably because FNDF:RDS was greater than 1:1.

The final experiment was conducted with duodenally cannulated cows to determine the effects of forage source and starch degradability on flow of nutrients to the duodenum. Substituting chopped wheat straw for 2/3 of the alfalfa hay NDF did not alter flow of OM, starch or CP fractions to the duodenum, but ruminal and total tract digestibility of cellulose was decreased slightly. Steam-flaking sorghum grain resulted in higher ruminal digestibility of starch and feed CP, and increased the flow of bacterial and non-ammonia CP to the duodenum, compared to dry rolling. Increased availability of energy (starch) and increased flow

of CP to the duodenum explain the improved lactational performance of cows fed steam flaked sorghum grain.

CHAPTER 8

LITERATURE CITED

Allen, M.S.. 1982. Investigation into the use of rare earth elements as gastrointestinal markers. M.Sc. Thesis, Cornell University, N.Y..

Allen, M.S. and D.R. Mertens. 1988. Effect of diet NDF level and forage source on intake and milk production of Holstein cows in early or late lactation. J. Dairy Sci. 71 (Suppl 1):176 (abstr).

AOAC. 1980. Official methods of analysis. 14th ed. Assoc. Offic. Anal. Chem., Washington, DC.

Bade, D.H., G.T. Lane, R.E. Leighton and A. Driedger. 1973. Acetic acid treatment of reconstituted sorghum grain for dairy cows. J. Dairy Sci. 56:124.

Balch, C.C. 1971. Proposal to use time spent chewing as an index of the extent to which diets for ruminants possess the physical property of fibrousness characteristics of roughages. Brit. J. Nutr. 26:383.

Beauchemin, K.A. and J.G. Buchanan-Smith. 1989a. Evaluation of markers, sampling sites and models for estimating rates of passage of silage or hay in dairy cows. Anim. Feed Sci. and Tech. 27:59.

Beauchemin, K.A. and J.G. Buchanan-Smith. 1989b. Effects of dietary neutral detergent fiber concentration and supplementary long hay on chewing activities and milk production of dairy cows. J. Dairy Sci. 72:2288.

Beauchemin, K.A. and J.G. Buchanan-Smith. 1990. Effects of fiber source and method of feeding on chewing activities, digestive function and productivity of dairy cows. J. Dairy Sci. 73:749.

Briceno, J.V., H.H. Van Horn, B. Harris, Jr., and C.J. Wilcox. 1987. Effects of neutral detergent fiber and roughage source on dry matter intake and milk yield and composition of dairy cows. J. Dairy Sci. 70:298.

Britton, R.A. and R.A. Stock. 1986. Acidosis, rate of starch digestion, and intAke. p 125 in "Feed Intake by Beef Cattle" Oklahoma State University MP 121.

Brown, W.H., L.M. Sullivan, L.F. Cheatham, Jr., K.J. Halbach and J.W. Stull. 1970. Steam processing versus pelleting of two ratios of milo and barley for lactating cows. J. Dairy Sci. 53:1488.

Brown, W.H., S.S. Khalaf, A. Marmolejo, R.S. Swingle and F.M. Whiting. 1990. Partial replacement of alfalfa hay with chopped wheat straw in diets for lactating dairy cows. J. Dairy Sci. 73 (in press).

Bush, L.J., B.J. Steevens, K.E. Rauch and R.M. Alexander. 1972. Methods of processing sorghum grain for lactating dairy cows. Okla. Agr. Exp. Sta. MP-87:146.

Bush, L.J., R.M. Alexander, G.D. Adams and R.D. Morrison. 1973. Relation of method of processing sorghum grain to utilization by dairy cows. Okla. Agr. Exp. Sta. MP-90:227.

Bush, L.J. and G.D. Adams. 1974. Micronized sorghum grain in rations for lactating dairy cows. Okla. Agr. Exp. Sta. MP-91:262.

Bush, L.J., D.T. Netemeyer and G.D. Adams. 1979. Reconstituted sorghum grain for lactation dairy cows. J. Dairy Sci. 62:1094.

Casper D.P. and D.J. Schingoethe. 1989. Lactational response of dairy cows to diets varying in ruminal solubilities of carbohydrate and crude protein. J. Dairy Sci. 72:928.

Casper, D.P., D.J. Schingoethe and W.A. Eisenbeisz. 1990. Response of early lactation dairy cows fed diets varying in source of nonstructural carbohydrate and crude protein. J. Dairy Sci. 73:1039.

Chase, L.E. 1988. Energy and fiber considerations in dairy ration formulation. J. Dairy Sci. 71 (Suppl 1):145 (abstr).

Cleale, R.M., IV and L.S. Bull. Effect of forage maturity on ration digestibility and production by dairy cows. J. Dairy Sci. 69:1587.

Cochran, R.C., D.C. Adams, M.L. Galyean and J.D. Wallace. 1986. Estimating particle turnover in the rumen of meal-fed beef steers: Procedural evaluations. J. Anim. Sci. 63:1469.

Coleman, S.W., B.C. Evans and G.W. Horn. 1984. Some factors influencing estimates of digesta turnover rate using markers. J. Anim. Sci. 58:979.

Colenbrander, V.F., D.L. Hill, M.L. Eastridge and D.R. Mertens. 1986. Formulating dairy rations with neutral detergent fiber. 1. Effect of silage source. J. Dairy Sci. 69:2718.

Colucci, P.E., L.E. Chase and P.J. VanSoest. 1982. Feed intake, apparent diet digestibility, and rate of particulate passage in dairy cattle. J. Dairy Sci. 65:1445.

Coppock, C.E. 1987. Supplying the energy and fiber needs of dairy cows from alternate feed sources. J. Dairy Sci. 70:1110.

Davis, C.L. 1979. The use of buffers in the rations of lactating dairy cows. P. 51 in Regulation of acid-base balance. W.H. Hale and P. Meinhardt, ed. Church and Dwight Co. Inc., Piscataway, NJ.

DePeters, E.J. and S.J. Taylor. 1985. Effects of feeding corn or barley on composition of milk and diet digestibility. J. Dairy Sci. 68:2027.

DePeters, E.J. and N.E. Smith. 1986. Forage quality and concentrate for cows in early lactation. J. Dairy Sci. 69:135.

Dhiman, T.R. and L.D. Satter. 1990. Response to postruminal infusion of glucose or protein during early lactation in dairy cows fed alfalfa silage. J. Dairy Sci 73 (Suppl 1):124 (Abstr.)

Ehle, F.R. 1984. Influence of feed particle density on particulate passage from rumen of Holstein cow. J. Dairy Sci. 67:693.

Ellis, W.C., J.H. Matis and C. Lascano. 1979. Quantitating ruminal turnover. Federation Proc. 38:2702.

Ellis, W.C., J.H. Matis and D. Poppi. 1988. Use of age-dependent compartmental models to estimate particulate flow in ruminants. J. Anim. Sci. 66(Suppl. 1):479 (Abstr.).

Erwin, E.S., G.J. Marco and E.M. Emery. 1961. Volatile fatty acid analysis of blood and rumen fluid by gas chromatography. J. Dairy Sci. 44:1768.

Faldet, M.A., T. Nalsen, L.J. Bush and G.D. Adams. 1989. Utilization of wheat in complete rations for lactating cows. J. Dairy Sci. 72:1243.

Goering, H.K. and P.J. Van Soest. 1970. Forage fiber analyses. US Dep. Agric., Agric. Handbook 379, Washington, DC.

Goetsch, A.L. and M.L. Galyean. 1983. Ruthenium Phenanthroline, dysprosium and ytterbium as particulate markers in beef steers fed an all-alfalfa hay diet. Nutr. Reports Int. 27:171.

Goetsch, A.L. and F.N. Owens. 1985. Effects of sampling site on passage rate estimates in heifers fed alfalfa hay or a high concentrate diet. J. Dairy Sci. 68.914.

Grovum, W.L. and V.J. Williams. 1973. Rate of passage of digesta in sheep. 4. Passage of marker through the alimentary tract and the biological relevance of rate constants derived from the changes in concentration of marker in the feces. Brit. J. Nutr. 30:313.

Herrera-Saldana, R. and J.T. Huber. 1989. Influence of varying protein and starch degradabilities on performance of lactating cows. J. Dairy Sci. 72:1477.

Herrera-Saldana, R.E., R. Gomez-Alarcon, M. Torabi and J.T. Huber. 1990. Influence of synchronizing protein and starch degradation in the rumen on nutrient utilization and microbial protein synthesis. J. Dairy Sci. 73.142.

Hooper, A.P. and J.G. Welch. 1985. Functional specific gravity of ground hay samples in ionic solutions. J. Dairy Sci. 68:848.

Hoover, W.H. 1986. Chemical factors involved in ruminal fiber digestion. J. Dairy Sci. 69:2755.

Kaiser R.M. and D.K. Combs. 1989. Utilization of three maturities of alfalfa by dairy cows fed rations that contain similar concentrations of fiber. J. Dariy Sci. 72:2301.

Khalaf, S.S. 1987. Utilization of wheat straw in rations for lactating dairy cows. PhD dissertation, University of Arizona, Tucson.

Kung, L., Jr., R.S. Tung and B.R. Carmean. 1989. Microbial fermentation and site of nutrient digestion in steers fed diets varying in forage and energy source. Abstracts of the 20th biennial conference on rumen function, November 7-9, 1989 (abstr #34).

Leonard, E.S., K.R. Pond, R.W. Harvey and R.G. Crickenberger. 1989. Effects of corn grinding and time of corn feeding on growth, starch utilization and digesta passage characteristics of growing steers fed hay-based diets. J. Anim. Sci. 67:1603.

Llamas-lamas, G. and D.K. Combs. 1990. Effect of alfalfa maturity on fiber utilization by high producing dairy cows. J. Dairy Sci. 73:1069.

Matis, J.H. 1972. Gamma time dependency in Blaxter's compartment model. Biometrics 28:597.

McCarthy, R.D., T.H. Klusmeyer, J.L. Vicini, J.H. Clark and D.R. Nelson. 1989. Effects of source of protein and carbohydrate on ruminal fermentation and passage of nutrients to the small intestine of lactating cows. J. Dairy Sci. 72:2002.

Mertens, D.R. 1982. Using neutral detergent fiber to formulate dairy rations. Proc. Cornell Nutr. Conf. p. 116.

Moe, P.W. and H.F. Tyrrell. 1976. Effects of feed intake and physical form on energy value of corn in timothy hay diets for lactating cows. J. Dairy Sci. 60:752.

Moore, J.A., M.H. Poore and R.S. Swingle. 1986. Minimal migration of dysprosium and ytterbium from marked feeds to unmarked stems in vitro. J. Anim. Sci. 63 (Suppl. 1):436 (Abstr.).

Moore, J.A., M.H. Poore and R.S. Swingle. 1989. Calculated ruminal extent of digestion as influenced by in situ particle size, forage dosing time and sampling site in Holstein cows. J. Anim. Sci. 67 (Suppl. 1):554 (Abstr.)

Moore, J.A., M.H. Poore and R.S. Swingle. 1990a. Influence of roughage source on kinetics of digestion and passage, and on calculated extents of ruminal digestion in beef steers. 1. 65% concentrate diets. J. Anim. Sci. 68 (in press).

Moore, J.A., M.H. Poore, T.P. Eck, M.J. Arana, R.S. Swingle and J.T. Huber. 1990b. Influence of sorghum grain processing and buffer inclusion on performance and digestibility by lactating Holstein cows. J. Dairy Sci. 73 (Suppl 1):127 (Abstr).

National Research Council. 1989. Nutrient requirements of dairy cattle. Natl. Acad. Sci., Washington, DC.

Nocek, J.E. and J.B. Russell. 1988. Protein and energy as an integrated system. Relationship of ruminal protein and carbohydrate availability to microbial synthesis and milk production. J. Dairy Sci. 71:2070.

Oldham, J.D., J.D. Sutton and A.B. McAllen. 1979. Protein digestion and utilization by dairy cows. Ann. Rech. Vet. 10:290.

Oliveira, J.S., J.T. Huber, D. Ben-Ghedalia, M. Pessarakli. 1990. Effect of sorghum grain processing on the performance of lactating dairy cows (LDC). J. Dairy Sci. 73 (Suppl 1): 127 (Abstr).

Orskov, E.R., C.A.G. Tait, G.W. Reid and G. Flachowski. 1988. Effect of straw quality and ammonia treatment on voluntary intake, milk yield and degradation characteristics of faecal fiber. Anim. Prod. 46:23.

Owens, F.N., R.A. Zinn and Y.K. Kim. 1986. Limits to starch digestion in the ruminant small intestine. J. Anim. Sci. 63:1634.

Pond, K.R., J.H. Matis, W.C. Ellis and L.D. Satter. 1982. Digesta flow through the ruminant's digestive tract. Federation Proc. 41:342 (Abstr.).

Pond, K.R., W.C. Ellis, J.H. Matis, H.M. Ferreiro and J.D. Sutton. 1988. Compartment models for estimating attributes of digesta flow in cattle. Br. J. Nutr. 60:571.

Pond, K.R. 1988. The use of rare earth-labeled and mordanted feeds to estimate particle flow. J. Anim. Sci. 66 (Suppl 1):478 (abstr).

Pond, K.R., W.C. Ellis, J.H. Matis and A.G. Deswysen. 1989. Passage of chromium-mordanted and rare earth labeled fiber: Time of dosing kinetics. J. Anim. Sci. 67:1020.

Poore, M.H., T.P. Eck, R.S. Swingle and C.B. Theurer. 1989a. Total starch and relative starch availability of feed grains. Abstracts of the 20th biennial conference on rumen function, November 7-9, 1989 (abstr #35).

Poore, M.H., J.A. Moore, R.S. Swingle, T.P. Eck, W.H. Brown and F.M. Whiting. 1989b. Influence of alfalfa hay or wheat straw fiber in 30% NDF diets on milk production and rate of passage in Holstein cows. J. Dairy Sci. 72 (Suppl 1):491 (abstr).

Poore, M.H., J.A. Moore, R.S. Swingle, T.P. Eck, W.H. Brown and F.M. Whiting. 1989c. Influence of forage quality and sorghum grain processing in diets formulated to contain 25% forage NDF on milk production by Holstein cows. J. Dairy Sci. 72 (Suppl 1):490 (abstr).

Poore, M.H., J.A. Moore and R.S. Swingle. 1990a. Differential passage rates and digestion of neutral detergent fiber from grain and forages in 30, 60 and 90% concentrate diets fed to steers. J. Anim. Sci. 68 (in press).

Poore, M.H., J.A. Moore, T.P. Eck, R.S. Swingle and C.B. Theurer. 1990b. Influence of steam flaking sorghum grain on starch and crude protein flow to the duodenum of lactating Holstein cows. J. Dairy Sci. 73(Suppl 1):125 (abstr).

Prange, E.W., N.A. Jorgensen and L.D. Satter. 1982. Rate of passage calculations based on duodenal or fecal collection sites. J. Dairy Sci. 65 (Suppl. 1):145 (Abstr.).

Ramanzin, M., E.R. Orskov and A.K. Tuah. 1986. Rumen degradation of straw. 2. Botanical fractions of straw from two barley cultivars. Anim. Prod. 43:271.

Robertson, J.B. and P.J. Van Soest. 1977. Dietary fiber estimation in concentrate feedstuffs. J. Anim. Sci. (Suppl 1):254 (Abstr.)

Robinson, P.H. and C.J. Sniffen. 1983. Comparison of rumen, duodenal and faecal sampling sites to estimate rumen turnover rate of markers. J. Dairy Sci. 66 (Suppl 1):187 (Abstr).

Robinson, P.H. and J.J. Kennelly. 1990. Evaluation of a duodenal cannula for dairy cattle. J. Dairy Sci. 73 (Suppl 1):239.

SAS. 1985. SAS Users Guide: Statistics. SAS Inst., Inc., Cary, NC.

Shaver, R.D., A.J. Nytes, L.D. Satter and N.A. Jorgensen. 1986. Influence of amount of feed intake and forage physical form on digestion and passage of prebloom alfalfa hay in dairy cows. J. Dairy Sci. 69:1545.

Shaver, R.D., L.D. Satter and N.A. Jorgensen. 1988. Impact of forage fiber content on digestion and digesta passage in lactating dairy cows. J. Dairy Sci. 71:1556.

Sniffen, C.J. and P.H. Robinson. 1987. Microbial growth and flow as influenced by dietary manipulations. J. Dairy Sci. 70:425.

Snyder, T.J., L.D. Muller, J.A. Rogers and S.M. Abrams. 1984. Digesta passage measured by markers in dairy cows fed two ratios of corn silage:grain with 0 or 1.2% sodium bicarbonate. J. Dairy Sci. 67:1953.

Stock, R.A., M.H. Sindt and F.K. Geodeken. 1988. Utilization of grain sorghum in cattle finishing diets as affected by processing method, dry corn addition, and roughage level. J. Anim. Sci. 66 (Suppl 1):475 (abstr).

Sudweeks, E.M., L.O. Ely, D.R. Mertens and L.R. Sisk. 1981. Assessing amounts and form of roughages in ruminant diets: roughage value index system. J. Anim. Sci. 53:1406.

Swingle, R.S., J.A. Moore, T.P. Eck, M.H. Poore and C.B. Theurer. 1990. Performance of feedlot steers fed isofibrous diets containing alfalfa hay and wheat straw in different proportions. J. Anim. Sci. 68 (Suppl 1):541.

Theurer, C.B.. 1979. Microbial protein synthesis as influenced by diet. P. 97 in Regulation of acid-base balance. W.H. Hale and P. Meinhardt, ed. Church and Dwight Co. Inc., Piscataway, NJ.

Theurer, C.B.. 1982. Microbial protein estimation using DAP, AEP and other amino acids as markers. Protein requirements for cattle. F.N. Owens, ed. Oklahoma State Univ., Stillwater.

Theurer, C.B.. 1986. Grain processing effects on starch utilization by ruminants. J. Anim. Sci. 63:1649.

Tommervik, R.S. and D.E. Waldern. 1969. Comparative feeding value of wheat, corn, barley, milo, oats and a mixed concentrate ration for lactating cows. J. Dairy Sci. 52:68.

Turnbull, G.W. and E.E. Thomas. 1987. Evaluation of rare-earth markers using an in vitro ruminal fermentation system and effect of processing method on ruminal turnover of sized corn particles. J. Anim. Sci. 64:1835.

Uden, P. P.E. Colucci and P.J. Van Soest. 1980. Investigation of chromium, cerium and cobalt as markers in digesta rate of passage studies. J. Sci. Food Agric. 31:625.

Ulyatt, M.J., D.W. Dellow, A. John, C.S.W. Reid and G.C. Waghorn. 1986. Contribution of chewing during eating and rumination to clearance of digesta from the ruminoreticulum. In: L.P. Milligan, W.L. Grovum and A. Dobson (eds) Control of digestion and Metabolism in Ruminants, Chapter 26, Printice-Hall publishers, Englewood Cliffs, N.J.

Van Soest, P.J. 1982. Nutritional Ecology of the Ruminant. O and B Books, Inc. Corvallis, OR.

Van Soest, P.J. 1987. Practical aspects of forage quality. Proc. Southwest Nutrition and Management Conference, University of Arizona, page 90.

Van Soest, P.J. 1990. Methods for dietary fiber, NDF and non-starch polysaccharides. J. Dairy Sci. 73 (Suppl 1):225 (abstr).

Wanderley, R.C., C.B. Theurer, S. Rhanema and T.H. Noon. 1985. Automated long-term total collection versus indicator methods to estimate duodenal digesta flow in cattle. J. Amim. Sci. 61:1550.

Wanderley, R.C., C.B. Theurer and M.H. Poore. 1987. Duodenal bacterial and nonbacterial protein supply in steers fed forage and grain diets. J. Anim. Sci., 64:295.

Weiss, W.P., G.R. Fisher and G.M. Erickson. 1989. Effect of source of neutral detergent fiber and starch on nutrient utilization by dairy cows. J. Dairy Sci. 72:2308.

Welch, J.G. and A.M. Smith. 1975. Milk fat depression and rumination stimulation. J. Dairy Sci. 58:678.

Welch, J.G. 1986. Physical parameters of fiber affecting passage from the rumen. J. Dairy Sci. 69:2750.

Woodford, J.A., N.A. Jorgensen, and G.P. Barrington. 1986. Impact of dietary fiber and physical form on performance of lactating dairy cows. J. Dairy Sci. 69:1035.

Woodford, S.T. and M.R. Murphy. 1988. Effect of forage physical form on chewing activity, dry matter intake, and rumen function of dairy cows in early lactation. J. Dairy Sci. 71:674.

Worrell, M.A., D.C. Clanton, W.W. Stroup and J.T. Nichols. 1986. Effect of harvest date on meadow hay quality. 1. Nutritional attributes, voluntary intake and rate of passage in growing cattle. J. Anim. Sci. 63:1527.

Zinn, R.A and F.N. Owens. 1986. A rapid procedure for purine measurement and its use for estimating net ruminal protein synthesis. Can. J. Anim. Sci. 66:157.