This is to certify that the

thesis entitled

Effectiveness of Whole Fuzzy Cottonseed Neutral Detergent Fiber Relative to Alfalfa Silage Neutral Detergent Fiber at Two Theoretical Lengths of Cut

presented by

Charles Steven Mooney

has been accepted towards fulfillment of the requirements for

Master's degree in Animal Science

Major professor

Date March 30, 1994

EFFECTIVENESS OF WHOLE FUZZY COTTONSEED NEUTRAL DETERGENT FIBER RELATIVE TO ALFALFA SILAGE NEUTRAL DETERGENT FIBER AT TWO THEORETICAL LENGTHS OF CUT.

By

Charles Steven Mooney

A Thesis

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Animal Science

1994

ABSTRACT

EFFECTIVENESS OF WHOLE FUZZY COTTONSEED NEUTRAL DETERGENT FIBER RELATIVE TO ALFALFA SILAGE NEUTRAL DETERGENT FIBER AT TWO THEORETICAL LENGTHS OF CUT.

By

Charles Steven Mooney

Twelve Holstein cows (125 DIM) were fed diets differing in theoretical length of cut of alfalfa silage (9.5 mm vs. 4.8 mm) and whole fuzzy cottonseed substituted for 0% or 27% of alfalfa silage NDF. A 2 x 2 factorial arrangement of treatments was replicated (n = 3) in a 4 x 4 Latin square design with 21 d periods. The objective was to determine effectiveness of whole fuzzy cottonseed NDF relative to alfalfa NDF at two lengths of cut as measured by the ability to stimulate chewing. Diets were formulated to 27% NDF. Chewing activity was recorded with halter-mounted pressure sensors and a computerized data collection system. Total chews per kilogram corrected (non grain) NDF intake were decreased by cottonseed ($P < .01$) and short length of cut ($P < .01$) with an interaction observed between the two effects ($P < .05$). Total chews per kilogram corrected NDF intake attributed to whole cottonseed was divided by total chews per kilogram corrected NDF intake attributed to alfalfa silage to calculate effectiveness. Effective NDF of cottonseed was calculated as 48% and 80% relative to long and short cut alfalfa silage, respectively.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND SYMBOLS

92CSM1	code for experiment
A:P	acetate to propionate ratio
ad lib	ad libitum
AD	acid detergent
AFI	adjusted forage index
CF	crude fiber
D	digestible fiber residue
DM	dry matter
DMI	dry matter intake
EDC	electronic data collection
EE	ether extract
eNDF	effective neutral detergent fiber
HCS	hay crop silage
I	indigestible fiber residue
L+	long cut, added WFCS diet
L0	long cut, no WFCS diet
meq	milliequivalents
MSU	Michigan State University
MPL	mean particle length
MPS	mean particle size
NDFI	neutral detergent fiber intake
rpm	revolutions per minute
RVI	roughage value index
S+	short cut, added WFCS diet
S0	short cut, no WFCS diet
UIP	undegraded intake protein
WFCS	whole fuzzy cottonseed

REVIEW OF LITERATURE

Introduction

As ruminants, dairy cows need dietary fiber for proper digestive function. Proper daily fiber intake is essential for optimum production and health of dairy cattle. Too much fiber may limit high producing cows and too little fiber or fiber lacking coarse texture may upset rumen fermentation, depress milk fat percentage, or threaten animal health (46). Therefore, an optimum dietary fiber level exists for the high producing dairy cow which will promote maximum energy and dry matter intake (46).

Determination of proper fiber intake requires accurate fiber characterization as well as an accurate description of requirements. Currently, fiber is quantified by the Van Soest detergent system (66) where the reagents are neutral and acid detergents. Neutral detergent insoluble residue or fiber (NDF), corrected for ash content, contains mainly the components of cell wall -- hemicellulose, cellulose and lignin. Acid detergent insoluble residue or fiber (ADF), corrected for ash content, contains mainly cellulose and lignin.

While both ADF and NDF are used as measures of fiber, the residues of neutral detergent most completely contain the components of cell wall and are, therefore, a more accurate measure of total fiber (44). NDF is more closely associated with diet fill as it is positively related to bulk density (44), negatively correlated with DMI (44, 65), and positively correlated with rumination time (71,73), while ADF is more negatively associated with apparent digestibility (46). The fiber requirement for dairy cattle is better expressed as NDF than ADF (66).

The amount of fiber recommended in a cow's diet is a function of many factors. The National Research Council (NRC) subcommittee on dairy cattle research (46) suggests the amount of fiber required by a cow is a function of such animal factors as body condition, level of production, and feeding frequency, and such fiber factors as type, physical character, amount, bulk density, and buffering capacity. For lactating cows, NRC (46) recommends that the diet contain a minimum of 28% NDF and 75% of the 28% should be supplied by forage sources. An exception is made for cows producing greater than 40 kg/day where the minimum diet NDF is lowered to 25%. No NDF maximum is suggested -- only that fiber concentration may be increased when energy needs are reduced.

As NRC (46) implies, fiber of different feedstuffs, particularly by-product feedstuffs, may have unique chemical and physical properties. While the Van Soest detergent system has advanced the measurement of fiber, the system is quantitative not qualitative and, therefore, does not encompass all the properties and characteristics that may be important to the cow.

Sequence of Events of Eating and Ruminating

As a ruminant, the cow reduces fiber particle size by chewing. The ruminant chews for two proposes: eating and ruminating. Across a range of diets, a dairy cow will spend 4 to 7 h each day eating and 5 to 9 h ruminating (8, 65). During this 9 to 16 h, the cow chews 30,000 to 50,000 times (8, 65, 70). Ruminants tend to eat feed rapidly then chew it more thoroughly later during rumination (8, 65). The chewing motion of rumination is more uniform in rate and amplitude than eating (8, 65, 70).

Eating begins the digestive process and has three phases: prehension, chewing and swallowing (8, 65). The tongue and lower incisors against upper dental pad gather the feed and bring it into the mouth (8, 65, 70). The molars grind the feedstuff with a lateral motion of the jaw reducing the feedstuff to a size that can be swallowed (70).

Coarser feedstuffs are chewed longer than fine (8, 65). Saliva is mixed with the feedstuff during chewing and the amount secreted is proportional to the time spent chewing (8, 65). Once reduced in size, the feed is formed into a bolus and swallowed (8, 65, 70).

Rumination is the cyclic process of regurgitation, remastication, and reswallowing (65). Coarse ingesta stimulates tactile and pressure receptors located in the reticulorumen (8, 65). The resulting nerve signals are sent to gastric centers in the medulla triggering rumination (8, 65). A feedstuff's ability to stimulate these receptors is termed "scratch factor." (8, 65) The amount of "scratch factor" in ingested particles is a function of feedstuff particle size and total diet fiber content (8, 65) as well as forage species and "toughness" as measured as resistance to digestion and physical reduction. Rumination is stimulated by coarse ingesta particles (74), primarily by those particles longer than 10 mm (70), by increased particle toughness (20), and by high dietary cell wall content (71). Rumination is inhibited by low pH, high osmotic pressure, or high volatile fatty acid concentrations of ruminal fluid (69).

Rumination begins with regurgitation of digesta (8, 65, 70). A bolus is formed by reticular contraction, transported into the esophagus by negative pressure caused by inspiration with the glottis closed, and moved to the mouth by rapid antiperistaltic motion (8, 65, 70). Once in the mouth, regurgitated material is squeezed and excess liquid and accompanying small particles are reswallowed (8, 65). The retained material is rechewed and mixed with saliva for about a minute and then reswallowed (70). This cycle can be repeated for some time and may be concurrent with other activities such as milking, walking, urinating and defecating (8, 65). A cow will ruminate during 10 to 20 periods per day with the total time of spent ruminating approaching a proposed upper limit of 10 hours (8).

Eating and ruminating stimulate saliva secretion (20). Saliva produced by the cow is the predominant source of ruminal buffering (25). Saliva is produced by five sets of paired glands and three unpaired glands (13). The parotid salivary glands account for

40 to 50% of the total saliva production (13). Saliva at a pH of 8.4 (25) contains mineral ions (sodium, potassium, phosphate, bicarbonate), which provide buffering to the rumen (8, 65). Saliva composition in cattle is fairly constant containing 125 meq/L HCO_3^- and 26 meq/L HPO_4^- (25). Though measurement of saliva flow in cattle has not been perfected, mean daily saliva flow is estimated at 171 L/d with a range of 108 to 308 L/d (25). Therefore, given the composition of saliva, 390 to 1115 g/d of disodium phosphate and 1134 to 3234 g/d of $NaHCO_3$ are introduced to the rumen daily (25). If dietary buffer were added at maximum of 1% of diet, the added acid neutralizing capacity of the diet would still only be 10% of that provided by rumination (26).

Though there is always some flow, chewing from eating and ruminating increases saliva flow (8, 65). Flows are estimated (12) to be 150 ml/min during resting, 177 ml/min during eating, and 300 ml/min during ruminating (These flows yield the maximum flow of saliva reported in the review by Erdman (25)). Therefore, total daily saliva flow to the rumen is proportional to total time spent chewing (8, 65). Saliva flow may be influenced by forage intake (as forage intake increases, saliva flow increases), forage particle size (as forage particle size increases, saliva flow increases), and the cow's physiological state as lactating cows have a higher resting saliva flow than dry cows (25).

The Concept of Fiber Effectiveness

In recent years, the concept of "effective fiber" has emerged. The concept is also called "fibrous characteristic" (6) and "roughage value" (45, 60). The concept is an attempt to adjust the chemically defined fiber fraction to better relate to responses by the animal.

Effective fiber needs of a dairy cow are satisfied if fiber is fed in an adequate amount of simulatory particle size (26). The minimum amount of effective fiber is achieved if chewing activity and saliva production maintain the rumen pH above 6.2, acetate to propionate ratio (A:P) above 2.2, and, consequently, maintain milk fat test above 3.5 % (52). Lack of coarseness of forages and increased fermentation rate of diet can have negative effects (8, 20, 26, 74) such as depressing feed intake below energy needs, lowering milk fat content, and increasing the incidence of health disorders such as acidosis, parakeratosis of rumen epithelium, bloat, displaced abomasum and laminitis.

Effectiveness of fiber is determined by the sum of many forage and animal factors. Factors implicated in fiber effectiveness include animal species, individual animal tendencies, animal body weight, animal physiological stage, time of access to feed, dry matter intake, protein content of ration, forage to concentrate ratio of diet, chemical composition of forage, particle size of the forage, type of concentrate, and pattern of feeding (8, 20).

Fiber effectiveness has been measured by using total chewing time, ruminal acetate to propionate ratio, or milk fat percentages. Higher chewing time, A:P, and milk fat percentages are interpreted to mean increased effectiveness of fiber.

Most experimenters have used the resulting milk fat percentage on a given diet as the measure of fiber effectiveness. Sufficient effective fiber maintains a near neutral ruminal pH (6.0 to 7.0) and promotes an acetate dominant fermentation in the rumen. An acetate fermentation, in turn, increases fat percentage of milk produced. Milk fat is, therefore, an indirect indicator.

Total chewing activity is a more direct measure of fiber effectiveness. Chewing activity stimulates saliva flow and increased flow carries more neutralizing ions to counter the acids of rumen fermentation. Maintaining a near neutral ruminal pH helps maintain rumen motility and dietary intake. Total chewing activity is also reflective of the "scratch factor" maintaining the healthy rumen epithelium.

With all methods, effective NDF (eNDF) of a particular feedstuff is determined by adjusting the chemical NDF measurement of cell wall content by a multiplier. The multiplier is based on the fiber's relative ability to stimulate milk fat percentage or total chewing activity. The multiplier may correct the chemical NDF measurement for such factors as particle size, ability to stimulate rumination, fermentability and fiber source. Implied in this correction is that the effectiveness of the NDF is measured relative to something such as a coarse forage (e.g. long grass hay).

Influence of Particle Size

Effectiveness of fiber is influenced by particle size. Smaller forage particle size in several forage species has reduced milk fat percentage (29, 30, 31, 53, 76, 77), ruminal acetate to propionate ratio (30, 31, 53, 77), and chewing time (7, 21, 22, 29, 30, 31, 36, 40, 47, 48, 53, 74, 76, 77).

Mean particle size (MPS) or length (MPL) is determined as the weighted average of material retained on sequential sieves. Forage material is sorted through a series of sieves of decreasing aperture in geometric progression. The average obtained is not really weighted by material length but by aperture opening. Several methods are used for sifting material through sieves (shaking (dry) and flushing with water (wet)) and for calculating the variance of the distribution (log normal, gamma, exponential) around the mean (2, 24).

Nørgaard (47) fed three early lactation (42 DIM, 550 kg) cows three 20% barley straw (78% NDF) and 80% concentrate diets in a 3 x 3 Latin square. The three diets were generated by replacing 80%, 50% and 0% of the long barley straw with the same straw pelleted. Chewing activity per day was determined using reticulorumen pressure measurements. Eating activity was defined as the presence of high frequency double contractions and ruminating activity was defined as the presence of triple contractions. As fed intake was fixed at 18 kg per day. Increasing the amount of the long barley straw linearly increased time spent eating (from 83 to 104 min/d, $P < .01$), time spent ruminating (from 125 to 403 min/d, $P < .01$), total chewing time (from 210 to 510 min/d, $P < .01$), number of ruminating periods (from 8 to 17, $P < .01$), and ruminating bout length (from 15 to 24 min/bout, $P < .01$).

For corn silage, reducing theoretical length of cut to 5 mm or less reduces ruminating time and total chewing time. Okamoto et al. (48) fed three only corn silage diets of three theoretical cuts: 4.8 mm, 9.5 mm, and 15.9 mm. The four cows on the experiment were fed at 28 to 30 kg DM per cow per day (intakes not reported) and chewing activity monitored with radio telemetry. NDF content of corn silage was not reported but crude fiber was measured at 20% for all three silages. Time spent ruminating (min/d) was reduced ($P < .05$) with reduction in theoretical length of cut (576 min, 509 min, and 427 min on 15.9 mm, 9.5 mm and 4.8 mm, respectively). DeBoever et al. (21) found that total chewing time per day increased with increased theoretical length of cut (4 mm, 8 mm, and 16 mm) as a result of increased eating time per kilogram DMI on the 16 mm cut (22 min vs. 20 min for 4 mm and 8 mm, $P < .05$) and decreased ruminating time per kilogram DMI on the 4 mm cuts (36 min vs. 39 min on 8 mm and 16 mm, $P < .05$).

Reducing average particle size of alfalfa hay reduces chewing time (30, 36, 40, 53, 76), milk fat percentage (30, 53, 76), and ruminal acetate to propionate ratio (30, 53). Kick et al. (40) meal fed three steers only alfalfa hay of four particle sizes: an uncut ("long"), a theoretical length of cut of 2" ("coarse"), a theoretical length of cut 1/4" ("fine") and a hammer milled ("ground") and monitored eating and ruminating time per day by counting chews with mechanical counters and noting the starting and stopping times for each bout. The "fine" and "ground" had less eating time ("ground" at 78 min/d, "fine" at 91 min/d, "coarse" at 130 min/d, "long" at 153 min/d, significance not determined) and "ground" had less ruminating time ("ground" at 277 min/d, "fine" at 414 min/d, "coarse" at 403 min/d, "long" at 402 min/d, significance not determined).

Shaver et al. (53) fed early lactation (3 to 11 wk), mid lactation (20 to 32 wk), and dry Holsteins diets containing 60% alfalfa hay of 41% NDF. The hay was three particle sizes: uncut long, chopped to an average length of 7.8 mm and pelleted with an average particle size of 1 mm (measured by dry sieving). When compared to long and chopped, the pelleted hay depressed milk fat percentage (3.6% vs. 3.1%, $P < .001$), reduced ruminal acetate to propionate ratio (3.9 vs. 2.5, $P < .001$), and reduced total chewing time minutes per day (576 min vs. 189 min, $P < .001$) and minutes per kilogram DMI (29 min vs. 10 min, $P < .001$). Particle size of hay had no effect on milk production (28 kg) or milk protein percentage (3.12%). They concluded that long and chopped alfalfa hay were equivalent and satisfactory in three measures of effectiveness.

Jaster and Murphy (36) fed 18 Holstein heifers (340 kg) three particle sizes of 63% NDF alfalfa hay in a 3 x 3 Latin square with consecutive 21 d periods. The three particle sizes of hay were uncut long, coarsely chopped (average particle size was 2.2 mm as measured by dry sieving), and finely chopped (average particle size was 1.4 mm as measured by dry sieving). Total time spent chewing (16.7 h/d, $P > .10$) was not different across diets. However, NDF intake was lower on long diets compared to coarse and fine diets (4.5 kg vs. 5.3 kg, $P < .0001$) which increased minutes of total chewing time per kilogram NDF intake.

Woodford et al. (76) fed four multiparous Holstein cows (56 DIM) in 4 x 4 Latin square four 27% NDF diets of 47% alfalfa hay (47% NDF) which varied in measured MPL. MPL of four chops of alfalfa hay were .26 cm, .46 cm, .64 cm, and .90 cm as measured by dry sieving. Total chewing time (as recorded visually every 5 minutes for 24 hours) increased from 525 min/d on .26 cm hay diet to 604 min/d on .90 cm hay diet. Milk fat percentage increased from 3.2% on .26 cm and .46 cm hay diets to 3.6% on .64 cm and .90 cm hay diets. Ruminal acetate to propionate ratio increased from 2.2 on .26 cm and .46 cm hay diets to 2.8 on .64 and .90 cm hay diets. However, these increases were not significant ($P > .05$). Four percent FCM production (27 kg), DMI (25 kg) and chewing time per kilogram NDF intake (84 min) were not different ($P > .05$) across treatments. They, none the less, concluded that milk fat depression was prevented when forage MPL was ≥ .64 cm.

Grant et al (30) fed alfalfa hay (46% NDF) at 55% of diet at three particle sizes to four early lactation (21 DIM) multiparous Holsteins in a crossover design. Two chops, a coarse and a fine, dry sieved to an average particle size of 2.2 mm and 1.0 mm, respectfully. The three diets were based on only coarse hay, only fine hay, and a 50:50 mix of the fine and the coarse (called "medium"). While NDF intake, DMI, and milk production (kg) were similar across diets (6.6 kg, 22.7 kg and 25 kg, respectively, $P >$ .10), the fine chop compared to medium and coarse had a lower milk fat percentage (3.1% vs. 3.7%, $P < .10$). Reducing particle size lead to a reduction in time spent eating, ruminating and total chewing per day (from 348 min/d on coarse to 322 min/d on fine, from 490 min/d on coarse to 381 min/d on fine, and from 838 min/d on coarse to 704 min/d on fine, respectively, $P < .05$). Also, with fine, an increased ruminal propionate (from 19 mol/100 mol on medium and coarse to 27 mol/100 mol on fine, $P < .05$), a decreased A:P (3.89 on coarse, 3.20 on medium, and 2.08 on fine, $P < .05$), and a decreased mean ruminal pH (6.25 on coarse vs. 5.80 on medium vs. 5.40 on fine, $P < .05$) were measured. Cows receiving the finely chopped diet also increased plasma glucose and serum insulin. They concluded that measured blood and rumen factors were supporting of the glucogenic theory of milk fat depression where increased ruminal propionate shifts fat metabolism away from the mammary gland and to body adipose.

Grant et al (31) fed 18 early lactation (21 DIM) Holsteins three diets with alfalfa silage (40% NDF) as 55% of the diet. The three particle size diets were generated with two theoretical cuts: a coarse cut at .95 cm and a fine cut at .48 cm. The three diets were the coarse cut only, the fine cut only, and a 50:50 mix of the two cuts. The MPS of the silages were 3.1 mm, 2.0 mm and 2.6 mm, respectively, measured with dry sieving of dried samples. Trends and changes were the same as the alfalfa hay study. Again, DMI and NDF intake were similar across diets (22.2 kg and 6.3 kg, respectively, $P > .05$). Milk production was similar for all diets (31.6 kg, $P > .05$), however, milk fat percentage on the fine diet (3.0%) was lower ($P < .05$) than the medium (3.6%) or coarse (3.8%)

diets leading to differences in 4% FCM ($P < .05$). Mean ruminal pH was lower ($P < .10$) on the fine diet (5.3) than medium (5.9) or coarse (6.0) diets. A:P increased ($P < .05$) with increasing forage coarseness (2.77 on fine, 3.13 on medium, and 3.52 on coarse). Total daily chewing time in minutes (as recorded visually every five minutes for 24 h) was increased with increased silage coarseness (570 min on fine, 671 min on medium, and 735 min on coarse, $P < .001$). In this study, the total chewing time in minutes per kilogram DMI can be calculated as 25.4 min, 30.5 min and 33.1 min for fine, medium and coarse silages, respectively. Total chewing time in minutes per kilogram corrected (forage only) NDF intake was calculated by 91.0 min, 107.7 min and 116.5 min for fine, medium and coarse silages, respectively.

Other studies using alfalfa silage of varied particle size (7, 29, 77) also showed reduction in total chewing time (7, 29, 77) and milk fat percentage (29, 77) on finer forage particle size diets. DeBoever et al. (22) tried to vary grass silage particle sizes with three cuts: an uncut, a 24 mm theoretical cut, and a 3.5 theoretical mm cut. However, the measured average particle sizes were 48 mm, 24 mm, and 14 mm, respectively, as measured by dry sieving. No difference was measured in total chewing time per kilogram DMI (72.6 min, $P > .05$) across cuts but with the "short cut" averaging 14 mm, it may not have been short enough to decrease total chewing time per DMI.

Figure 1 presents a summary of the influence of forage particle size on fiber effectiveness as measured by total chewing activity. In those papers where both could be determined, total chewing time in minutes per kilogram corrected (nongrain) NDF intake is plotted against mean particle size in millimeters determined by dry sieving. In these experiments (exception Woodford et al. (76)), reducing dry sieve MPS reduced total chewing time in minutes per kilogram corrected (nongrain) NDF intake.

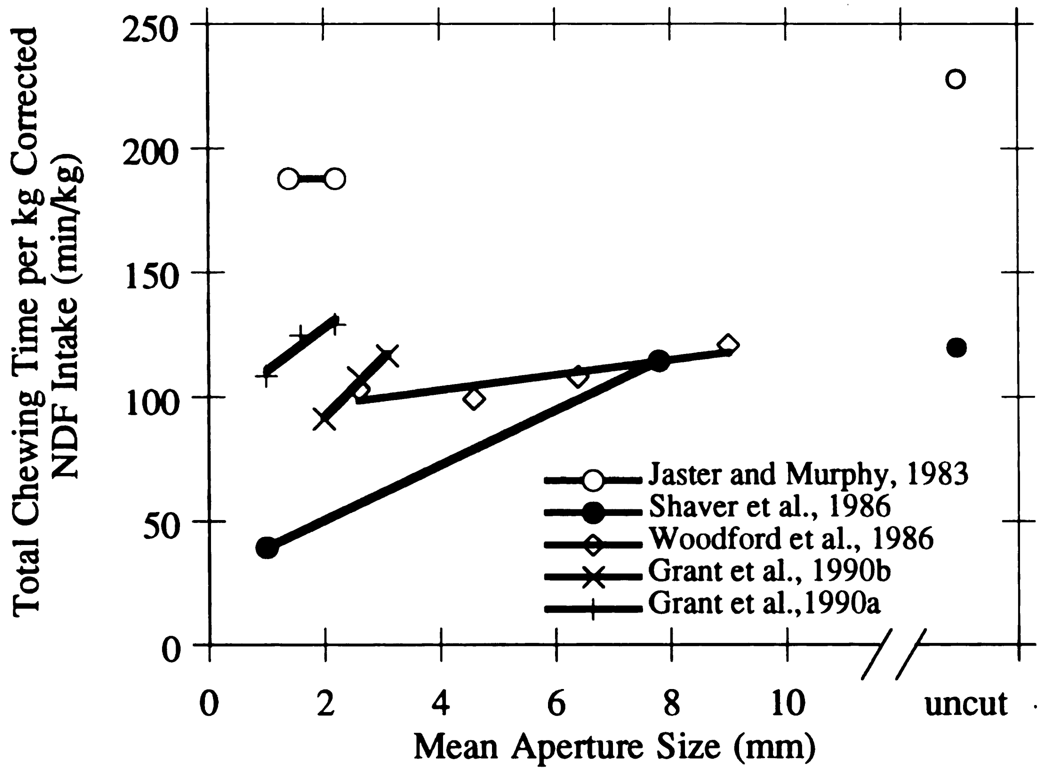

Figure 1. Total chewing time per kilogram corrected NDF intake reported in studies with cattle varying particle size of alfalfa forage.

Influence of NDF Content of the Diet

Increasing the NDF content of diets usually by increasing forage to concentrate ratio has increased milk fat percentage (9, 76) and increased total chewing times (9, 10, 38, 57, 76). Reducing the diet NDF content by increasing the proportion of the diet from grain leads to a more acid fermentation. A more acid fermentation can result in milk fat depression. Increasing the proportion of the diet from grain also leads to a reduction in total chewing activity on the diet. Decreased total chewing reduces the amount of saliva produced and introduced into the rumen to neutralize the fermentation acids (8, 25, 65). However, while total diet effectiveness was reduced in most experiments, effectiveness per kilogram NDF was constant as measured by total chewing activity suggesting the effectiveness of each unit of forage is constant.

Woodford et. al. (76) fed four multiparous Holstein cows (63 DIM) in a 4 x 4 Latin square and varied NDF content of alfalfa hay (46% NDF) based diets by altering the forage to concentrate ratio. NDF contents achieved were 21%, 24%, 27%, and 30%. On an average DMI across diets of 24.5 kg ($P > .05$), total chewing time and milk fat percentage increased linearly with increasing NDF concentration. Total chewing time increased from 629 min on 21% NDF to 794 min on 30% NDF but, total chewing time per kilogram NDF intake was similar (115 min/kg NDF intake, $P > .05$) A:P increased ($P > .05$) from 2.6 on 21% NDF to 4.0 on 30% NDF and milk fat percentage increased ($P > .05$) from 3.5% to 4.0%. A numeric maximum 4% FCM of 32.3 kg was achieved at 27.5% NDF though 4% FCM output was similar on all diets ($P > .05$).

Jorgensen et al. (38) fed 20 Holstein cows (49 DIM) in two groups. One group was fed a diet that was 50% forage and the other diet was 33% forage on a DM basis. The forage was alfalfa silage of 42% NDF. Fat corrected milk production was similar across diets (27 kg/d, $P > .05$). Total chewing time per day (as recorded by visual observation every 5 minutes for 72 hours) was decreased with decreasing forage (600 min vs. 504 min, $P < .05$) but min per kilogram NDF were similar (102 min, $P > .05$).

Welch and Smith (71) reported a high correlation (r = .99) between rumination time and NDF intake in sheep. They determined that "1.05 min rumination time was required for each gram of cell wall constituents." Welch and Smith (73) reported a similar correlation for cattle (r = .94).

In 1977, Sudweeks (57) fed mature Jersey and Guernsey steers diets that were 90%, 60% and 30% forage. NDF contents were not reported. Combined results of the factorial crossing the forage type (wheat silage, sorghum silage, or bermudagrass hay) with concentrate type (citrus pulp, corn or soybean mill feed) showed an increase in chewing time ($P < .05$) with increasing forage. Steers chewed 713 min/d on 90% diet, 490 min/d on 60% diet, and 387 min/d on 30% diet. Source of forage or concentrate did not affect total chewing time ($P > .05$).

Beauchemin (9) fed six diets ad lib to six ruminally fistulated Holsteins (80 DIM) in a 6 x 6 Latin square with 28 d periods. The diets were composed of alfalfa hay and a barley based concentrate. The hay and the concentrate were fed separately. The factorial of diets crossed maturity of alfalfa hay (an early bloom of 39% NDF and a mid bloom of 48% NDF) and total NDF content of diet (31%, 34%, and 37%). DMI was similar across diets (22.3 kg/d, $P > .05$) and total NDF intake (kg/d) was proportional to NDF content of diet. Increasing NDF concentrations by adjusting forage to concentrate ratio tended to linearly decrease milk production (from 27 kg to 25 kg, $P = .09$), linearly increased milk fat percentage (from 2.7% to 3.3%, $P < .001$), but had no effect on FCM (22 kg, $P = .32$). Increasing NDF concentrations linearly increased mean ruminal pH (from 5.6 to 6.0, $P < .001$) and linearly increased mean ruminal A:P (from 3.3 to 4.9, $P < .001$). Chewing activities were monitored during the last week of each test period using a strain gauge transducer built into a halter and linked to a computerized data acquisition system. Increasing NDF of diet from 31% to 37% increased total chewing activity in minutes per day (from 767 min to 852 min, $P < .001$), minutes per kilogram DMI (from 34.1 min/kg DMI to 39.0 min/kg DMI, $P < .001$), but the diet did not effect minutes per kilogram

NDF intake (106 min/kg NDF intake, *P* > .05) and decreased minutes per kilogram hay NDF intake (from 265 min to 144 min, *P* < .001). Increase of diet NDF content from 31% to 37% affected total chews similarly.

Figure 2 presents total chewing minutes per day for kilogram corrected NDF intake in studies that reported both. Woodford et al. (76) and Jorgensen et al. (38) reported a linear relationship between total chewing time and kilogram corrected NDF intake. Beauchemin (9) found a linear relationship between total chewing time and total NDF intake, but not corrected NDF intake. Overall, the studies reviewed suggest a linear relationship between total chewing time and kilogram corrected (nongrain) NDF intake.

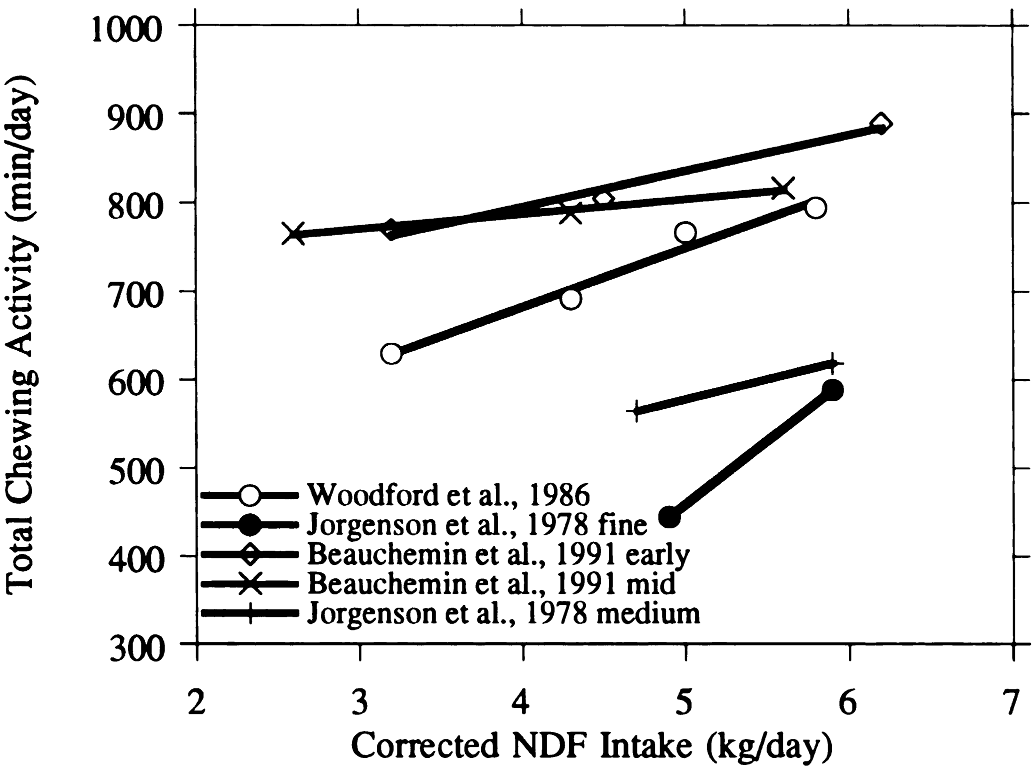

Figure 2. The total chewing activity (min/d) at given corrected NDF intake in cattle for several published studies reported in the Review of Literature.

Influence of Maturity of Forage

Effectiveness of fiber is influenced by maturity of forage. Most forages, excluding corn, increase in NDF content as they mature. As the NDF content of a forage increases and concurrently the digestibility of that NDF is reduced, the quality of the forage is reduced as the whole plant becomes less digestible. Welch and Smith (73) found a .94 correlation between rumination time and NDF content of test meals in dairy heifers and steers. After fasting or feeding pelleted alfalfa for two days, a 5 kg (as fed) meal of test forages varying in maturity was fed. Chewing behavior was recorded with an air bladder on a halter and a paper recorder. As maturity of the forage increased (i.e. NDF content increased and, though not reported, fiber digestibility probably also decreased), rumination time was increased ($P < .05$). However, rumination time per gram of NDF intake was constant ($P > .05$) at approximately .14 min/g NDF intake. Eating times were not reported.

Beauchemin (9) fed an early bloom of 39% NDF and a mid bloom of 48% NDF. Quality of hay had no effect on mean ruminal pH, mean ruminal acetate to propionate ratio, milk production, or milk composition ($P > .05$). Chewing activities were monitored during the last week of each test period using a strain gauge transducer built into a halter and linked to a computerized data acquisition system. Total chewing activity (measured either as minutes or chews) was affected by quality of hay ($P < .05$). Total chewing activity as measured in minutes per day, minutes per kilogram DMI, and minutes per kilogram NDF intake were lower on mid bloom alfalfa hay diets than early bloom hay diets. However, when barley NDF was removed, total chewing activity per kilogram hay NDF intake was higher on mid bloom hay diets than on early bloom (207 min vs. 188 min, $P < .05$) suggesting the more mature alfalfa hay of higher NDF and lower DM digestibility was more effective.

DeBoever and coworkers have examined the effects of increased forage maturity on chewing activity of 19 perennial ryegrass grass silages (2) and 14 corn silages (21).

Eight cows were each fed a fixed amount of supplement (3 kg for grass silage experiment and 2.2 kg for corn silage experiment) and ad lib test forage. Chewing activity was recorded by transducing air pressure changes in a halter mounted bladder to electric signals and registering them with a paper recorder on the last four days of a test period. Increased maturity of grass silage from "vegetative" to "full ears" increased total chewing time per kilogram DMI (from approximately 80 min. to approximately 90 min, $P < .05$). Increased maturity of corn silage from "milk dough" to "hard dough" decreased total chewing time per kilogram DMI (from approximately 62 min to approximately 58 min, $P < .05$). However, NDF content of forages were variable (mean 46.8% and range 41.7% to 54.8% for grass silages and mean 38.5% range 35.7% to 43.2% for corn silage). Generally, maturity increased NDF content of grass silages and decreased NDF content of corn silages. Total chewing time per kilogram NDF was not reported for the grass silages. Total chewing time per kilogram NDF was reported for the corn silages but, the probability of maturity effects was not reported.

Influence of Animal Factors

The measurement of fiber effectiveness can be influenced by animal factors as individual animals can respond differently to the same diets. This is particularly true of chewing activities. Species of animal affects chewing activity over a range of diets. Sheep and goats chew more per kilogram intake than cattle (20, 69). These differences persist even when chewing activity is corrected for metabolic body weight (20, 69). Sheep also chew faster than cows (20).

Within a species, individuals have distinct tendencies. In a review, DeBoever et al. (20) reported a coefficient of variation of 15% for chewing activities per unit of DMI among 14 dry pregnant British Friesian cows on a hay only diet. Dado and Allen (19) reported daily chewing activity variables with coefficients of variation as high as 22% for 12 Holstein cows (63 DIM) producing 21.7 to 47.6 kg/d milk per day and fed a common

TMR of alfalfa silage, corn silage and concentrate. Coefficients of variation in the experiment (19) were 17.3%, 21.0%, and 20.1% for eating time (min) per day, per kilogram DM, and per kilogram NDF, respectively. The ruminating coefficients of variation were 16.3%, 22.5%, and 22.3% time (min) per day, per kilogram DM, and per kilogram NDF, respectively. And total chewing coefficients of variation were 12.6%, 17.1%, and 17.0% for time (min) per day, per kilogram DM, and per kilogram NDF, respectively,

Body size is a major source of chewing variation (70). Bae et al. (4) fed all hay diets to 59 mature cows of several breeds and reported, as the body weight increased, total chewing time per kilogram NDF decreases. Breed of dairy cow may also have effects of chewing activity. Welch et al. (75) reported differences ($P < .05$) among dairy breeds in rumination time in minutes per gram of NDF intake per kilogram metabolic body weight. Guernsey had the lowest times then Holstein and Ayrshire and Jersey had the highest times (5.3, 6.8, 7.0, and 9.2, respectively). Physiological stage of animal can also influence chewing activity. In some experiments, pregnancy increased chewing time per unit of feed (20).

As intake increases, eating, ruminating, and total daily chewing activities increase. This increase in activity may (5) or may not (53, 59, 72) be constant chews per kilogram intake. Bae et. al. (5) fed four dry cows all hay diets in a 4 x 4 Latin square at 50%, 75% , 100% and 125% of NRC recommended intake. They found total chewing time per kilogram NDF to be constant (about 135 min, $P > .05$). Welch and Smith (72) fed 100% grass hay to sheep. As intake increased from 250 g to 1800 g, total rumination time increased (from 231 min to 588 min), but rumination time per gram of NDF intake decreased (from 1.36 min to .55 min, P not reported). Sudweeks et al. (59) fed steers 90% corn silage diet (NDF content not reported) at three levels: 87% (7.4 kg), 122% (10.4 kg), and 165% (12.2 kg) of "maintenance net energy milk"[sic]. Total chewing times in minutes increased with intake (476 min, 628 min, and 706 min, $P < .05$) but, total chewing minutes per kilogram DMI decreased with increased intake (67.5 min/kg DMI, 62.8 min/kg DMI, and 57.1 min/kg DMI, $P > .05$).

To vary intake, Shaver et al. (53) fed six Holstein cows a 60% alfalfa hay diets during early lactation (3 to 11 wk), mid lactation (29 to 32 wk), and the dry period. The prebloom alfalfa hay was obtained as bales from one field and was 41% NDF. Dry matter intakes were different ($P < .001$) at 24 kg for early lactation cows, 20 kg for mid lactation cows, and 14 kg for dry cows. Total chewing activity (min/d) increased with intake (386 min/d, 424 min/d, and 530 min/d, $P < .001$) and total chewing activity per kilogram DMI was higher ($P < .001$) during dry period (27 min/kg DMI) than early or mid lactation (21 min/kg DMI).

Measurement of Forage Fiber Effectiveness

Both chemical and physical characteristics of forage fiber affect their utilization by ruminants and, therefore, both must be measured in an optimum eNDF system (45). To measure the physical characteristics of a feed, Balch (6) proposed the use of "time spent chewing per unit of DMI" as an index of "fibrousness characteristic of roughages" because physical character directly stimulates rumination.

Balch (6) selected daily total time spent chewing as part of his index because the total time spent chewing was less variable than either time spent eating or ruminating. Eating and ruminating time vary in opposition to each other (e.g. the more time spent eating, the less time the cows spends ruminating) whereas total chewing time per kilogram DMI relatively constant (20). Balch measured total chewing time by recording pressure changes in halter mounted balloons as traces on a paper recorder. Total chewing time was divided by kilogram DMI to correct for variation in amount consumed and feed access time. Total chewing time is proportional to saliva production and easier to measure (25).

Balch (6) reported indexes (total minutes chewing per kilogram DMI) obtained on one ingredient diets fed to dry Short Horn and Friesian cows: oat straw was 145 to 191 min/kg DMI, "good quality" hay was 87 to 105 min/kg DMI, grass silage was 99 to 120 min/kg DMI, one ingredient pelleted concentrate diet was 4 to 29 min/kg DMI, and finely ground hay diets was 13 to 19 min/kg DMI. The indexes of pelleted concentrate diet and finely ground hay diet were a fraction of the coarse forages and were characterized by irregular chewing activity.

Sudweeks and coworkers (58, 60) have tried to quantify effectiveness of forage fiber through their "roughage value index system." Based on the proposal by Balch (6), roughage value index (RVI) is defined as the total time spent chewing per kilogram DMI. They (60) fed 12 Holstein cows (70 DIM) alfalfa hay (all from one source) diets ad lib of three forms: long, chopped at 3.81 cm theoretical cut, and pelleted. Grain was fed separately at a constant amount to all cows within a block. Total chewing time per kilogram DMI was measured with a bellows pneumograph on the halter and a paper recorder system. They also fed these diets without any grain to six dry Holsteins. Neutral detergent fiber contents were not reported. Mean total chewing time per kilogram DMI for lactating cows was reported as 37 min on the long hay diet, 28 min on the chopped hay diet and 15 min on the pelleted hay diet. The pelleted hay diet was lower ($P < .05$) than the long or chopped hay diets. For dry cows, the indexes were 62 min, 44 min, and 37 min, respectively and the long hay diet was higher ($P < .05$) than the chopped or pelleted hay diets. Regressing each lactating cow's milk fat percentage on her minutes of chewing time per kilogram DMI, they reported that, to maintain 3.5% milk fat or higher (their minimum criteria for fiber effectiveness), total diet index had to be 31 minutes per kilogram DMI or higher.

Sudweeks et al. (58) also did an extensive review of the literature to collect and calculate roughage index values. In diets that combined fiber sources, they used linear regression to partition the total chew time per kilogram DMI to each fiber source. A sampling of the values reported is in Table 1 (58). Using their literature review, they developed a predictive equation that could be used to calculate individual feedstuff RVI based on dry sieving particle size and chemical analysis as follows: Individual feedstuff RVI (min/kg) = 10.86 + (dry sieve particle size in mean diameter)(21.59) - (DMI in kg)(1.91) + (NDF content of feedstuff)(.541). Individual feedstuff RVI could be used to calculate total diet RVI which they recommended should be at least 31 min/kg to maintain a milk fat content of 3.5%.

Table 1. A sampling of roughage index values for cattle reported by Sudweeks et al. (58).

	Total Chewing Time/kg DM, min.
Alfalfa hay, long	61.5
Alfalfa hay, pelleted	36.9
Oat straw	160.0
Orchard grass, early cut	74.0
Orchard grass, late cut	90.0
Alfalfa silage	22.3 to 26.0
Corn silage	40.0 to 66.1
Grass silage	90.0 to 120.0
Barley ground	15.0
Ground corn	1.0 to 9.2

Santini et al. (50) proposed another system that would combine chemical and physical measurements in an effort to measure diet fiber effectiveness. They proposed an adjusted forage intake system which was calculated by multiplying forage intake in kilogram by MPL. MPL is determined as the weighted average of material retained on standard sieves after dry sieving. They hypothesized that, if adjusted forage intake (AFI) correlated to total chewing time, the tedious measurement of chewing activities could be avoided. They fed six multiparous Holsteins (60 DIM) in two 3 x 3 Latin squares alfalfa based diets ad lib. One Latin square had 33:67 forage to concentrate ratio and the other was 50:50. Forage component of diet differed (*P* not reported) in mean particle length:

.31 cm, .43 cm, and .51 cm. The differing diet particle size were achieved by substituting alfalfa hay (55% NDF, 15% CP) for alfalfa hay crop silage (45% NDF, 21% CP), confounding particle size and fiber content. The .31 cm diet was achieved with 100:0 silage DM: hay DM ratio, .43 cm with a 67:33 and .51 cm with a 33:67. They monitored chewing activity visually every five minutes for 24 h and calculated AFI in kg·cm. They reported that the relationship between total chewing time in min per kg·cm (Y) and adjusted forage intake in kg·cm (X) was $Y = 365.2 - 69.6 X + 4.73 X^2$. As adjusted forage intake (kg·cm) increased to 125, total chewing time in min per kg·cm decreased until AFI = 7 where became asymptotic to X axis. They concluded that adjusted forage intake was closely associated with total chewing time over the range of forage intakes (7.7 to 12.2 kg/d) and mean particle length (.31 to .51 cm) in their study and that the use of AFI to calculate the roughage index of forages had merit.

DeBoever and coworkers also tried to replace the measurement of total chewing index with a combination of chemical and physical lab methods. They fed eight cows in two experiments (described in an earlier section): one for grass silage (22) and one for corn silage (21). They varied maturity, length of chop and year of cutting. They measured chewing activities electronically and reported a range of indexes for grass silage of 58.5 to 96.9 min per kg DMI and for corn silage of 50.8 to 75.5 min per kg DMI. They also measured dry matter content, crude fiber content, NDF content, ADF content, lignin content, sugar content, dry sieve particle distributions, milling resistance, forage density and in vitro digestibility and regressed them on total chewing indexes of the silages. For their grass silages, crude fiber content accounted for 74% of variation in total chewing index and the addition of physical characteristics to the regression added little. However, the shortest measured particle size was measured at greater than 14 mm. For corn silage, in vitro digestibility combined with percent of non grain DM retained by sieves of ≥2.38 mm (they considered this material stimulatory to rumination) accounted for 87% of variation. In vitro digestibility alone accounted for 66% of the variation and percent of non grain DM retained by sieves of ≥2.38 mm accounted for 63% of the variation.

Use of High Fiber By-products as Supplements

The fiber in a dairy cow's ration normally comes from on-farm forages. On-farm forage NDF can be supplemented at luxury or at necessity with high NDF by-products. High fiber by-products are often an inexpensive source of energy and bypass protein. However, while some by-products may be similar to forages in NDF content, by-product NDF may have a diminished ability to stimulate chewing, to maintain near normal ruminal pH and to maintain milk fat content of approximately 3.5% (26, 56).

By-products that have been used to supplement fiber are listed in Table 2. Corrugated paper and cottonseed hulls are almost all fiber while others (distiller's grain and whole fuzzy cottonseed) add fiber as part of a total package of fiber, energy, and protein. Some are highly digestible (beet pulp, pineapple bran, soybean hulls) and others (rice hulls, sunflower hulls, oat hulls) have low digestibility (33,35). Whole fuzzy cottonseed and soybean hulls are used extensively throughout the United States while peanut hulls, beet pulp, brewers grains, and distillers grains are regionally available (33, 56). By-products are highly variable in fiber composition and digestibility (56). Consequently, estimates of effectiveness within a by-product can be highly variable, therefore, measurements, where possible, are recommended (56). The by-product feed variability of chews per kilogram NDF intake is not known.

Table 2. NDF percentages of high fiber by-product feed reported in review by Harris, 1991 (33).

	% NDF of DM
Beet pulp	54
Citrus pulp	23
Corn cobs	85
Corrugated paper	92
Cottonseed hulls	90
Dried brewer's grains	46
Oat hulls	78
Peanut hulls	74
Pineapple bran	73
Rice hulls	80
Soybean hulls	67
Sugarcane bagasse	86
Sunflower hulls	83
Whole fuzzy cottonseed	44

Whole fuzzy cottonseed (WFCS, also called "whole cottonseed with lint"; IFN 5-01-614) is an attractive by-product for feeding lactating dairy cows as WFCS is high in fiber, energy, and protein (particularly UIP). These multiple benefits often make it part of the diet in a linear programming or a least cost environment (16). NRC (46) lists WFCS as 2.23 Mcal NE_L/kg, 23% crude protein, 20% ether extract, 44% NDF, 34% ADF, and 5% ash.

Whole fuzzy cottonseed has feeding limits because it contains gossypol. Gossypol, a phenolic compound found in the pigment glands of cottonseed, is toxic to animals (16). However, ruminants are less affected than nonruminants because gossypol is bound in rumen (16). In ruminants, gossypol toxicity is possible but unlikely in typical feeding rates of 3 to 4 kg per day (16). Symptoms of toxicity are depressions in hemoglobin and total blood proteins and increases erythrocyte fragility (16, 17). Whole cottonseed can be fed to lactating dairy cows at up to 25% the diet with no effect on total intake (16, 56).

When fed to lactating cows, WFCS generally tends to increase milk yield and milk fat test while decreasing milk protein test (16). However, results may depend on forage base of diet (55). WFCS addition to corn silage based diets at 10% to 15% tends to increase milk production and decrease milk fat (56, 64) and WFCS addition to alfalfa based diets at 10% to 30% tends to maintain milk yield but increase milk fat percentage (54). Also, the addition of WFCS to lactating dairy diets can affect milk fat production by altering the fatty acid composition of the milk fat. Whole cottonseed in diets reduces the proportion of short chain (C6 to C14) fatty acids in milk fat and increases the dietary transfer of longer chain (C18) fatty acids to milk fat. (34, 54, 55)

Measurement of By-product Fiber Effectiveness

Since by-products can not generally be fed at 100% of diet, by-products must be fed as a portion of the diet. The challenge then becomes separating the by-product effects from the other diet components.

In one of the earlier studies of by-product effectiveness, Lofgren and Warner (42) measured by-product effectiveness using milk fat percentage response. They compared beet pulp, corn cobs, and oat hulls to a mixed grass/legume hay. After a minimum five week preliminary period in which a 20% mixed hay and 80% pelleted concentrate diet was fed to depress milk fat percentage, 21 lactating Holsteins (≥70 DIM) were fed one of four test diets for 16 weeks. These diets were all 14% crude protein and 15% crude fiber with 60% of the crude fiber coming from hay (38% crude fiber, 68% NDF and 41% ADF). The remaining 40% of crude fiber came from one of four sources: beet pulp (21% crude fiber, 40% NDF and 22% ADF), corn cobs (28% crude fiber, 69% NDF and 33% ADF), oat hulls (33% crude fiber, 75% NDF and 37% ADF), or additional hay as a control. (All component concentrations are reported on air-dry basis.) After two weeks on experiment diets, monitoring of milk production and composition began. All experiment diets corrected the milk fat depression (2.3% vs. 3.3%, $P < .001$) induced by the pre-experiment diet. No milk fat differences across treatment diets were found suggesting that by-product crude fiber is just as effective as added hay crude fiber as measured with milk fat percentage. Using data from each individual cow, they correlated fat test change (from pre-experiment to experiment) against change in percent intake of dietary components from pre-experiment to experimental diets. Change in percent intake of ADF was the most highly ($P < .05$) correlated with change in fat test. Change in percent intake of crude fiber and change in percent intake of cellulose were correlated ($P < .05$), but to lesser extent. Change in percent intake of NDF was not correlated ($P > .05$).

In 1991, Beauchemin et al. (11) reported an experiment to examine the fiber effectiveness of pelleted alfalfa, beet pulp and oat hulls relative to alfalfa hay. Nine lactating Holsteins (80 DIM) in two 5 x 5 Latin squares were fed five alfalfa hay forage (42% NDF) and barley based concentrate diets. Hay and concentrate fed sequentially. The five diets were: a 29% NDF diet with 65% of dry matter from the concentrate, a 32% NDF diet with 65% of dry matter from the concentrate which contained added suncured alfalfa pellets, a 32% NDF diet with 65% of dry matter from the concentrate which contained added beet pulp, a 32% NDF diet with 65% of dry matter from the concentrate which contained added oat hulls, and a 32% NDF diet with 55% of dry matter from the barley based concentrate. They recorded chewing time and number using a strain gauge transducer mounted on a halter and linked to a computerized data acquisition system, milk production and composition, and rumen parameters. DMI was similar for all diets (21 kg/d), but NDF intake was higher on 32% NDF diets than the 29% NDF diet (6.7 kg/d vs. 6.1 kg/d, $P < .001$). Total chewing activities were similar across diets in per day measures (740 min/d and 46,000 chews/d, $P > .05$) and in per kilogram DMI measures (35.5 minutes per kg DMI and 2220 chews per kg DMI, $P > .05$). However, total chewing activities per kg NDF intake were greater on the 29% NDF diet than on 32% NDF diets (126 min and 7940 chews vs. 111 min and 6915 chews, $P < .05$). Milk production was similar across diets (26 kg/d, $P > .05$). Milk fat percentage was lowest on the 29% NDF (2.2%), intermediate on NDF supplemented concentrate diets (2.9%) and highest on the 32% NDF all hay diet (3.2%, $P < .05$). Fat corrected milk was greater on 32% NDF all hay diet as well (23.2 kg/d vs. 21.5 kg/d, $P <.05$). Mean ruminal acetate to propionate was lowest on the 29% NDF (1.57), intermediate on NDF supplemented concentrate diets (1.94), and highest (2.27)on the 32% NDF all hay diets ($P < .001$). They concluded when forage must be limited in the diet, suncured alfalfa pellets, beet pulp, or oat hulls can be added to enhance milk fat percentage. However, increasing NDF content of the diet by increasing the forage to concentrate ratio of the diet is more effective than by-product supplementation. Thus, the effectiveness of NDF of suncured alfalfa pellets, beet pulp and oat hulls is greater than 0% but less 100% when compared with alfalfa hay.

Work from The Ohio State University reported in 1991 (51) and in 1992 (27) tested the validity of the NRC (46) recommendation that 75% of total diet NDF should come from forage. Sarwar et al. (52) fed five duodenally and ruminally cannulated Holstein heifers (500 kg) in a 5 x 5 Latin square with 17 d periods. The five diets all at 31% NDF were based on 50:50 (DM basis) corn silage to alfalfa. Using soyhull and corn gluten feed NDF to replace forage NDF, the five diets were: a control diet with 85% of the diet NDF from the forage mix; a test diet with 65% of the diet NDF from forage and 20% from corn gluten feed, a test diet with 45% of the diet NDF from forage and 40% from corn gluten feed; a test diet with 65% of the diet NDF from forage and 20% from soyhulls; and a test diet with 45% of the diet NDF from forage and 40% from soyhulls. A tendency toward lower ruminal pH 3 h post feeding was recorded on 45% forage NDF diets when compared with 65% forage NDF diets (5.6 vs. 5.9, $P = .07$). Ruminal A:P was similar across diets ($P > .05$) at 3 h (3.5), 6 h (3.3), and 9 h (3.7) post feeding. Based on ruminal and whole tract measurements, they (51) suggested that 65% of dietary NDF from forage may be sufficient when corn gluten feed or soyhulls replace the forage.

In a follow up study, Firkins and Eastridge (27) replaced forage NDF with soyhull NDF in lactating cow diets. After common pretreatment diet, 40 early lactation (4 weeks) cows were blocked for parity, previous milk and DIM. These cows were fed 28% NDF diets in a randomized block design for 16 weeks. A control diet contained 75% of NDF from a forage mix of 3:1 (DM basis) corn silage (NDF content not reported) and alfalfa silage (55 to 58% NDF). Two of the three test diets had soyhulls (NDF content reported) replacing corn silage on a DM for DM basis to lower the forage contribution of the diet NDF to 62.5%. These three diets measured 36% NDF. On these three diets, intakes (24 kg DM/d), body weight change (.36 kg/d), 4% FCM (33 kg/d), milk fat percentage (3.4%), and milk protein percentage (3.2%) were not affected by diet ($P > .10$). Even though these diet NDF contents were higher than the NRC (46) recommendations and 77% of the required 28% NDF was form forage (.60 x 36%÷ 28%), they concluded the results suggest the addition of soyhulls can reduce forage contribution to total NDF to 60 to 65%.

Wagner et. al. (68) replaced corn silage (NDF content not reported) with wheat middlings (% NDF not reported). Five lactating cows in 5 x 5 Latin square were fed five diets which were 33.5% NDF. The high forage control had 50% of dry matter as corn silage. Four test diets had 15% of diet as wheat middlings replacing corn silage. The addition of wheat middlings to replace corn silage increased DMI (19.3 kg vs. 20.6 kg, $P = .01$) and had no effects ($P > .10$) on milk production (30 kg/d), milk composition (3.6% milk fat, 3.5% milk protein), or ruminal pH or acetate to propionate ratio. They concluded that wheat middlings at 15% of dry matter can effectively substitute for corn silage in lactating cows diets. This suggests wheat middlings equal corn silage in fiber effectiveness.

Research at the University of Wisconsin is the first attempt to quantify effectiveness of by-products. A series of studies reported in the 1990's (14, 15, 61, 67) examined a variety of by-products. In these studies, by-product NDF effectiveness was calculated relative to alfalfa silage NDF using milk fat percentages. To establish the standard in each of these experiments, milk fat percentages were measured on a low and high NDF control diets. The increases in milk fat percentage from low NDF to high NDF alfalfa silage diets were divided by the increase in the nongrain NDF content of total diet from low to high. This ratio was called the "slope coefficient." By-product NDF was also added to the basal low alfalfa silage NDF diet and slope coefficients for these by-products were calculated comparing the high NDF from by-product diet to the basal NDF diet. The slope coefficients from various by-products were divided by the slope coefficient established for alfalfa silage on a given experiment to give the relative effectiveness of by-product NDF compared to alfalfa silage NDF.

Swain et al. (61) reported NDF effectiveness using the slope coefficient method for brewer's grain, oat hulls, corn gluten feed, beet pulp and malt sprouts. Using two experiments, they fed 21 multiparous midlactation Holsteins (DIM not reported) in an incomplete block design with seven treatment diets in three 21 d periods. With concentrate NDF negated, the low NDF alfalfa silage diet was 14.4% nongrain NDF and the high NDF alfalfa silage diet was approximately 21% nongrain NDF. For test diets, they added by-product NDF to basal diet to bring total diet nongrain NDF content to the same level as the high alfalfa silage control. Slope coefficients were calculated for each by-product and alfalfa silage. By-product fiber effectiveness was approximately 50% of alfalfa silage. (Actual coefficients are presented in Table 3.) Milk fat test on low NDF control was 2.5% and on high alfalfa silage control was 3.0%. They reported that added brewer's grain, oat hulls and corn gluten feed raised fat test above basal diet ($P < .01$) but not to the extent of high alfalfa diets ($P < .10$).

Table 3. Effective fiber coefficients for by-products reported by Swain et al. (61) and Vaughan et al. (67).

	Coefficient	Source
Beet pulp	.44	(61)
Brewer grains	.33	(61)
Corn gluten feed	.56	(61)
Ground corn cobs	.45	(67)
Malt sprouts	.47	(61)
Oat hulls	.66	(61)
Wheat middlings	.57	(67)

Vaughan et al. (67) compared the effectiveness of NDF from ground corn cobs and wheat middlings against alfalfa silage using the slope coefficient method. They used three 4 x 4 Latin squares with 21 day periods and 12 multiparous midlactation (DIM not reported) cows. Again, negating concentrate NDF, the four alfalfa silage diets were: (1) the basal diet at 23% nongrain NDF, (2) the added alfalfa diet (high control) at 27.4% nongrain NDF, (3) the added ground corn cobs diet at 29% nongrain NDF, and (4) added wheat middlings diet at 28% nongrain NDF. DMI (25 kg/d) and milk yield (32 kg/d) were not different ($P > .05$) across diets. Milk fat percentages were 3.05%, 3.38%, 3.24%, and 3.27% for diets (1), (2), (3), and (4), respectively. To contrast milk fat tests, three comparisons were used: (3) vs. (4), (3) and (4) vs. (1), and (3) and (4) vs. (2). Only the (3) and (4) vs. (1) contrast was reported to be significant ($P < .05$). Again, slope coefficients were determined and effectiveness of NDF relative to alfalfa silage was calculated to be approximately half. (Actual coefficients are presented in Table 3.)

In 1993, Clark and Armentano (15) reported determinations of effectiveness of NDF using the slope coefficient method for dried distiller's grain (32% NDF) and whole cottonseed (45% NDF) relative to alfalfa silage (43% NDF, MPL = 7.6 mm by dry sieving of wet material). They fed sixteen multiparous Holstein (135 DIM) cows in 4 x 4 Latin squares with 21 d periods. The four diets were: (1) a basal diet 13% NDF with all

NDF from alfalfa silage, (2) a high control alfalfa silage diet at 19% NDF, (3) the basal diet plus dried distiller's grain NDF equaling 6% of diet (total diet = 19% nongrain NDF), and (4) the basal diet plus whole cottonseed NDF equaling 6% of diet (total diet = 19% nongrain NDF). Calculated diet NE_L were 1.77 Mcal/kg for (1), 1.71 Mcal/kg for (2), 1.75 Mcal/kg for (3), and 1.78 Mcal/kg for (4). Contribution of concentrate NDF was negated in diet NDF content calculations. The fat contents (as measured as the sum C14 to C18 fatty acids) of diets were reported as 5.0% for low fiber control, 4.7% for high fiber control and dried distiller's grain added diets and 4.2% for whole cottonseed added diets (standard error not reported). The high control alfalfa diet had lower ($P < .05$) DMI (22.8 kg vs. 24.0 kg), milk production (30.6 kg vs. 32.1 kg) and FCM (27.1 kg vs. 28.2 kg) than other three diets. Milk fat percentages were 3.16%, 3.30%, 3.27%, and 3.34% for the basal diet, high control alfalfa diet, added dried distiller's grain fiber and added whole cottonseed fiber diets, respectively, and were not different ($P > .10$). Ruminal contents were collected by stomach tube once for VFA analysis. Ruminal A:P obtained was higher ($P < .01$) on high control alfalfa diet than other diets (3.7 vs. 2.9). Total chewing activity (measured visually every five minutes for one 24 h period) in minutes per day was higher ($P < .05$) on (2) and (4) than on (1) and (3) (754 min/d vs. 666 min/d). From the numbers reported, total chewing time minutes per kilogram nongrain NDF intake was calculated as 220 min/kg, 176 min/kg, 155 min/kg, and 167 min/kg for (1), (2), (3), and (4), respectively. Using the slope coefficients method, effectiveness of NDF was calculated as .80 for dried distiller's grain and 1.30 for whole cottonseed relative to 1.0 for alfalfa silage. Clark and Armentano concluded the NDF of the by-products was approximately as effective as alfalfa silage in stimulating fat synthesis. They also stated the nonsignificant differences of fat tests lowered the precision but not accuracy of calculated effectiveness factors. However, they cautioned that corroborating studies were needed before the NDF effectiveness factor of 1.3 for whole cottonseed could be recommended for use.

In a follow up study, Clark and Armentano (14) tested the validity of the coefficients they derived. Using a 4 x 4 Latin square design, they fed 16 multiparous Holsteins (DIM not reported) four diets in 21 d periods. Using slope coefficient methods for comparison of diet, they fed a basal diet at 12% nongrain NDF and a high fiber control diet at 22% nongrain NDF with the increase achieved by the addition of alfalfa silage NDF. In contrast to previous work, forage NDF of basal proportion of the diet was not solely from alfalfa silage but from a mix contributing equal amounts of NDF from corn silage and alfalfa silage (NDF contents of forages not reported). The two test diets added a mix of nonforage fiber (dried distiller's grain, whole cottonseed and wheat middlings; mix proportions and NDF contents not reported) to basal forage to achieve total diet nongrain NDF contents of 17% (NFF1) and 22% (NFF2). Based on previous work, they expected the NFF1 diet to have a milk fat response midway between basal and high fiber diets and the NFF2 diet to have a milk fat response equal to the high fiber diet. DMI (22 kg) and milk production (33 kg) was similar on all diets ($P > .05$) but milk fat and milk protein percentages were affected by treatment ($P < .05$). Contrary to prediction, milk fat percentage on NFF2 diet (3.2%) was not equivalent to milk fat percentage of standard diet (3.5%) and milk fat percentage of NFF1 (2.9%) was not midway between standard (3.5%) and basal (2.8%) diets. These results suggest the effectiveness coefficients determined in previous experiments using milk fat percentage were overestimated or that the change in forage base had an effect. Chewing time (min/d) was affected by treatment ($P < .05$) with standard diet (457 min) higher than basal, NFF1, and NFF2 diets (394 min, 375 min, and 409 min, respectively).

Summary

The concept of effective fiber is an attempt to quantify the properties of feedstuff fiber beyond the chemical measurement of fiber. Fiber is effective when it stimulates chewing and salivation for increased milk fat by increased acetate production.

Effectiveness of fiber is determined by the sum of many factors. Reduced forage particle size by chopping too fine or pelleting reduces fiber effectiveness as measured as total chewing per kilogram NDF intake. Lowering NDF content of diet reduces the effectiveness of the diet as measured by total daily chewing activity, but effectiveness of forage as measured by total chewing activity per kilogram remains constant. Increasing maturity of forage tends to increase effectiveness as measured as total chewing activity per kilogram NDF intake. Fiber effectiveness measures may be influenced by such animal factors as species, body size, and intake.

The index of fiber's physical character has been recommended to be time spent chewing per unit of DMI (6). Several effective fiber systems have tried to use this or a correlated substitute based on chemical, physical or production measurements to develop practical ration balancing systems. The use of activity per unit of DMI is a concern because it does not account for the great variation of fiber content across the range of feedstuffs used.

High fiber by-products can be used to supplement diet fiber. WFCS is an attractive fiber supplement because it is also high in protein and energy. By-product NDF effectiveness has been measured by chewing activity, ruminal A:P, or, most commonly, by its ability to correct milk fat depression. By-product NDF is generally less effective than coarse forage NDF but it depends on source of the by-product fiber. The range of effectiveness coefficients have been determined from .33 for dried brewer's grains (61) to 1.3 for WFCS (15).

PURPOSE AND OBJECTIVES

WFCS is widely used in Michigan as dairy feed. Knowing the effectiveness of WFCS NDF is important because the high producing cows that receive WFCS are approaching the lower limits of dietary fiber where accurate fiber balance is important for maximizing energy intake.

The objective of this study was to measure the effectiveness of WFCS NDF relative to alfalfa silage at two lengths of cut using total chews per kilogram NDF intake to calculate effectiveness. Chewing activity was viewed as a direct indicator of NDF effectiveness as the stimulation of chewing activity increases salivation to neutralize the fermentation acids in the rumen. The null hypothesis postulated that WFCS NDF was equal to alfalfa silage NDF in its ability to stimulate chewing activity.

The sub objectives of this experiment were:

1. To compare the number and type of chews from WFCS NDF and alfalfa silage NDF.

2. If differences existed, to examine chewing activity as affected by length of cut by NDF source interactions.

3. To calculate the effective fiber coefficient of whole fuzzy cottonseed relative to alfalfa silage of two chop lengths based on total chew counts divided by intake.

MATERIALS AND METHODS

Experimental Design

An experiment designed as a 4 x 4 Latin square was replicated (n=3) and balanced for carryover effects. Three squares containing twelve midlactation (125 DIM) cows were run concurrently with four consecutive 21 d periods. The four treatments were generated by a 2 x 2 factorial. The factorial design crossed alfalfa silage length of cut ("long" and "short") with WFCS treatment. The long cut alfalfa was obtained with a forage harvester set at a 3/8" (9.5 mm) theoretical length of cut and was typical of material removed from a bunker silo. The short cut alfalfa was a 3/16" (4.8 mm) theoretical cut and was typical of material removed from a bottom unloading upright silo. Treatment with WFCS called for the replacement of 0% or 25% of the forage NDF with WFCS NDF. Each period began with a 14 day adjustment period and ended with a seven day collection period. Treatment assignments to the Latin square are presented in Table 4. This experiment was conducted in the Fall of 1992.

Table 4. Final treatment[1] assignments for the 4 x 4 Latin square used in experiment 92CSM1.

	Period			
Cow	1	2	3	4
1	S0	L0	S+	L+
2	L0	L+	S0	S+
3	S+	S0	L+	L0
4	L+	S+	L0	S0

[1] Where treatments were coded as: L0 = long cut, 0 WFCS, L+ = long cut, + WFCS, S0 = short cut, 0 WFCS, and S+ = short cut, + WFCS.

Cow Description

Twelve midlactation cows from the MSU Dairy Farm were reserved for this experiment. Cows were blocked by parity, days in milk and pre-experiment milk production. Two squares were composed of multiparous cows and one of primiparous cows. At the beginning of the experiment, the twelve cows used in the experiment averaged 125 ± 32 (mean ± standard deviation) days in milk, 593 ± 60 kg in body weight and 41.0 ± 4.6 kg milk produced daily.

Cow Management

Animal use forms were submitted to and approved by the MSU All-University Committee on Animal Use and Care and the MSU Department of Animal Science. During the experiment, cows were housed in the activity monitoring unit at the MSU Dairy Farm. This 12 tie stall setup is located in a barn with a white interior and without windows. The barn also has continuous lighting and ventilation is driven by exhaust fans. Cows were milked in place twice daily at 7 a.m. and 7 p.m. Cows were fed once daily at 9 a.m. At 9 a.m., feed tub access doors were closed. After feed tubs were emptied of orts, filled with fresh TMR, and allowed to stabilize, feed tub access doors were reopened. This process took approximately 40 minutes. Diets were offered for a refusal rate at 5 to 10% to insure ad libitum intakes. During nontest weeks, cows were let out into a cement floored exercise area by square once daily after one milking for exercise and a heat check. During test weeks, the cows remained in the stalls. These tie stalls were bedded twice daily at 5 a.m. and 8 p.m. with shredded phone books.

Forage Harvesting and Preservation

Two alfalfa silages were harvested from a 39 acre field of a second cutting mostly alfalfa forage. The field was mowed and conditioned with a sickle bar mower-conditioner (New Holland Model 1499) and the wilted herbage was chopped the next day with two forage harvesters (New Holland Model 900): one set for a long cut at a theoretical 3/8" cut and one set for a short cut at a theoretical 3/16". Alternating sets of four adjacent windrows, a long cut was harvested first then the short cut was harvested. Each load of herbage from the field was weighed in tared wagons before unloading. With one Ag Bagger™ (Ag Bag Corporation, Astoria, Oregon) fitted with 8' diameter bag, two Ag Bags™ were filled and sealed as per manufacturer directions. Stage of maturity was determined as mean stage by weight (39). Eight samples of 100 to 150 stems were collected from the field and individual stems in each sample were sorted into alfalfa stage, grass or weed categories. Category samples were dried at 55°C then weighed. Percentage dry weight for each category within the sample was calculated and then averaged by category across samples to determine the inputs for the mean stage by weight formula.

Diet Formulation

Experimental diets were composed of alfalfa silage, grain mix, and WFCS. The grain mix contained 78.5% dry ground shell corn, 19.6% soybean meal 44, and 1.9% minerals and vitamins. In diets containing WFCS, 25% of the alfalfa silage NDF was replaced with WFCS NDF. The rations were balanced using Spartan Dairy Ration Balancer 2 (63) to 27% NDF, 12% Absorbable Protein (using default values for UIP), and 1% calcium. The diets were formulated to be isofibrous for NDF and isonitrogenous but not isocaloric. Experimental diets were mixed daily at 7 a.m. To maintain ration specs, diet inputs were monitored for changes. Forage samples were taken daily for dry matter determination. Diet inputs were sampled at the end of each test week and analyzed for 55°C DM content, ash content, NDF content, and CP content. Diet reformulation to experimental specifications occurred as necessary for dry matter and at least once per period for nutrient analyses.

Data Collected

At each milking throughout the experiment, milk production per cow was recorded to the nearest .05 kg. Each day at the beginning of the 9 a.m. feeding, water meter readings were recorded manually for all cows. At the daily feeding, the as fed weight of TMR offered and weight of orts from previous day were recorded to nearest .5 kilograms. Body weights to nearest .5 kilograms of all cows were taken after the morning milking on each of the first two days of the period and on the first two days following the end of period four. Consecutive days were averaged to calculate change in body weight across a period. All cows were given a body condition score (23) to the half score on a 1 to 5 scale by three independent scorers. Scores were taken on the first day of each period and again at the end of the experiment. The scores at each time point were averaged across scorers and used to calculate change in body condition score across a period. Health and reproductive information was recorded at occurrence.

Samples Collected

Milk from all cows was sampled for composition analysis at each milking on days 15, 17, and 19 of each period. Morning and evening milk samples were not composited. After weighing the milk and recording the weight, all milk was poured into another bucket and then all was poured back again. Using a sampling dipper, milk was collected and poured into 6 oz. milk sample bag containing a 40 mg potassium dichromate tablet (Whirl-pak™, Nasco, Fort Atkinson, WI). Samples were sealed and placed in cooler. At the end of test week, all milk samples were taken to Michigan DHI (East Lansing, MI) for analysis for fat, protein, lactose and somatic cell count with infrared spectroscopy. Using DHI milk composition analysis, fat corrected milk (46) and solids corrected milk (Tyrell and Reid (62), assuming .7% ash) were calculated.

During each test week, diet inputs (.5 kg), experimental diets (.5 kg) and individual cow orts (one-eighth of daily orts) were collected daily, frozen, and composited across the test week. At the end of the test week, all composites were dried at 55°C for 48 hours. The entire composite was ground in a Wiley mill (Arthur H. Thomas, Philadelphia, PA) with a 6 mm screen. The 6 mm grind was subsampled by rolling and quartering, ground through a Wiley mill with a 1 mm screen (except WFCS where a 2 mm screen was used for the final grind) and stored in a 120 ml screw top plastic specimen cup at room temperature until analysis. After each grind, the Wiley mills were cleaned and the residue was collected quantitatively.

Sample Analysis

Diet, diet ingredients and ort samples were analyzed for NDF, ADF and AD sulfuric acid lignin sequentially (66), CP as N x 6.25 (32), crude fat (ethyl ether extraction in a modified Soxhlet apparatus for 24 hours) and ash (ignited at 500°C for 5 h). When possible, duplicates were run on separate days. Duplicates were rejected as unacceptable when the coefficient of variation was greater than 1% for sequential fibers, 2% for CP and 5% for crude fat and ash. Concentrations of all nutrients, except DM, were expressed as a percentage of DM determined from forced air oven drying at 105°C. To compare the silages, several additional analyses were performed. On dried ground samples, insoluble nitrogen (41) and in vitro true digestibility (28) at 0 h, 10 h, 20 h, and 120 h were also run. Wet silage composites were also collected during test weeks and frozen. These samples were used to quantify silage acids, silage pH, and silage particle size.

Results of in vitro digestion were used to calculate NDF digestion rate and extent. The fraction of fiber that is indigestible (I) was defined as the residual NDF after 120 hours of in vitro fermentation and was calculated as the 120 hour in vitro NDF residue divided by zero hour NDF. The fraction of fiber that is potentially fermentable (D) was defined as the NDF that disappeared during in vitro fermentation and was calculated as 1 - I. The rate of NDF digestion was calculated as:

$$\text{rate} = \frac{\ln[(X - Z) / D] - \ln[(Y - Z) / D)]}{10 \text{ h.}}$$

where:

X = 10 h in vitro fermentation NDF residue

Y = 20 h in vitro fermentation NDF residue

Z = 120 h in vitro fermentation NDF residue

D = the proportion of NDF that disappeared during in vitro fermentation

Water extraction of wet silage samples was used for measurement of silage pH and silage acid content. A representative wet silage sample of 10.0 grams was blended in 100 ml distilled water with a Sorvall Omni Mixer 17150 (I. Sorvall, Inc., Newtown, CT, USA) for 45 seconds at speed 10. After blending, pH was measured (Digital Ionizer, Orion Research, Inc., Cambridge, MA, USA.) and homogenized samples were squeezed through four layers of cheese cloth into two 50 ml centrifuge tubes. Samples were centrifuged at 20,000x g for 30 minutes. Supernatant was stored frozen until analysis for acid content. Silage lactic, acetic, propionic and butyric acids were measured on a HPLC. The column used was an Aminex HPX-87H (Bio-Rad Laboratories, Richmond, CA). Column temperature was 50°C and solvent was .005 N H_2SO_4. Detection was by refractive index (Waters® 410, Millipore Corp., Milford, MA).

Particle size was determined by wet sieving wet silage containing 5 g of DM following a macro neutral detergent extraction where the ratio of dry matter to neutral detergent solution was 5 g DM to 1 L . Samples were wet sieved through the following screens sequentially: 19000, 9500, 4750, 2360, 1180, 600, 300, 150 and 75 microns. Percent of dry NDF residues by weight by sieve was used to determine mean particle size. Variance was determined by fitting results to a gamma distribution (2).

Electronic Data Collection (EDC)

Cow activities were monitored electronically for 5 days beginning on day 15 of each period. An electronic data acquisition system for continuous monitoring of feed intake, water intake, and chewing activity of 12 cows (18) was used. The computer received and processed three signals for each cow: one from a load cell suspending a feed tub; one from a water flow meter; and one from a pressure sensors on the halter. The calibrated load cell monitored the changing weight of the hanging feed tub. The water flow meter monitored the water sent to each cow's drinking cup. The pressure sensor connected to water filled bladder, which was attached to the halter under mid jaw, monitored the pressure changes caused by the movement of the jaw. All signals sent to the computer were processed and summarized by Labtech Notebook™ to individual cow period print files every 5 seconds.

Calibration, adjustment and repair of equipment were done as needed and actions during test week were recorded for later reference. Daily water meter readings and daily as fed intakes were recorded manually for later comparison to data collected electronically. Cow trainers in the whole barn were kept off during test weeks as their pulse of voltage decreased accuracy of water meter reading. Chew halters were placed on cows one day prior to collection for animal adjustment. Disruption of animal activity was kept to a minimum during test weeks.

Electronic data collection recorded 48 cow period files. These raw data were summarized on an IBM 3090 mainframe computer (International Business Machines Corporation, Armonk, NY) with an interpretive algorithms in SAS® (see Dado and Allen (18) for defining parameters). The resulting eating, ruminating and drinking activity summaries were internally labeled and screened for accuracy using equipment test week logs and manual intake records. Errant data within a day resulting from faulty equipment removed the whole cow day from the final activity data set. Meals and bouts were defined and calculated as per Dado and Allen (19). Using postexperiment lab analysis, dry matter and NDF intakes for each recorded meal was calculated. Corrected (nongrain) NDF content for each diet was calculated by subtracting grain NDF from the total diet NDF. Corrected NDF intake was determined by multiplying DMI by corrected NDF content of diets. With meal information complete, the final activity was summarized by day then averaged by cow and period. Variables summarized included number and length of eating bouts, total eating chews and time, meal size, number and length of ruminating bouts, total ruminating chews and time, number and size of drinking bouts.

Statistical Analysis

Cow period daily averages were analyzed as a replicated (n=3) 4 x 4 Latin square with cows nested within squares using JMP® Version 2 (37; SAS Institute, Inc. Cary, NC) . Preplanned orthogonal contrasts were used to determine the significance of the main treatment effects of length of cut, WFCS treatment and their interaction. Another set of preplanned orthogonal contrasts compared squares. Model effects were declared significant when $P < .05$. The degrees of freedom for each source of variation in this experiment are presented in Table 5. Composition of silage was compared by unpaired t test on period means. Pearson correlations (37) were run on selected activity variables.

Table 5. Degrees of freedom for each source of variation.

Source of Variation	Degrees of Freedom
Square	2
Orthogonal contrasts:	
primiparous vs. multiparous	(1)
multiparous 1 vs. multiparous 2	(1)
Cow in square	9
Period	3
Treatment	3
Orthogonal contrasts:	
chop length (L0, L+ vs. S0, S+)[1]	(1)
whole cottonseed (L+, S+ vs. L0, S0)	(1)
interaction (L+, S0 vs. L0, S+)	(1)
Error	30
Total	47

[1]Where treatments were coded as: L0 = long cut, 0 WFCS, L+ = long cut, + WFCS, S0 = short cut, 0 WFCS, and S+ = short cut, + WFCS.

Calculation of Fiber Effectiveness Coefficient

The calculation of the effectiveness coefficient for WFCS fiber was based on the total chews per kilogram NDF intake of alfalfa silage and WFCS within length of cut. The formula was:

$$eNDF = \frac{A-(1-B)(C)}{(B)(C)}$$

where:

A = total chews per kilogram corrected NDF intake of diet containing WFCS

B = the measured proportion of alfalfa silage NDF replaced by WFCS NDF.

C = total chews per kilogram corrected NDF intake of diet without WFCS.

The three assumptions in the calculation are: a linear relationship exists between total chews per day and alfalfa silage NDF intake for the range of intakes in this study, all chews were due to alfalfa silage NDF and WFCS NDF and not grain mix NDF, and the number of chews was negligible at 0 NDF intake. For comparison, WFCS effectiveness coefficients were calculated for each length of cut. Total chews were defined as the sum of the daily averages of eating and ruminating chews on a given treatment. Kilograms corrected NDF intake was the total NDF intake minus the NDF associated with the grain mix. The numerator is the total chews per kilogram corrected NDF intake attributed to WFCS NDF and the denominator is the total chews per kilogram corrected NDF intake attributed to alfalfa silage. This calculation is illustrated graphically in Figure 3.

The 95% confidence interval of the true mean for total chews per kilogram corrected NDF intake was calculated for each treatment. These ranges were used to calculate the range of eNDF values of WFCS for each length of cut. Also, eNDF coefficients were calculated in the same manner using total chewing time instead of total chews.

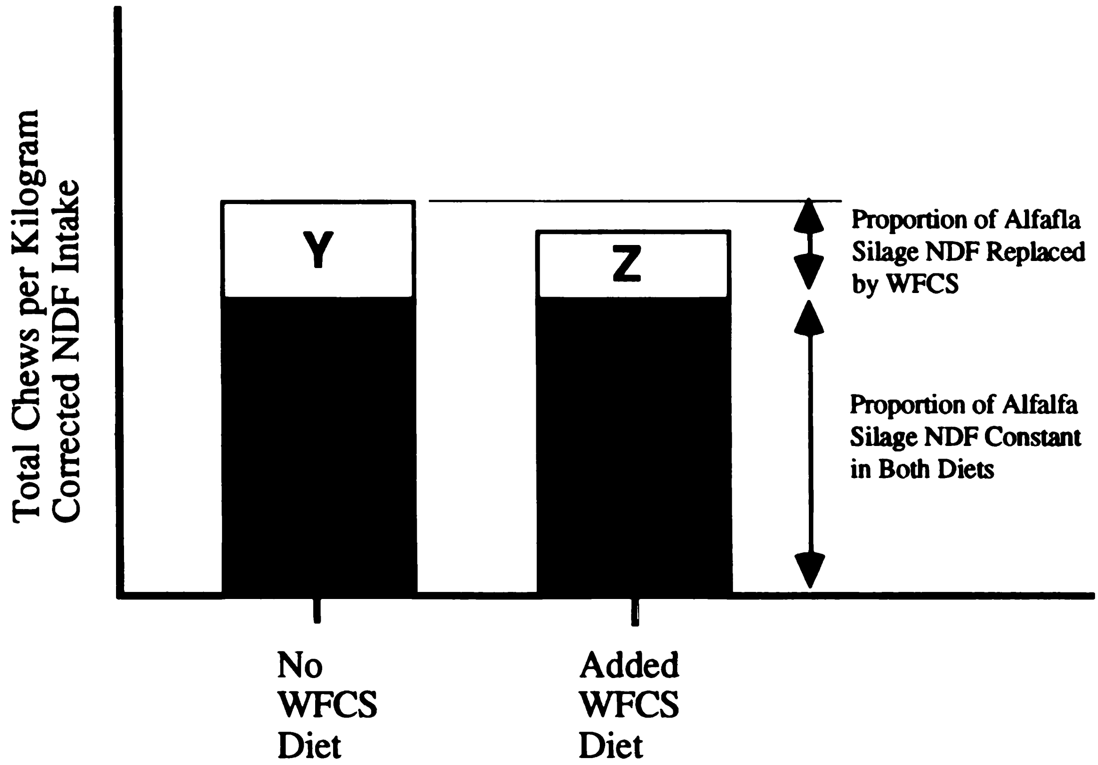

Figure 3. Graphical representation of the formula used to partition the total chews per kilogram corrected NDF intake. The calculation of fiber effectiveness is Z divided by Y where Z = the proportion of chews attributed of WFCS NDF = A-(1-B)(C), Y = the proportion of chews attributed the replaced alfalfa silage NDF = (B)(C), A = total chews per kilogram corrected NDF intake of diet containing WFCS, B = the measured proportion of alfalfa silage NDF replaced by WFCS NDF, and C = total chews per kilogram corrected NDF intake of diet without WFCS.

RESULTS

Comparison of Silages

The field used in this experiment was composed of 88.0% alfalfa, 10.2% grass and 1.8% weeds on a dry matter basis. The alfalfa mean stage by weight was determined to be 4.6, which is between late bud ("4") and early flower ("5"). About six metric tons of dry matter were harvested for each length of cut. The long cut silage was twice the MPS (11.4 mm vs. 5.8 mm, $P < .01$) of the short cut silage. Measurements made on samples collected during the experiment (Table 6) revealed the silages were similar ($P > .05$) in NDF content (42%), NDF indigestibility (44%), rate of NDF digestion (9%/h), ADF content (28%), lignin content (6.6%), CP content (22%), insoluble CP content (9.7%), ash content (9%), and crude fat content (3%). The long cut silage was also wetter (38% DM vs. 50% DM, $P <.01$), lower in pH (4.53 vs. 4.85, $P <.01$) and contained more lactate (6.58% of DM vs. 3.65% of DM, $P < .01$), more acetate (1.78% of DM vs. .91% of DM, $P < .01$) and more propionate (.29 % of DM vs. .20 % of DM, $P < .01$) than the short cut silage. Table 7 presents the average percentage across periods of dry weight of macro NDF residue retained on standard sieves following wet sieving for each silage. After fitting wet sieving results to a gamma distribution, the standard deviation of particle size across periods for the long cut was ± 2.6 mm and for the short cut was ± .7 mm.

Table 6. Description of long and short cut alfalfa silages.

	Length of Cut			
	long	short	SE	P[1]
Kg harvested				
wet	32840	23140	-	-
dry	12560	11610	-	-
55°C DM %	37.6	49.5	.5	**
NDF, % of DM	42.4	41.9	.5	NS
In vitro NDF digestibility, %[2]	56.3	55.3	1.0	NS
In vitro NDF indigestibility, %[3]	43.7	44.7	1.0	NS
Rate of NDF digestion(%/hour)	9.5	8.8	.4	NS
ADF, % of DM	28.3	28.4	.5	NS
Lignin, % of DM	6.46	6.70	.22	NS
Mean particle size, mm[4]	11.4	5.8	.9	**
CP, % of DM	22.6	22.1	.4	NS
Insoluble CP, % of DM[5]	9.76	9.72	.22	NS
pH	4.53	4.85	.03	**
Acids, % of DM				
lactic	6.58	3.65	.16	**
acetic	1.78	.91	.05	**
propionic	.29	.20	.02	**
butyric	nd[6]	nd	-	-
Ash, % of DM	8.4	9.5	.4	NS
Crude fat, % of DM	2.9	2.9	.3	NS

[1]Statistical comparisons were done by unpaired t-test.

[2]Proportion of original NDF content disappearing after 120 h in vitro fermentation.

[3]Proportion of NDF residue remaining after 120 h in vitro fermentation.

[4]As determined by wet sieving

[5]Solvent was borate phosphate buffer as per Krishnamoorthy et al. (41)

[6]nd = not detected

*$P < .05$

**$P < .01$

Table 7. Average percentage across periods of NDF residue retained on standard sieves following wet sieving by length of cut.

	Percentage of NDF retained	
screen size (μm)	long length of cut	short length of cut
19000	15	4
9500	31	12
4750	31	24
2360	11	32
1180	4	13
600	2	5
300	2	5
150	2	3
75	2	3

Ingredient and Diet Composition

Ingredient and diet composition are presented in Tables 8 and 9. Values represent average ingredient and nutrient composition from across the entire experiment. Postexperiment analysis of diet composites revealed diet NDF contents higher than expected. During the experiment, grain mix NDF was estimated to be 10%. However, in postexperiment NDF analysis, the grain mix NDF content of 15% was observed. The higher total diet NDF contents are due almost solely to the higher than estimated grain mix NDF content and, to a lesser extent, higher WFCS NDF content. The postexperiment analysis of WFCS NDF was 55% compared to the preexperiment value of 47%. The reason for this increase is unknown by one may speculate that this is an error in sampling. All other experiment and postexperiment measurements agree.

Table 8. Nutrient composition of forages and concentrates as measured during the experiment for diet formulation and after experiment on test week composites.

	LONG[1]	SHORT	WFCS	Grain mix[2]
During experiment				
55°C DM %	37.2	48.9	89.4	nd[3]
Ash, % of DM	8.29	8.98	3.60	nd
CP, % of DM	22.96	22.60	20.43	nd
NDF, % of DM	41.07	40.37	47.28	nd
After experiment				
55°C DM %	36.7	49.0	89.1	88.6
Crude fat, % of DM	2.95	2.92	19.34	2.88
Ash, % of DM	8.41	9.47	3.84	4.91
CP, % of DM	22.57	22.12	20.06	16.79
NDF, % of DM	41.77	42.23	54.81	14.77
ADF, % of DM	28.28	28.38	35.27	4.15
Lignin, % of DM	6.45	6.70	11.01	.59

[1]LONG = long cut alfalfa silage, SHORT = short cut alfalfa silage, WFCS = whole fuzzy cottonseed

[2]Grain mix contained 78.5% dry ground shelled corn, 19.6% soybean meal 44, .5% dicalcium phosphate, .5% limestone, .5% trace mineral salt, .2% magnesium oxide and .2% vitamin and trace mineral supplements.

[3]nd = not determined

Table 9. Ingredient and nutrient composition of diets by treatment as balanced during experiment and as measured postexperiment on test week composites.

	Treatment[1]				
	L0	L+	S0	S+	SE
Ingredients, % DM of diet					
Alfalfa hay crop silage	55.29	40.99	55.29	40.99	
WFCS	-	11.89	-	11.89	
Grain Mix[2]	44.72	46.69	44.72	46.69	
Limestone	-	.43	-	.43	
Composition, as balanced during experiment					
55°C DM %	49.20	55.63	59.60	65.15	
CP, % of DM	20.17	19.76	20.17	19.76	
Absorbable CP, % of DM	11.49	12.06	11.49	12.06	
NDF, % of DM	26.98	26.92	26.98	26.92	
Ca, % of DM	1.03	1.00	1.03	1.00	
Composition, as measured postexperiment					
55°C DM %	50.1	56.3	60.9	66.1	1.11
Crude fat, % of DM	3.26	5.29	2.93	4.90	.26
Ash, % of DM	6.87	6.68	7.62	7.05	.40
CP, % of DM	20.01	19.25	19.44	19.63	.65
NDF, % of DM	29.64	30.95	30.90	30.75	.91
ADF, % of DM	17.30	18.15	18.05	17.88	.65
Lignin, % of DM	3.70	4.20	3.99	4.32	.25
Corrected NDF, % of DM[3]	23.03	24.05	24.29	23.85	nd[4]

[1]Treatment codes are: L0 = long cut, no WFCS, L+ = long cut, added WFCS, S0 = short cut, no WFCS, and S+ = short cut, added WFCS.

[2]Grain mix contained 78.5% dry ground shelled corn, 19.6% soybean meal 44, .5% dicalcium phosphate, .5% limestone, .5% trace mineral salt, .2% magnesium oxide and .2% vitamin and trace mineral supplements.

[3]corrected NDF = Total NDF - Grain NDF

[4]nd = not determined.

Milk Production and Composition

Milk production and composition data are presented in Table 10. Length of cut did not effect (*P* < .05) milk yield or composition. Cottonseed addition increased milk yields (35.5 kg vs. 33.7 kg, *P* < .01) but did not effect (*P* > .05) milk composition. Cottonseed addition also increased (*P* < .05) 3.5% FCM (35.4 kg vs. 33.5 kg), 4.0% FCM (32.8 kg vs. 31.1 kg), and SCM (33.1 kg vs. 31.5 kg). There were no interactions (*P* > .05) between length of cut and WFCS treatment on milk yield or composition.

Feed Intake, Body Weight and Condition, and Cow Health

Intake and body weight and condition data are presented in Table 11. Manual (7 day averages) DM and water intakes agree closely with electronic data collection (EDC) intakes (5 day averages). Long length of cut had lower EDC DMI (23.5 kg vs. 24.3 kg, *P* < .05) and lower water intakes (85 L vs. 92 L, *P* < .01) when compared to short length of cut. Added WFCS increased EDC dry matter (24.8 kg vs. 23.0 kg, *P* < .01) and water intakes (90 L vs. 86 L, *P* < .01). NDF intake was proportional to DMI. An interaction of length of cut and WFCS (*P* < .05) made the difference of EDC DMI of the two short cut diets (2.7 kg) greater than the difference of the two long cut diets (.8 kg). Change in body weight and change in body condition score across periods were unaffected (*P* > .05) by length of cut or WFCS treatment. Incidence of health problems is presented in Table 12. With the exception of one displaced abomasum, all cows were healthy during the experiment. The cow with the displaced abomasum was not removed from the study, but only one day of data was used for the period in which the displaced abomasum occurred.

Table 10. Effect of treatment on milk production and composition means.

	Treatment[1]					Effect[2]		
	L0	L+	S0	S+	SE	L	C	L x C
Milk Yield, kg/d								
Actual	34.3	35.7	33.0	35.2	.6	NS	**	NS
FCM, 3.5%	34.1	35.6	32.9	35.1	.8	NS	*	NS
FCM, 4.0%	31.7	33.0	30.5	32.6	.7	NS	*	NS
SCM	32.0	33.2	30.5	33.0	.7	NS	*	NS
Milk Composition								
Fat, %	3.48	3.49	3.54	3.49	.08	NS	NS	NS
Protein, %	3.27	3.27	3.21	3.30	.05	NS	NS	NS
Lactose, %	4.85	4.78	4.77	4.88	.05	NS	NS	NS
SNF, %	8.84	8.76	8.69	8.89	.09	NS	NS	NS
SCC, 1000's/ml	62	61	56	60	7	NS	NS	NS

[1]Treatment codes are: L0 = long cut, no WFCS, L+ = long cut, added WFCS, S0 = short cut, no WFCS, and S+ = short cut, added WFCS.

[2]L = Main effect of length of cut; C = Main effect of WFCS treatment; L x C = Interaction of length of cut and WFCS treatment.

*$P < .05$

**$P < .01$.

Table 11. Effect of treatment on intake, body weight, and body condition.

	Treatment[1]					Effect[2]		
	L0	L+	S0	S+	SE	L	C	L x C
Dry Matter Intake, kg/d								
Manual	23.3	25.0	23.0	25.8	.7	NS	**	NS
EDC[3]	23.1	23.9	22.9	25.6	.4	*	**	*
Water Intake, L/d								
Manual	82.4	87.5	89.6	94.8	1.2	**	**	NS
EDC	82.0	86.9	89.6	94.1	1.3	**	**	NS
NDF Intake, kg/d								
EDC	6.8	7.4	7.1	7.9	.1	**	**	NS
corrected[4]	5.3	5.7	5.5	6.1	.1	*	**	NS
Body Wt. Change, kg	11	13	10	17	5	NS	NS	NS
Body Condition Change[5]	.11	.08	.02	.08	.06	NS	NS	NS

[1]Treatment codes are: L0 = long cut, no WFCS, L+ = long cut, added WFCS, S0 = short cut, no WFCS, and S+ = short cut, added WFCS.

[2]L = Main effect of length of cut; C = Main effect of WFCS treatment; L x C = Interaction of length of cut and WFCS treatment.

[3]EDC = electronic data collection

[4]corrected NDF intake = total grain NDF minus grain NDF

[5]on 1 to 5 scale (23)

*$P < .05$

**$P < .01$.

Table 12. Summary of animal health data during experiment listing the number of occurrences during each treatment.

	Treatment[1]			
Problem	L0	L+	S0	S+
Subdermal milk vein rupture	0	0	0	1
Traumatized teat end	1	0	0	0
Displaced abomasum	0	0	1	0
Cystic ovaries	1	0	0	0
Clinical mastitis	0	0	0	0
Clinical ketosis	0	0	0	0

[1]Treatment codes are: L0 = long cut, no WFCS, L+ = long cut, added WFCS, S0 = short cut, no WFCS, and S+ = short cut, added WFCS.

Chewing Activity

Eating, ruminating and total activity means by treatment are presented in Tables 13, 14 and 15, respectively. All 48 cow periods are represented and 92% (220 out of 240) of the cow days were successfully collected. Eating activity was affected by length of cut and WFCS treatment. Long length of cut increased eating chews when measured per day (17197 vs. 15520, $P < .01$), per eating bout (1798 vs. 1534, $P < .05$), per kilogram DMI (742 vs. 650, $P < .01$), per kilogram NDF intake (2460 vs. 2108, $P < .01$), and per kilogram corrected NDF intake (3169 vs. 2711, $P < .01$). Long length of cut increased eating time in minutes per day (273 vs. 248, $P < .01$), per eating bout (28.4 vs. 24.6, $P < .01$), per kilogram DMI (11.8 vs. 10.4, $P < .01$), per kilogram NDF intake (39.0 vs. 33.7, $P < .01$), and per kilogram corrected NDF intake (50.2 min vs. 43.4 min, $P < .01$). Length of cut did not effect ($P > .05$) number of eating bouts per day (10.5), meal size in kilogram dry matter (2.4 kg) or kilogram NDF (.73 kg) or intermeal interval (115 min). The addition of WFCS to treatment diets decreased eating chews as measured per day (15654 vs. 17064, $P < .01$), per kilogram DMI (638 vs. 752, $P < .01$), per kilogram NDF intake (2070 vs. 2498, $P < .01$), and kilogram corrected NDF intake (2671 vs. 3209, $P < .01$). The addition of WFCS to treatment diets also decreased eating time in minutes per day (252 min vs. 270 min, $P < .01$), per kilogram DMI (10.2 min vs. 11.9 min, $P < .01$), per kilogram NDF intake (33.3 min vs. 39.4 min, $P < .01$), and per kilogram corrected NDF intake (43.0 min vs. 50.6 min, $P < .01$). However, the addition of WFCS did not effect ($P > .05$) the number of eating chews per bout (1666), minutes per eating bout (26.5 min) or number of eating bouts per day (10.5). The addition of WFCS increased average meal size in kilogram dry matter (2.5 kg vs. 2.4 kg, $P < .05$) and kilogram NDF (.76 kg vs. .70 kg, $P < .01$). Cottonseed treatment had no effect ($P > .05$) on eating chew rate (61.6 chews per min) or intermeal interval (115 min). A length of cut and WFCS interaction was observed for daily measures of eating chews ($P < .05$) and time ($P < .01$). Eating chews and time on short diets (15678 chews and 250 min for short cut, no WFCS diet vs. 15363 chews and 247 min for short cut, added WFCS diet) were close, whereas, eating chews and time on long cut diets were not (18449 chews and 289 min for long cut, no WFCS diet vs. 15945 chews and 257 min for long cut, added WFCS diet). However, dividing by unit of intake removed the interaction.

Ruminating activity as affected by treatment is presented in Table 14. Long length of cut had more ruminating chews and time per day than short length of cut (30484 vs. 28062; 491 min vs. 460 min, respectively, $P < .01$). Relationships continued when corrections were made for DMI, NDF intake and corrected NDF intake. Ruminating time per bout and chews per bout were similar across treatments (32.2 min and 1978 chews, respectively, $P > .05$) but long length of cut had one more ruminating bout per day (15.4 vs. 14.6, $P < .05$). The increase in ruminating bouts per day reduced the mean time between ruminating bouts (61.6 min vs. 68.0 min, $P < .01$). The addition of WFCS to the diets did not change ($P > .05$) ruminating chews per day (29273), ruminating chews per kilogram DMI (1239), ruminating time per day (475.3 min), ruminating chews per bout (1978), ruminating time per bout (32.2 min), ruminating bouts per day (15.0), or the mean time between ruminating bouts (65 min). However, the addition of WFCS reduced ruminating chews per kilogram NDF intake (3927 vs. 4204, $P < .05$), ruminating chews per kilogram corrected NDF intake (5068 vs. 5407), ruminating time per kilogram DMI (19.6 min vs. 20.7 min, $P < .01$), ruminating time per kilogram NDF intake (64.6 min vs. 68.8 min, $P < .01$), and ruminating time per kilogram corrected NDF intake (82.0 min vs. 88.5 min, $P < .01$). An interaction of length of cut and WFCS treatment was observed for ruminating chews per day ($P < .01$), ruminating time per day ($P < .05$), and ruminating chews per kilogram NDF intake ($P < .05$). Ruminating chew rate was unaffected by treatment (61.01 chews/min, $P > .05$).

Total chewing activities, the sum of eating and ruminating activities, are reported in Table 15. Long length of cut had greater total chews and total chewing time ($P < .01$) per day (47680 vs. 43582 and 764 min vs. 708 min, respectively), per kilogram DMI

(2046 vs. 1823 and 32.8 min vs. 29.6 min, respectively), per kilogram NDF intake (6780 vs. 5920 and 108.6 min vs. 96.3 min, respectively), and per kilogram corrected NDF intake (8740 vs. 7614; 140.2 min vs. 128.8 min, respectively). Addition of WFCS did not change total chews or total chewing time (45631 chews, 736.0 min, respectively, $P > .05$), but did reduce total chews per kilogram DMI (1850 vs. 2020, $P < .01$), total chews per kilogram NDF intake (5998 vs. 6702, $P < .01$), total chews per kilogram corrected NDF intake (7738 vs. 8616, $P < .01$), total chewing time per kilogram DMI (29.8 min vs. 32.6 min, $P < .01$), total chewing time per kilogram NDF intake (96.8 min vs. 108.2 min, $P < .01$), and total chewing time per kilogram correcting NDF intake (125.0 min vs. 139.0 min, $P < .01$).

An interaction was observed for length of cut and WFCS treatment for total chews and total chewing time per day ($P < .01$). For the long length of cut, the addition of WFCS decreased total chews per day (49376 vs. 45985) and total chewing time per day (785 min vs. 742 min) and, for short length of cut, the addition of WFCS increased total chews per day (42492 vs. 44671) and total chewing time per day (697 min vs. 719 min). The interaction was not observed when total chews and total chewing time were divided by kilograms DMI. Length of cut and WFCS treatment interaction was observed ($P < .05$) for total chews per kilogram NDF intake and total chews per kilogram corrected NDF intake with the effect of cottonseed addition being greater for the long cut than the short cut. A trend ($P < .10$) for a similar interaction was found for total chewing time per kilogram NDF intake and per kilogram corrected NDF intake.

Table 13. Eating activity as affected by treatment.

	Treatment[1]					Effect[2]		
	L0	L+	S0	S+	SE	L	C	L x C
Eating Chews								
/d	18449	15945	15678	15363	527	**	*	*
/bout	1940	1657	1563	1504	102	*	NS	NS
/kg DMI	810	673	695	604	27	**	**	NS
/kg NDFI	2744	2177	2252	1964	87	**	**	NS
/kg corrected NDFI	3527	2811	2891	2531	113	**	**	NS
Eating Time, min								
/d	289	257	250	247	5	**	**	**
/bout	30.1	26.7	24.9	24.2	1.2	**	NS	NS
/kg DMI	12.7	10.8	11.1	9.7	.3	**	**	NS
/kg NDFI	42.9	35.0	35.8	31.6	1.0	**	**	NS
/kg corrected NDFI	55.1	45.2	46.0	40.7	1.3	**	**	NS
Eating Bouts, /d	10.4	10.2	10.6	10.6	.3	NS	NS	NS
Meal Size								
kg DM	2.4	2.5	2.3	2.5	.1	NS	*	NS
kg NDF	.70	.77	.70	.76	.02	NS	**	NS
Chew Rate, chews/min	62.6	61.0	61.3	61.3	1.3	NS	NS	NS
Intermeal Interval, min	114.7	118.2	113.8	112.9	4.3	NS	NS	NS

[1]Treatment codes are: L0 = long cut, no WFCS, L+ = long cut, added WFCS, S0 = short cut, no WFCS, and S+ = short cut, added WFCS.

[2]L = Main effect of length of cut; C = Main effect of WFCS treatment; L x C = Interaction of length of cut and WFCS treatment.

*$P < .05$

**$P < .01$.

Table 14. Ruminating activity as affected by treatment.

	Treatment[1]					Effect[2]		
	L0	L+	S0	S+	SE	L	C	L x C
Ruminating Chews								
/d	30927	30040	26815	29308	612	**	NS	**
/bout	1996	1987	1914	2011	48	NS	NS	NS
/kg DMI	1347	1263	1187	1160	30	**	NS	NS
/kg NDFI	4563	4077	3846	3777	103	**	*	*
/kg corrected NDFI	5876	5266	4938	4869	136	**	*	NS
Ruminating Time, min								
/d	496	486	447	472	7	**	NS	*
/bout	32.1	32.2	31.9	32.4	.7	NS	NS	NS
/kg DMI	21.6	20.5	19.8	18.7	.4	**	**	NS
/kg NDFI	73.4	66.2	64.1	60.9	1.4	**	**	NS
/kg corrected NDFI	94.6	85.5	82.4	78.6	1.9	**	**	NS
Ruminating Bouts, /d	15.6	15.2	14.4	14.8	.3	*	NS	NS
Chew Rate, chews/min	61.8	61.3	59.6	61.4	.8	NS	NS	NS
Interruminating Interval, min[3]	60.5	62.8	70.1	65.8	1.8	**	NS	NS

[1]Treatment codes are: L0 = long cut, no WFCS, L+ = long cut, added WFCS, S0 = short cut, no WFCS, and S+ = short cut, added WFCS.

[2]L = Main effect of length of cut; C = Main effect of WFCS treatment; L x C = Interaction of length of cut and WFCS treatment.

[3]Interruminating interval is the elapsed time between the end of one ruminating bout and the start of next ruminating bout.

*$P < .05$

**$P < .01$.

Table 15. Total activity as affected by treatment.

	Treatment[1]					Effect[2]		
	L0	L+	S0	S+	SE	L	C	L x C
Total Chews								
/d	49376	45985	42492	44671	902	**	NS	**
/kg DMI	2157	1936	1882	1764	47	**	**	NS
/kg NDFI	7307	6254	6098	5741	163	**	**	*
/kg corrected NDFI	9404	8077	7829	7400	216	**	**	*
Total Chewing Time, min								
/d	785	742	697	719	7	**	NS	**
/kg DMI	34.3	31.3	30.8	28.4	.6	**	**	NS
/kg NDFI	116.2	101.1	100.0	92.5	2.1	**	**	NS
/kg corrected NDFI	149.7	130.6	128.4	119.3	2.8	**	**	NS

[1]Treatment codes are: L0 = long cut, no WFCS, L+ = long cut, added WFCS, S0 = short cut, no WFCS, and S+ = short cut, added WFCS.

[2]L = Main effect of length of cut; C = Main effect of WFCS treatment; L x C = Interaction of length of cut and WFCS treatment.

*$P < .05$

**$P < .01$.

Drinking Activity

Drinking activity as affected by treatment is presented in Table 16. All 48 cow periods are represented and 98% (236 out 240) of the cow days represented. Short length of cut increased water intake (91.8 L/d vs. 84.4 L/d, $P < .01$), increased the number of drinking bouts per day (16.6 vs. 15.3, $P < .01$), and time spent drinking each day (17.2 min vs. 15.7 min, $P < .01$). Short length of cut diets also had a shorter interval between drinking bouts (94 min vs. 104 min, $P < .05$). WFCS addition increased water intake (90.5 L vs. 85.8 L, $P < .01$), increased drinking time (17.1 min vs. 15.8 min , $P < .01$), and increased drinking bout length (1.18 min vs. 1.08 min, $P < .05$). Interaction between length of cut and WFCS treatment was observed for daily drinking time ($P < .05$). Length of cut and WFCS treatment had no effect ($P > .05$) on drinking rate (5.35 L/min.) or drinking bout size (6.17 L).

Correlations

Pearson correlation coefficients among the 48 cow period means of 22 feeding activity variables are presented in Table 17. Due to the experimental design, a high correlation was found between DMI and NDF intake ($r = .96$) and, therefore, the variables produced when any feeding activity was divided by both DMI and NDF intake had a similar correlation coefficients with any other variable of comparison. Measures of number of chews per day and time spent chewing within a type of activity were highly correlated ($r = \geq .85$). The three ways used to measure eating chews (per day, per kilogram DM and per kilogram NDF) were highly correlated ($r = \geq .85$) with each other. All activities (eating, ruminating and total) measured with number of chews and time spent chewing were highly correlated ($r = \geq .85$) with each other when divided by kilogram DM and kilogram NDF.

Table 16. Drinking activity as affected by treatment.

	Treatment[1]					Effect[2]		
	L0	L+	S0	S+	SE	L	C	L x C
Water Intake, L/d	82.0	86.9	89.6	94.1	1.3	**	**	NS
Drinking Time, min/d	15.4	16.0	16.2	18.2	.3	**	**	*
Drinking Bouts, /d	15.8	14.8	16.6	16.6	.4	**	NS	NS
Drinking Bout Size, L	5.9	6.5	6.1	6.1	.2	NS	NS	NS
Drinking Bout Length, min	1.08	1.19	1.09	1.18	.04	NS	*	NS
Drinking Rate, L/min	5.3	5.4	5.5	5.2	.1	NS	NS	NS
Interdrink Interval, min	102.9	104.5	97.2	90.9	4.2	*	NS	NS

[1]Treatment codes are: L0 = long cut, no WFCS, L+ = long cut, added WFCS, S0 = short cut, no WFCS, and S+ = short cut, added WFCS.

[2]L = Main effect of length of cut; C = Main effect of WFCS treatment; L x C = Interaction of length of cut and WFCS treatment.

*$P < .05$

**$P < .01$.

Table 17. Pearson correlation coefficients among 48 cow period means of various feeding activity variables.[1]

	Variable Number																				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)
Intake																					
(1) DM, kg/d																					
(2) NDF, kg/d	.96																				
Eating chews																					
(3) /d	-.12	-.15																			
(4) /kg DM	-.58	-.58	.86																		
(5) /kg NDF	-.58	-.62	.86	.99																	
Eating time																					
(6) min/d	-.03	-.08	.90	.74	.75																
(7) min/kg DM	-.64	-.65	.76	.95	.95	.77															
(8) min/kg NDF	-.62	-.69	.75	.92	.95	.77	.98														
Bouts/d																					
(9) Eating	.16	.19	-.30	-.32	-.33	-.41	-.40	-.41													
(10) Ruminating	-.11	-.12	.16	.19	.19	.26	.25	.25	-.12												
Ruminating chews																					
(11) /d	.07	.08	.42	.29	.28	.31	.19	.17	-.15	.37											
(12) /kg DM	-.60	-.56	.46	.67	.65	.31	.63	.59	-.25	.36	.74										
(13) /kg NDF	-.61	-.63	.49	.69	.70	.35	.65	.66	-.27	.36	.71	.98									
Ruminating time																					
(14) min/d	-.08	-.07	.31	.29	.28	.15	.17	.17	-.05	.29	.89	.74	.73								
(15) min/kg DM	-.75	-.71	.34	.65	.64	.17	.61	.59	-.17	.26	.53	.93	.91	.70							
(16) min/kg NDF	-.74	-.76	.36	.66	.68	.21	.63	.65	-.19	.26	.50	.89	.93	.68	.97						
Total chews																					
(17) /d	-.01	-.02	.78	.63	.61	.65	.51	.49	-.25	.33	.89	.74	.73	.77	.54	.52					
(18) /kg DM	-.65	-.62	.70	.89	.87	.55	.84	.81	-.31	.31	.59	.93	.93	.59	.88	.86	.75				
(19) /kg NDF	-.64	-.67	.71	.89	.90	.57	.85	.86	-.32	.31	.56	.90	.94	.57	.86	.89	.73	.98			
Total chewing time																					
(20) min/d	-.08	-.09	.70	.60	.60	.63	.53	.52	-.24	.36	.86	.75	.75	.86	.64	.64	.94	.74	.74		
(21) min/kg DM	-.78	-.76	.56	.85	.84	.45	.84	.82	-.28	.28	.44	.90	.90	.55	.94	.93	.58	.96	.95	.66	
(22) min/kg NDF	-.76	-.81	.56	.84	.86	.47	.84	.86	-.30	.28	.41	.85	.90	.52	.90	.95	.56	.92	.96	.65	.97

[1]Significant correlation (P<.01) for variables greater than .37 or less than -.37. Significant correlation (P<.05) for variables greater than .28 or less than -.28.

Results of eNDF Calculations

Results of fiber effectiveness calculations are shown in Table 18. The measured proportion of alfalfa silage NDF replaced by WFCS NDF was .27. Using total chews per kilogram corrected NDF intake, effectiveness coefficients were calculated as .48 for WFCS NDF in long alfalfa silage and .80 for WFCS NDF in short alfalfa. To calculate the range for eNDF coefficients, the 95% confidence interval of the true treatment means were determined as the measured treatment means ±137 chews. Using these ranges to calculate the ranges of effectiveness coefficients, the eNDF of WFCS in long cut alfalfa silage was maximum at .58 and minimum at .38, and the eNDF of WFCS in short cut alfalfa silage was maximum at .93 and minimum at .67. The effectiveness of short alfalfa NDF relative to long alfalfa NDF was calculated as .835 ± .025 (7829 (= total chews per kilogram corrected NDF intake for short cut, no WFCS) ÷ 9404 (= total chews per kilogram corrected NDF intake for long cut, no WFCS)).

Using similar equations, total chewing time per kilogram corrected NDF intake was used to calculate effectiveness coefficients. eNDF of WFCS in long alfalfa silage was .53 ± .08, eNDF of WFCS in short alfalfa silage was .74 ± .10 and short alfalfa silage NDF relative to long alfalfa silage NDF was .86 ± .02.

Table 18. Fiber effectiveness coefficients calculated in this experiment.

	Calculated by Total Activity as recorded	
	by Chews	by Time
Fiber effectiveness of WFCS in long length of cut	.48	.53
Fiber effectiveness of WFCS in short length of cut	.80	.74
Fiber effectiveness of short length of cut relative to long length of cut	.84	.86

Comparison of Responses by Square

A comparison of responses by square is presented in Table 19. Preplanned orthogonal contrasts revealed differences between the primiparous square (square 3) and the multiparous squares (square 1 and 2) and between the two multiparous squares.

When compared with the multiparous squares, the primiparous square produced less milk (32.7 kg vs. 35.5 kg, $P < .01$) of similar milk fat content (3.5%, $P > .05$), ate less DM (23.0 kg vs. 24.4 kg, $P < .01$), less NDF (7.0 kg vs. 7.4 kg, $P < .01$), and less corrected NDF (5.4 kg vs. 5.8 kg, $P < .01$) per day in larger meals (2.6 kg DM vs. 2.3 kg, $P < .01$), and drank less water (80.4 L/d vs. 92.0 L/d, $P < .01$) in less time (15.6 min/d vs. 16.9 min/d, $P < .01$). The primiparous square ate and drank fewer times per day (9.4 vs. 11.0 and 14.8 vs. 16.6, respectively, $P < .01$) but ruminated more times per day (16.3 vs. 14.4, $P < .01$). The primiparous square chewed more times per day and per kilogram corrected NDF intake ($P < .01$) while eating, ruminating and overall.

A comparison of the multiparous squares revealed that Square 2 produced more milk (37 kg vs. 34 kg, $P < .01$) of similar milk fat (3.5%, $P > .05$), ate ($P < .05$) and drank ($P < .01$) more total in fewer ($P < .01$) bouts per day than Square 1. Chewing activity per day was similar ($P > .05$) between these two squares, but the higher intake of the Square 2 reduced ($P < .05$) ruminating and total chews per kilogram corrected NDFI.
Because treatment effects were significant ($P < .05$) within square 2 and 3 , eNDF coefficients were calculated within square. The eNDF coefficient of WFCS NDF in long cut alfalfa silage were .60, .49, and .40 for Squares 1, 2, and 3, respectively. The eNDF coefficient of WFCS NDF in short cut alfalfa silage were .92, .86, and .64 for Squares 1, 2, and 3, respectively. The eNDF coefficient of short cut alfalfa silage relative to long cut alfalfa silage NDF were .83, .87, and .81 for Squares 1, 2, and 3, respectively.

Table 19. Comparison of responses by square.

	Square				Effect[1]	
	1	2	3	SE	M vs. P	1 vs. 2
Parity[2]	M	M	P	-	-	-
DIM[3]	99	148	129	-	-	-
Body Weight, kg[4]	628	598	551	-	-	-
Milk Yield, kg/d	34.0	36.9	32.7	.5	**	**
Milk Fat, %	3.5	3.5	3.5	.1	NS	NS
Dry Matter Intake, kg/d	23.8	24.9	23.0	.3	**	*
NDF intake, kg/d	7.3	7.6	7.0	.1	**	*
Corrected NDF intake, kg/d	5.6	5.9	5.4	.1	**	*
Meal Size, kg DM	2.1	2.5	2.6	.1	**	**
Water Intake, L/d	87.5	96.5	80.4	1.1	**	**
Drinking Time, min/d	18.4	15.3	15.6	.3	**	**
Bouts/d						
eating	11.9	10.2	9.4	.3	**	**
ruminating	14.7	14.0	16.3	.3	**	NS
drinking	18.9	14.3	14.8	.3	**	**
Chews/d						
eating	15431	15483	18162	457	**	NS
ruminating	29118	27968	30731	530	**	NS
total	44548	43452	48893	781	**	NS
Chews/kg corrected NDF intake						
eating	2764	2639	3418	98	**	NS
ruminating	5207	4793	5711	118	**	*
total	7971	7432	9129	187	**	*

[1]Orthogonal contrasts comparing squares.

[2]M = multiparous; P = primiparous.

[3]Average days in milk at start of experiment

[4]Average body weight at start of experiment

*$P < .05$

**$P < .01$.

DISCUSSION

Ingredients and Diets

The particle sizes of the two silages were different ($P < .05$). Theoretical cut matched measured particle size reasonably well (9.5 mm and 4.8 mm vs. 11.4 mm and 5.8 mm, respectively). The long cut was attained with 3/8" theoretical cut and had more long particles (>9500 microns) by weight than the short cut at 3/16" (Table 7). While different in particle size, these two silages are not a typical of silages found on Michigan dairy farms. The theoretical cut of 3/8" is the recommended length of cut for alfalfa silage as it provides enough long particles for chewing (52) and is still packable (49). The material resulting from this theoretical cut is representative of a silage that is reduced little in particle size by the storage and handling between field chopping and cow feeding, such as with a bunker silage. The short length of cut at 3/16" could be considered typical of 3/8" material that was reduced in particle size between harvesting and feeding as with an upright bottom unloading silo that cuts material out,.

Because forages were chopped sequentially and not simultaneously, the long cut, harvested first, was wetter than the short cut, harvested second. Still, the DM contents were appropriate for material put up in trench silos (long cut) and upright silos (short cut). The two silages of this experiment differed in measured pH and acid content. These differences may be due to the difference in dry matter content of the silages as drier conditions inhibit bacteria or to the possible difference of sugar content at ensiling due to time of respiration in the field differences. However, both silages were of good quality and were well preserved as judged by smell and pH at the given dry matters (49). These, along with the similarities in NDF content and NDF digestibilities give support to the assertion that, with regard to chewing activity, the difference between the silages was particle size.

Theoretical length of cut was set on the chopper, but several factors in addition to theoretical cut determine the final particle size of the chopped herbage. They include sharpness of knives, speed (rpm) of machinery operation, and rate (weight/min) of herbage pick up (52). Since these cannot be standardized across studies, the measurement of MPL is appropriate (52). Contrary to most reported studies, particle size in this study was determined with wet sieving. Most studies use dry sieving methods, therefore, it is difficult to compare forage particle sizes between this and other studies.

Type of forage, method of processing, and sieving method influences the final measurement of particle size (24). Dry sieving gives lower ($P < .01$) mean particle sizes than wet sieving (2, 24). An explanation for this difference can be found in how the two methods sort material. Wet sieving, the slurrying of wet suspensions through standardized sieves arranged in decreasing pore size top to bottom, tends to sort material by length (65) and, in contrast, dry sieving, done by sifting material via mechanical shaking of wet or dry material through the standard sieves, tends to sort according to cross-sectional diameter (65). Gamma distributions fit feedstuff particle distributions better than log normal (2) and were used to determine the variances.

This study departed from the convention of measuring MPL with dry sieving because it was felt that particle distributions obtained by wet sieving may be more meaningful relative to physical processes occurring in the rumen (2). Physical form of the diet is a major factor stimulating rumination (74). Welch and Hooper (70) suggest that rumination is stimulated primarily by ingesta particles ≥ 10 mm. They also note that particles between 1 and 10 mm in length affect rumination, but are not as important as longer material in stimulating rumination. Therefore, wet sieving may be more appropriate as it sorts by length. Wet sieving is more tedious and less mechanized than dry (24) explaining why wet sieving is less used even though it may be more meaningful.

In this experiment, wet sieving was done following a macro NDF extraction. Due to surface area effects, proportionally, more soluble material would be removed from the smaller particles during the five to ten minutes of the wet sieving process than from the larger particles. Pretreatment by macro NDF eliminated this problem by uniformly extracting detergent soluble materials from all particles.

The protocol of this experiment was to feed 27% NDF diets with the addition of WFCS NDF replacing 25% of the alfalfa silage NDF. The NDF of treatment diets of 27% was selected to allow possible differences that would be masked by overfeeding NDF. Experimental diets were measured at 30% NDF. This discrepancy was the result of the grain mix NDF content being 5% higher than estimated. The measured replacement of alfalfa silage NDF with WFCS NDF was 27%. This 2% increase above planned was due to the increase of WFCS NDF content from 47% to 55%. Measured CP content of experimental diets was as balanced. Final calcium content of the experimental diets was not measured. All other measured components were similar across experimental diets.

Cow Performance

The addition of WFCS to experimental diets increased milk production (actual, FCM and SCM). This is consistent with the increased energy available to the animals due to increased DMI and to increased energy density of the WFCS added diets. Short length of cut and addition of WFCS increased water intake. These diet ingredients made the experimental diets drier which may have been responsible for the increased daily water consumption. Also, since milk is 87% water, greater production with added WFCS diets may also have drove increased daily water consumption. Increased drinking time was recorded on diets containing the short length of cut and added WFCS. Short length of cut increased drinking time by increasing the number of drinking bouts per day. The addition of WFCS increased daily drinking time by lengthening of each drinking bout.

Across diets, the cows on experiment gained body weight and body condition suggesting they were in positive energy balance. Regardless of diet, the cows gained 51 kg of body weight and .29 condition points during the experiment. Animals were healthy throughout the experiment. Only one health related problem (see Table 12) was known to effect measurements taken, a displaced abomasum diagnosed on Day 20 of short cut, no WFCS diet period. Data were dropped from Day 16, the day before animal behavior was noted as abnormal.

Chewing Activity

An increase in chewing suggests an increased dietary "scratch factor" resulting from increased fiber effectiveness. Increased chewing activity leads to greater saliva flow to the rumen. In this experiment, the long length of cut alfalfa silage had more chewing activity than short length of cut. The long cut was ingested at slower rate requiring more time and chews per unit of dry matter to process the diet to swallowable boluses. While all diets had a similar number of meals per day (10.4), the meals of the long cut diets were greater in minutes and in number of chews resulting in greater total daily eating time and chews. The long cut silage added one more 30 minute ruminating bout to each day. The addition of one more ruminating bout increased daily ruminating time and chews, decreased interruminating intervals, and increased ruminating activity per unit of intake. The increased eating and ruminating activities on the long length of cut of alfalfa silage summed to greater total chewing activity per day.

The addition of WFCS NDF to the experimental diets to replace alfalfa silage NDF lowered chewing activity. The addition of WFCS did not change the number of eating or ruminating bouts per day. While ruminating activity per bout was similar with and without the addition of WFCS, the addition of WFCS made eating bouts shorter with fewer chews. The addition of WFCS to the experimental diets reduced eating and ruminating activity per kilogram intake (DM, NDF, and corrected NDF) and, subsequently, reduced total chewing activity per kilogram intake measured in minutes and chews. The addition of WFCS increased meal size (intake per eating bout) as measured in kilogram DM or kilogram NDF. Rate of chewing for eating and ruminating was constant across the experiment diets at 61 chews/min. The interactions of length of cut and WFCS treatment caused the difference in total chewing activity divided by intake between long cut, no WFCS and long cut, added WFCS diets to be greater than the difference between short cut, no WFCS and short cut, added WFCS diets.

Chewing activities were correlated. Since chew rates were generally 61 chews per min, chews per day, per kilogram DMI and per kilogram NDFI were highly correlated to minutes per day, per kilogram DMI and per kilogram NDFI, respectively. Total chews per kilogram NDF and total chewing time per kilogram NDF were highly correlated (r = .96) suggesting that the use of chews is equivalent to time as an index for the measurement of effectiveness when both are determined with this EDC system (18).

Comparison of Responses by Square

Multiparous Square 2 consumed more dry matter and water and produced more milk. Primiparous Square 3 consumed less dry matter and water and produced less milk. The multiparous squares processed more material with fewer chews than the primiparous square suggesting greater efficiency. To a lesser extent, Multiparous Square 2 was also more efficient than Multiparous Square 1. A comparison of eNDF coefficients by square showed that WFCS NDF was least effective in Primiparous Square 3 and more effective in Multiparous Square 1. The differences in effectiveness coefficients may be due to the differences in body size or in chewing efficiency by square.

A comparison of this experiment's multiparous and primiparous cows to those of Dado and Allen (19) show some similarities and differences. Dado and Allen fed a corn silage and alfalfa silage based diet, while the cows on this experiment received an all alfalfa silage forage base. Their cows were earlier in lactation (63 DIM vs. 125 DIM) and their multiparous cows consumed a similar amount of dry matter (24.8 kg vs. 24.4 kg) in an similar number of meals (11 per day). However, they produced more milk (37.5 kg vs. 35.5 kg) per day than the cows on this experiment. Dado and Allen's multiparous cows had more eating chews (19256 vs. 15457) and similar ruminating chews (28946 vs. 28543) for a greater total chews per day (48201 vs. 44000). Dado and Allen's primiparous cows consumed less dry matter (20.0 kg vs. 23.0 kg) and produced less milk (28.7 kg vs. 32.7 kg) on more meals per day (11.3 vs. 9.4) than the cows on this study. Dado and Allen's primiparous chewed per day equally while eating (18276 vs. 18162) and less while ruminating (29645 vs. 30731) for lower total daily chews (47921 vs. 48893). Overall, the activity measures of the cows on this experiment fell between the activities of the primiparous and multiparous cows of Dado and Allen (19).

Comparison of Chewing Activity in Other Experiments

The indexes (total chewing min per kilogram DMI) of this experiment's long cut, no WFCS diet (34 min) and short cut, no WFCS diet (31 min) were higher than the index of 26 min/kg DMI for "medium cut alfalfa silage" as reported in review by Sudweeks et al. (58) -- even though the NDF contents of the diets on this experiment were probably lower than the NDF content of the only silage diet.

Grant et al. (31) had alfalfa silages that were similar in composition (40% NDF) and in proportion of diet (55% of diet DM) as this experiment. This experiment's long cut, no WFCS diet recorded total chewing activity results similar to their "coarse" diet (34.3 min per kg DMI vs. 33.1 min per kg DMI and 116.2 min per kg NDF and 116.5 min per kg NDF). This experiment's short cut, no WFCS diet total chewing activities (30.8 min per kg DMI and 100.0 per kg NDF) was closer to their "medium" cut (30.5 per kg DMI min and 107.7 min kg NDF) than their "fine" cut (25.4 min per kg DMI and 91.0 min kg NDF).

Clark and Armentano (15) also used an alfalfa silage. The NDF content in that experiment was 43% -- one percent higher than this experiment. Their high alfalfa silage control diet had 757 min of total daily chewing activity and 4.3 kg of corrected (nongrain) NDF intake. This experiment's long cut, no WFCS diet had 785 min of total daily chewing activity and 5.3 kg of corrected NDF intake and this experiment's short cut, no WFCS diet had 697 min and 5.5 kg, respectively. If total minutes per kilogram corrected NDF intake is calculated, their high alfalfa silage control diet is more effective in stimulating chewing per kilogram than this experiment's long cut, no WFCS diet and short cut, no WFCS diet (176 min per kg corrected NDF vs. 150 min per kg corrected NDF and 128 min per kg corrected NDF, respectively).

eNDF Coefficients for This Experiment

Based on the calculated fiber effectiveness coefficients, the long cut alfalfa silage NDF stimulated chewing activity more than the short cut alfalfa silage NDF. The two silages in turn had greater effectiveness of fiber than WFCS. Greater chewing activity probably increased saliva flow and probably increased buffer secretion into the rumen which neutralized greater amount of fermentation acids.

Fiber effectiveness results in this experiment suggest three things: (1) that WFCS is less effective than alfalfa silage as measured by total chewing activity per kilogram corrected NDF intake, (2) results of by-product eNDF calculations are dependent on the character of the background forage, and (3) effectiveness measurements are similar when calculated with either total chews per kilogram corrected NDF intake or total chewing time per kilogram corrected NDF intake as measured by an electronic collection system (18) in a recommended experimental design (19). WFCS NDF is a fraction of the effectiveness of alfalfa silage NDF depending on silage particle size. The two silages were of particle sizes that are typical for Michigan dairy farms. While milk fat percentage were similar across experimental diets, chewing activity differences were detected. How critical these differences are would need to be determined by further study.

Comparisons to Effectiveness Coefficients of Other Experiments

In the only other study to quantify whole WFCS effectiveness, Clark and Armentano (15) measured fiber effectiveness as the ability to correct milk fat depression. Using their slope coefficient method, they calculated .80 for dried distiller's grains in alfalfa silage and 1.30 for WFCS in alfalfa silage. These calculations suggest dried distiller's grains NDF is 20% less effective than alfalfa silage NDF and that WFCS NDF is a third more effective than alfalfa silage NDF. However, there are several concerns of using the slope coefficient approach with milk fat contents in this experiment. First, milk fat percentages across all diets were not different (P>.05). They suggested, that while accurate, the fat test method lacked precision and was therefore unable to separate means. However, an alternate explanation is that, due to the nonsignificance, all milk fat percentages are a sampling of the same mean. If is true, then, as they noted, dried distiller's grains and WFCS are approximately the same as alfalfa silage in fiber effectiveness (i.e. all = 1.0) as measured by ability to stimulate fat synthesis.

Since milk fat percentage is a result of the whole diet intake, two other concerns are noted. First, the high alfalfa silage diets had the lowest DMI (P<.01) and lowest diet NE_L concentrations as calculated from NRC values. These two factors combined to give the high alfalfa silage diets an intake of 3 less Mcal per day than all other diets. Second, WFCS alters milk fat fatty acid proportions as discussed earlier. The net result of these two factors on milk fat percentage is unknown.

If the results for total chewing time reported by Clark and Armentano are put into the effectiveness equations developed in this experiment, the effectiveness of dried distiller's grain NDF in alfalfa silage is .60 ((155-(.70)(176))/((.30)(176)) and the effectiveness of WFCS NDF in alfalfa silage is .88 ((167-(.56)(176))/((.44)(176)) based on total chewing time per kilogram corrected NDF intake. In both cases, effectiveness coefficients less than those calculated with the milk fat methods and less than alfalfa silage NDF.

Comparison of Methods of Effective Fiber Calculation

The assumptions of this experiment's method of effective fiber calculation is compared graphically to the method used at University of Wisconsin in Figures 4 and 5, respectively. In both systems, corrected (nongrain) NDF intake is used because the grain contribution to fiber effectiveness is assumed to be zero. This assumption is based on a review of the literature. This experiment's calculations are based one assumption, two data points and one measured proportion. Starting with the assumption that there is no chews at zero kilograms corrected NDF intake, chews increase linearly with corrected NDF intake to the measured total chews at the measured kilogram corrected NDF intake of the no WFCS diet. Next, the breakpoint for WFCS NDF is determined by using the measured proportion of WFCS NDF replacing alfalfa silage NDF to partition out the NDF intake and chews due to alfalfa silage NDF. From this breakpoint a line is drawn to measured total chews by kilogram corrected NDF intake of added WFCS diet. Effectiveness calculation is equivalent to the slope of breakpoint to added WFCS diet data point divided by slope of origin to the no WFCS diet data point.

The calculations of University of Wisconsin are shown in Figure 5. The axes of Figure 5 change from Figure 4. The X axis is corrected NDF content of diet showing this method does not account for intake. This is problem if treatment affects DMI. The Y axis is their measure of effectiveness, milk fat content. The milk fat content is measured on three diets to obtain the two slopes needed for the fiber effectiveness calculation. From the milk fat content on the low alfalfa silage NDF diet, two lines are drawn to the milk fat contents of high fiber diets -- one to the high fiber alfalfa silage control and one to the test by-product. A linear response of milk fat content from low fiber to high fiber is assumed. Again, they negate grain NDF in their calculation of NDF content as they assume grain has no effect on milk fat content. With the use of low fiber control, their slopes are not forced through the origin meaning that, at zero NDF content of diet, milk fat percentage does not necessarily equal to zero.

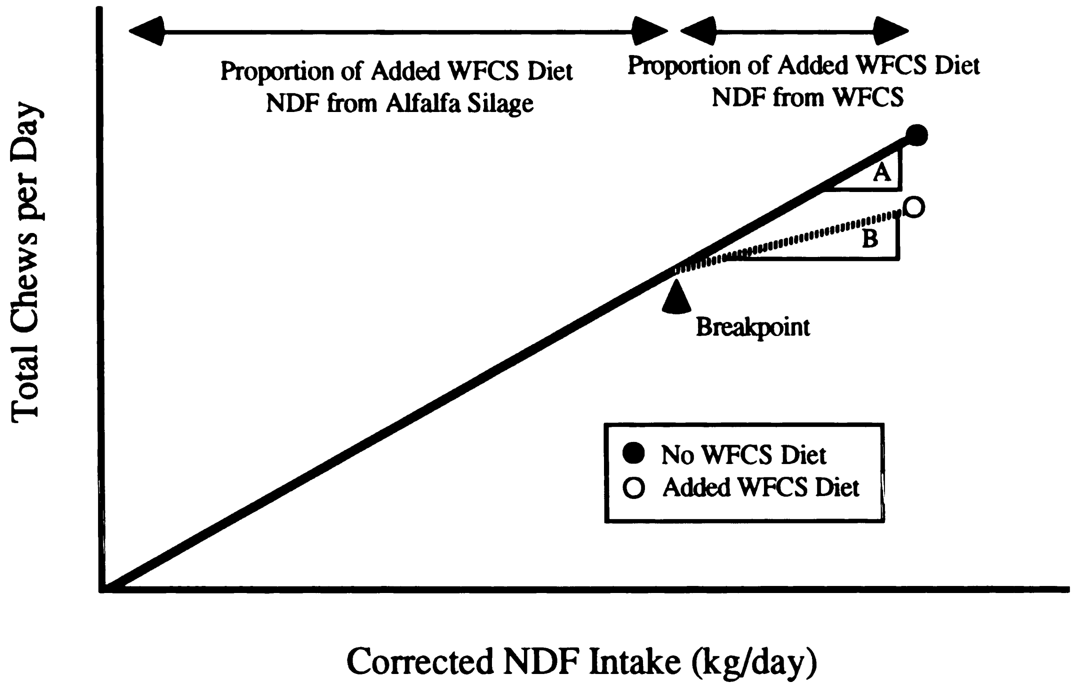

Figure 4. Graphical representation of assumptions and mathematics of this study. The calculation of fiber effectiveness is the slope "B" divided by slope "A."

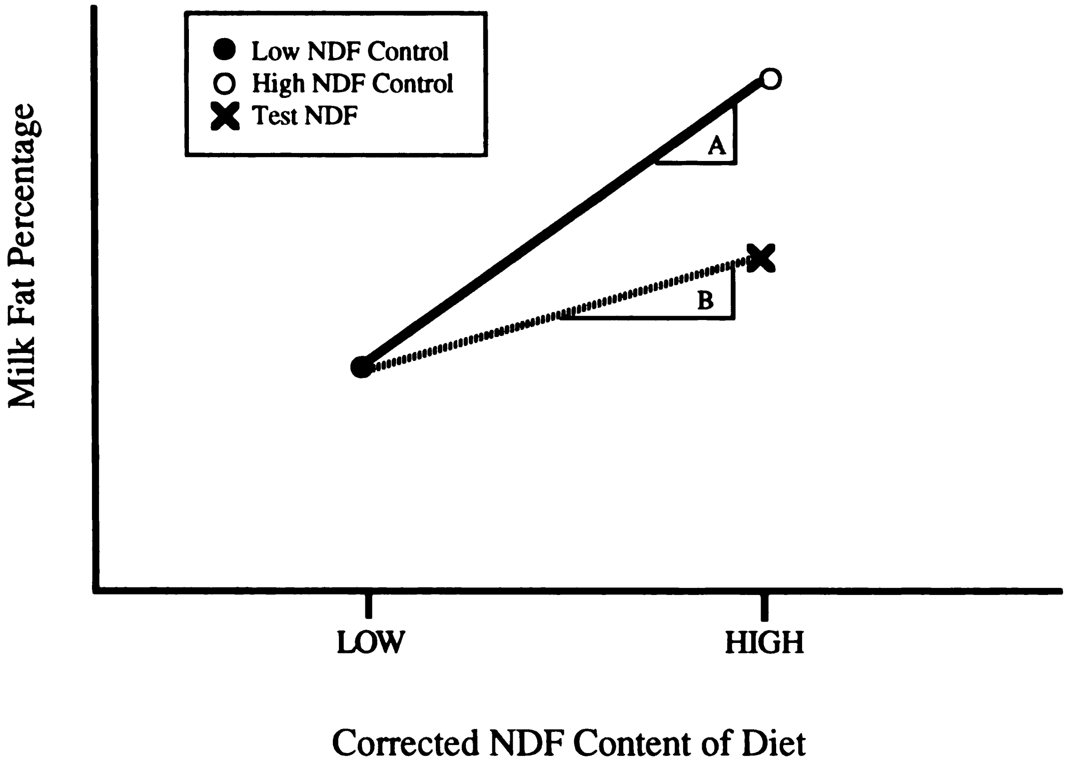

Figure 5. Graphical representation of assumptions and mathematics of the slope coefficient method used by Armentano and coworkers (14, 15, 61, 67). The calculation of fiber effectiveness is the slope "B" divided by slope "A."

Assumptions of Calculations of eNDF for This Experiment

The first assumption was that the contribution of the grain mix NDF to total chewing activity measured on experimental diets was negligible. Grain mix NDF was subtracted from total diet NDF to yield corrected NDF intake. Ruminants have a very strong drive to ruminate (69, 70). Rumination may provide the psychological benefits of sleep as well (1). On grain only and pelleted diets, ruminating chews are low in number and irregular in nature (6). These three points taken together suggest that ruminating chews on these diets may be as much higher brain stimulated as ruminally stimulated. If a coarse forage were added to these diets, one would expect the stimulus of forage to ellipse, not add, to any stimulation already present because of the forage's greater ability to stimulate rumination.

The second assumption was that the total chewing activity responds linearly to NDF intake across the range of intakes measured in this experiment. With the significant effects on DMI, it was necessary to correct total chews and total time chewing for intakes to avoid the bias of intake. A calculation to test for linearity using the results of the effectiveness calculations supports this assumption. If the eNDF coefficient of WFCS in short cut alfalfa silage is multiplied by the short cut to long cut ratio, the product should equal the eNDF coefficient of WFCS in long cut alfalfa silage if there is linear relationship. Using the ranges for coefficients calculated with total chews per kilogram corrected NDF intake [(.93 to .67) * (.86 to .81) = (.58 to .38)] and with total chewing time per kilogram corrected NDF intake [(.84 to .64) * (.88 to .84) = (.61 to .44)] suggest that linearity is a reasonable assumption. In the future, these assumptions will have to be tested.

Choice of Method of eNDF Calculations for This Experiment

The presence of sufficient effective fiber in the diets has a number of effects. An individual animal consumes the fiber of the diet and responds according to the chemical and physical properties of the fiber. Higher diet proportions of fiber and coarser texture of fiber stimulate chewing activity increasing saliva flow. Increased saliva flow adds more bicarbonate to the rumen. Higher NDF proportions of the diet promote an acetate fermentation and maintain a more neutral ruminal pH. This fermentation allows normal milk fat percentages but, increased effective fiber is not linearly related to milk fat percentage.

High acetate fermentation and high chewing stimulus are not always linked. An example of this disassociation is soyhulls. Soyhulls are high in fermentable fiber and their substitution for grain may increase milk fat due to increased acetate production yet may not provide any buffering due to salivation because of their lower ability to stimulate chewing.

Total chews per kilogram corrected NDF intake, chosen as the measurement of fiber effectiveness for this experiment, has several advantages. First, lactation is not required and, therefore, may be tested and applied over a range of ruminants. Second, the measurement of chewing activity and intake is non invasive as it does not require the rumen cannulation necessary for accurate sampling of ruminal acids and pH. And third, the measurement of chewing activity is a more direct measure of fiber effectiveness, rumen health, and rumen action than milk fat percentages or ruminal acid ratios.

The use of total chews per kilogram corrected NDF intake to calculate effectiveness of fiber was an extension of Balch's index (6), total chewing time per kilogram DMI. Total chews were chosen over total chewing time because (1) the EDC system used (18) allowed easy and accurate measurement of individual chews and (2) saliva output may be more related to activity than time. However, indexes as measured with total chews and total time were determined for later comparison. NDF intake was chosen to partition total chews rather than DMI because forages and by-products vary so greatly in NDF.

Effectiveness coefficients were calculated using total chewing activity, the sum of eating and ruminating chewing activity. As noted by Erdman (25), saliva flow rates are greater during rumination than during eating. In the future, more accurate eNDF coefficients might be obtained by dividing total chewing activity back into its component parts, ruminating activity and eating activity, with each adjusted by a coefficient describing saliva flow.

Enough effective fiber in the diet allows commonly reported (mid 3's) milk fat percentages. However, milk fat percentage may not be the best measure of fiber effectiveness particularly with WFCS in the diet. Milk fat percentage, an indirect indicator, is a function of several factors and milk fat percentage and level of dietary fiber are not highly related. Regressions of increased fiber in diet, increased ruminal A:P, and increased milk fat percentage are related by linear components but, the relationships are still not direct (25). Milk fat percentage results may not be solely a response to fiber effectiveness, especially in early lactation when milk fat is less responsive to fiber levels in the diet due to the high adipose mobilization during the negative energy balance.

Fatty acids of milk fat triglycerides come from two sources. Triglyceride fatty acid chains of 16 carbons or less are synthesized in mammary gland from acetate and beta hydroxybutyrate. Triglyceride fatty acid chains of 18 carbons or more are transferred from the diet and from the adipose tissue. Though often equal contributors to the total milk fat produced, the balance of the two processes is a function of such factors as influence of diet components, character of rumen fermentation and energy balance (65). Measuring fiber effectiveness of diets containing WFCS or WFCS products against diets containing no WFCS, using milk fat percentage as an indicator may have dubious utility as WFCS alters fatty acid composition of milk fat (34, 54, 55) as changes in milk fat percentage may not be the result of fiber effectiveness.

Milk fat percentage is also becoming less important to the producer. Due to less consumer demand, milk fat has been and will continue to become less important economically. Producers will be increasing ruminally fermented carbohydrate in the cow diet to increase fluid milk and milk protein production. This change will shift the emphasis of effective fiber from its effect on milk fat percent to its effect on buffering the fermentation acids produced by increased ruminally fermented carbohydrate.

SUMMARY

Dry matter intake, NDF intake, and water intake were increased by short length of cut and with WFCS addition. Milk production was increased with the addition of WFCS to treatment diets. Milk composition was not affected by treatment. Chewing activities as measured by count and time were reduced by the short length of cut and by WFCS addition. Total chews per kilogram NDF intake were reduced with short length of cut and with WFCS addition. Total chews per kilogram NDF intake were used to calculate the effectiveness of WFCS NDF. The interaction of length of cut and WFCS treatment caused two different coefficients for effectiveness of WFCS NDF. Effectiveness of WFCS NDF in long cut alfalfa silage was calculated as .48 ± .10 and effectiveness of WFCS NDF in short cut alfalfa silage was calculated as .80 ± .13.

CONCLUSIONS

Measurement of by-product effectiveness is influenced by the background forage the by-product is measured against and, therefore, characterization of background forage is extremely important. Using total chews per kilogram corrected NDF intake to measure effectiveness of by-product NDF has merit but, further research is needed. Effective NDF of whole fuzzy cottonseed as measured by chews per kilogram corrected NDF intake ranges from approximately 50% of long cut alfalfa silage NDF to approximately 80% of short cut alfalfa NDF.

FUTURE WORK

This experiment suggests that the use of total chewing activity per kilogram corrected NDF intake is viable. However, the assumptions used in this experiment need to be tested: Is the relationship between total chews and NDF intake linear?, Are the chews from grain mix proportion of the diet negligible?, and Is chews per kilogram of WFCS NDF constant at different diet proportions? With the total chewing activity per kilogram corrected NDF intake system, critical, minimum, and maximum levels need to be determined for effectiveness of fiber.

In the future, more accurate eNDF coefficients might be obtained by dividing total chewing activity back into its component parts, ruminating activity and eating activity, with each adjusted by a coefficient describing saliva flow. As noted by Erdman (25), saliva flow rates are greater during rumination than during eating.

When testing by-product fiber effectiveness, by-product is fed with a background forage with distinct characteristics. It is possible that the forage fed with the by-product is variable in fiber effectiveness from experiment to experiment. These differences may influence the measurement of the by-product effectiveness. Therefore, the background forage must be characterized as in the past and the characterization reported, particularly particle size.

A cooperative effort among research groups for more standardization of reporting of experimental parameters would be beneficial. Reporting a standard set of variables is needed for comparison of effective fiber systems until one approach proves superior. When testing by-product effectiveness, reporting the characterization of background forages remains important. Also, across all effectiveness studies, a standard of comparison needs to be agreed upon. Whether the standard is coarse alfalfa silage, long grass hay, 100% NDF forage extrapolated from long grass hay, or some other, remains to be determined.

APPENDICES

Appendix A. Cow days lost for 92CSM1 and reason they were removed from final data set.

Cow	Period	Day	Reason removed	removed from chewing data	removed from drinking data
863	3	5	halter failure	x	
2347	2	5	halter failure	x	
2473	1	1	halter failure	x	
2480	1	2	halter failure	x	
2480	3	1	halter fit too tight	x	
2502	1	1	halter failure	x	
2502	1	2	halter failure	x	
2552	1	5	uncorrectable interference	x	
2552	2	2	health; suspected DA	x	x
2552	2	3	health; suspected DA	x	x
2552	2	4	health; suspected DA	x	x
2552	2	5	health; confirmed DA	x	x
2616	1	5	halter failure	x	
2616	4	1	uncorrectable interference	x	
2616	4	2	halter failure	x	
2617	2	1	uncorrectable interference	x	
2619	2	5	halter failure	x	
2619	3	2	halter failure	x	
2619	4	1	halter failure	x	
2635	2	3	possible halter failure	x	

DA = displaced abomasum

Appendix B. Pre-experiment individual cow information for 92CSM1.

Stall	cow	FDATE	lact. #	Square	305ME	DIM	BW	Milk #
1	2347	6-24-92	4	1	22670	77	640	97
2	2525	5-24-92	2	1	25800	108	677	103
3	2552	5- 8-92	2	1	27140	124	597	100
4	2473	6-14-92	3	1	23190	87	599	87
5	2502	5- 2-92	2	2	28340	130	590	100
6	863	4- 4-92	2	2	24120	158	571	83
7	535	4-17-92	6	2	23960	145	523	100
8	2480	4- 3-92	3	2	26980	159	710	96
9	2619	5-23-92	1	3	27660	109	593	86
10	2617	3-21-92	1	3	27420	172	556	80
11	2616	4-11-92	1	3	23170	151	556	73
12	2635	6-17-92	1	3	26270	84	501	79

FDATE = date of freshening

lact. # = lactation number

305ME = current projected 305 d mature equivalent milk production

DIM = days in milk on 9-8-92

BW = initial body weight in kilograms

Milk # = pre-experiment daily milk production in pounds

Appendix C. Summary of cow information by square on Sept. 8, 1992 for 92CSM1.

Square	Milk	DIM	BW	lactation
1	43.9 ± 3.2	99 ± 21	628 ± 38	multiparous
2	43.0 ± 3.7	148 ± 14	598 ± 79	multiparous
3	36.1 ± 2.4	129 ± 40	551 ± 38	primiparous
ALL	41.0 ± 4.6	125 ± 32	593 ± 60	-

Milk = average milk in kg (mean ± standard deviation)

DIM = average days in milk (mean ± standard deviation)

BW = average body weight in kg (mean ± standard deviation)

Appendix D. Formulas used in 92CSM1.

% solids not fat (% SNF)
= % milk protein + % milk lactose + % milk ash
-assumed .71 % for % milk ash
Source: Tyrrell and Reid. JDS 48:1215.

solids corrected milk (SCM)(lb..)
=(12.3)(fat lb.) + (6.56)(solids not fat lb.) - (.0752)(milk lb.)
Source: Tyrrell and Reid. JDS 48:1215.

kilograms = (lb.)(.454)

liters = (gallons)(3.785)

dry matter intake (DMI)
= dry matter fed (lb.) - dry matter pounds refused (lb.)
= (as fed lb.)(TMR %DM/100) - (orts lb.)(orts %DM/100)

% orts
= dry matter lb. refused ÷ dry matter pounds fed

change in body condition score or body weight
= avg. @ start of the period - avg. @ the end of the period

average % fat for test week (similar for %protein, %lactose and SCC)
= (total lb. fat produced for six sampled milkings) ÷ (total lb. of milk produced for six sampled milkings)
= ((lb. of milk from first milking)(first milking % fat/100) + (fat lb. from second milking) + ... + (fat lb. from sixth milking)) ÷ ((lb. of milk from first milking) + (lb. of milk from second milking) + ... + (lb. of milk from sixth milking))

4.0% FCM (source: NRC)
= milk kg (.4 + (.15)(% milk fat))

3.5% FCM (source: NRC)
= milk kg (.43 + (.162)(% milk fat))

LIST OF REFERENCES

LIST OF REFERENCES

1 Albright, J. L. 1993. Feeding behavior in dairy cattle. J. Dairy Sci. 76:485.

2 Allen, M. S., J. B. Robertson, and P. J. VanSoest. 1984. A comparison of particle size methodologies and statistical treatments. Page 39 *in* Techniques in particle size analysis of feed and digesta in ruminants. Proc. Workshop Can. Soc. Anim. Sci., Banff. P. M. Kennedy, ed. Occas. Publ. 1, Can. Soc. Anim. Sci., Edmonton, Alta., Can.

3 Association of Official Analytical Chemists. 1984. Official methods of analysis. 14th Ed. AOAC, Washington, DC.

4 Bae, D. H., J. G. Welch, and B. E. Gilman. 1983. Mastication and rumination in relation to body size of cattle. J. Dairy Sci. 66:2137.

5 Bae, D. H., J. G. Welch, and A. M. Smith. 1981. Efficiency of mastication in relation to hay intake by cattle. J. Anim. Sci. 52:1371.

6 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 characteristic of roughages. Br. J. Nutr. 26:383.

7 Ballesteros, J. P. G. 1975. The effects of the chopped of the ensilaged alfalfa and conservation system upom alimentary behaviour of sheep.[sic] Revista Nutr. Anim. 13:7.

8 Beauchemin, K. A. 1991. Ingestion and mastication of feed by dairy cattle. Veterinary Clinics of North America: Food Animal Practice. 7(2):439.

9 Beauchemin, K. A. 1991. Effects of dietary neutral detergent fiber concentration and alfalfa hay quality on chewing, rumen function, and milk production of dairy cows. J. Dairy Sci. 74:3140.

10 Beauchemin, K. A., and J. G. Buchanan-Smith. 1989. 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.

11 Beauchemin, K. A., B. I. Farr, and L. M. Rode. 1991. Enhancement of the effective fiber content of barley-based concentrates fed to dairy cows. J. Dairy Sci. 74:3128.

12 Cassida, K. A., and M. R. Stokes. 1986. Eating and resting salivation in early lactation dairy cows. J. Dairy Sci. 69:1282.

13 Church, D.C. 1988. Salivary function and production. Page 117 *in* The ruminant animal: digestive physiology and nutrition. D. C. Church, ed. Prentice Hall, Englewood Cliffs, NJ.

14 Clark, P. W. and L. E. Armentano. 1993. Replacement of alfalfa NDF with a combination of nonforage fiber sources. J. Dairy Sci. 76(1):210. (Abstr.)

15 Clark, P. W. and L. E. Armentano. 1993. Effectiveness of neutral detergent fiber in whole cottonseed and dried distillers grain compared with alfalfa haylage. J. Dairy Sci. 76:2644.

16 Coppock, C. E., J. K. Lanham, and J. L. Horner. 1987. A review of the nutritive value and utilization of whole cottonseed, cottonseed meal and associated by-products by dairy cattle. Anim. Feed Sci. Tech. 18:89.

17 Coppock, C. E., and D. L. Wilks. 1991. Feeding whole cottonseed and cottonseed meal to dairy and beef cattle. Page 43 *In* Proceedings of National Invitational Symposium: Alternative feeds for dairy and beef cattle. St. Louis, MO.

18 Dado, R. G., and M. S. Allen. 1993. Continuous computer acquisition of feed and water intakes, chewing, reticular motility, and ruminal pH of cattle. J. Dairy Sci. 76:1589.

19 Dado, R. G., and M. S. Allen. 1994. Variation in and relationships among feeding behavior variables measured continuously from lactating dairy cows. J. Dairy Sci. 77:132.

20 DeBoever, J. L., J. I. Andries, D. L. DeBrabander, B. G. Cottyn, and F. X. Buysse. 1990. Chewing activity of ruminants as a measure of physical structure -- a review of factors affecting it. Anim. Feed Sci. Tech. 27:281.

21 DeBoever, J. L., D. L. DeBrabander, A. M. DeSmet, J. M. Vanacker, and C. V. Boucque. 1993. Evaluation of physical structure. 2. maize silage. J. Dairy Sci. 76:1624.

22 DeBoever, J. L., A. DeSmet, D. L. DeBrabander, and C. V. Boucque. 1993. Evaluation of physical structure. 1. grass silage. J. Dairy Sci. 76:140.

23 Edmonson, A. J., I. J. Lean, L. D. Weaver, T. Farver and G. Webster. 1989. A body condition scoring chart for Holstein dairy cows. J. Dairy Sci. 72:68.

24 Ehle, F. R., 1984. Measurement of mean particle size of forages by wet and dry sieving techniques. Page 18 *in* Techniques in particle size analysis of feed and digesta in ruminants. Proc. Workshop Can. Soc. Anim. Sci., Banff. P. M. Kennedy, ed. Occas. Publ. 1, Can. Soc. Anim. Sci., Edmonton, Alta., Can.

25 Erdman, R. A., 1988. Dietary buffering requirements of the lactating dairy cow: a review. J. Dairy Sci. 71:3246.

26 Firkins, J. L. 1992. Effectiveness of fiber from non-forage sources. Page 7 *in* Proc. of Tri-State Dairy Nutrition Conf. Fort Wayne, IN.

27 Firkins, J. L., and M. L. Eastridge. 1992. Replacement of forage or concentrate with combinations of soyhulls, sodium bicarbonate, or fat for lactating dairy cows. J. Dairy Sci. 75:2752.

28 Goering, H. K., and P. J. VanSoest. 1970. Forage fiber analysis (apparatus, reagents, procedures, and some applications). Agric. Handbook No. 379. ARS-USDA, Washington, DC.

29 Grant, R. J., V. F. Colenbrander, and J. L. Albright. 1990. Effect of particle size of forage and rumen cannulation upon chewing activity and laterality in dairy cow. J. Dairy Sci. 73:3158.

30 Grant, R. J., V. F. Colenbrander, and D. R. Mertens. 1990. Milk fat depression in dairy cows: role of particle size of alfalfa hay. J. Dairy Sci. 73:1823.

31 Grant, R. J., V. F. Colenbrander, and D. R. Mertens. 1990. Milk fat depression in dairy cows: role of silage particle size. J. Dairy Sci. 73:1834.

32 Hach, C. C., B. K. Bowden, A. B. Lopelove, and S. V. Brayton. 1987. More powerful peroxide kjeldahl digestion method. J. Assoc. Offic. Anal. Chem. 70(5):783.

33 Harris, B. 1991. Value of high-fiber alternative feedstuffs as extenders of roughage sources. Page 138 *In* Proceedings of National Invitational Symposium: Alternative feeds for dairy and beef cattle. St. Louis, MO.

34 Hawkins, G.E., K. A. Cummins, M. Silverio, and J. J. Jilek. 1985. Physiological effects of whole cottonseed in the diet of lactating dairy cows. J. Dairy Sci. 68:2608.

35 Hsu, J. T., D. B. Faulkner, K. A. Garleb, R. A. Barclay, G. C. Fahey, Jr., and L. L. Berger. 1987. Evaluation of corn fiber, cottonseed hulls, oat hulls and soybean hulls as roughage sources for ruminants. J. Anim. Sci. 65:244.

36 Jaster, E. H., and M. R. Murphy. 1983. Effects of varying particle size of forage on digestion and chewing behavior of dairy heifers. J. Dairy Sci. 66:802.

37 JMP® User's Guide: Software for statistical visualization on the Apple® Macintosh®. Version 2 Edition. 1989. SAS Inst., Inc., Cary, NC.

38 Jorgensen, N. A., M. F. Finner, and J. P. Marquardt. 1978. Effect of forage particle size on animal performance. Paper No. 78-1048. Am. Soc. Agric. Engineers. St. Joseph, MI.

39 Kalu, B. A., and G. W. Fick. 1981. Quantifying morphological development of alfalfa for studies of herbage quality. Crop Sci. 21:267.

40 Kick, C. H., P. Gerlaugh, A. F. Schalk, and E. A. Silver. 1937. The effect of mechanical processing of feeds on the mastication and rumination of steers. J. Agric. Res. 55(8):587.

41 Krishnamoorthy, U., T. V. Muscato, C. J. Sniffen, and P. J. VanSoest. 1982. Nitrogen fractions in selected feedstuffs. J. Dairy Sci. 65:217.

42 Lofgren, P. A. and R. G. Warner. 1970. Influence of various fiber sources and fractions on milk fat percentage. J. Dairy Sci. 53: 296.

43 McDonald, P. 1981. The biochemistry of silage. John Wiley & Sons, Ltd., Chichester, England.

44 Mertens, D. R. 1980. Fiber content and nutrient density in dairy rations. Proc. Distillers Feed Conf. 35:35.

45 Mertens, D. R. 1991. Physical and chemical characteristics of fiber that determine its roughage value. Proc. of the 17th Biennial Ruminant Health-Nutrition Conf. of NYS Vet. Med. Society: Feeding and managing cows in transition.

46 National Research Council, 1989. Nutrient requirements of dairy cattle. 6th rev. ed. Nat. Acad. Sci., Washington, DC.

47 Nørgaard, P. 1989. The influence of physical form of ration on chewing activity and rumen motility in lactating cattle. Acta Agric. Scand. 39:187.

48 Okamoto, M., K. Deoka, and T. Bando. 1979. Effects of cut lengths of corn silage on ruminating behavior of cows. Bull. No. 10 Shintoku Anim. Husb. Exp. Stn.

49 Pitt, R. E. 1990. Silage and hay preservation (NRAES-5). Northeast Regional Agricultural Engineering Service, Ithaca, NY.

50 Santini, F. J., A. R. Hardie, N. A. Jorgensen, and M. F. Finner. 1983. Proposed use of adjusted intake based on forage particle length for calculation of roughage indexes. J. Dairy Sci. 66:811.

51 Sarwar, M., J. L. Firkins, and M. L. Eastridge. 1991. Effect of replacing neutral detergent fiber of forage with soyhulls and corn gluten feed for dairy heifers. J. Dairy Sci. 74:1006.

52 Shaver, R. D. 1990. Forage particle length in dairy rations. Page 58 *in* Proc. Dairy Feeding System Symp., Harrisburg, PA.

53 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.

54 Smith, N. E., L. S. Collar, D. L. Bath, W. L. Dunkley, and A. A. Franke. 1981. Digestibility and effects of whole cottonseed fed to lactating cows. J. Dairy Sci. 64:2209.

55 Smith, W. A., B. Harris, Jr., H. H. Van Horn, and C. J. Wilcox. 1993. Effects of forage type on production of dairy cows supplemented with whole cottonseed, tallow, and yeast. J. Dairy Sci. 76:205.

56 Stern, M. D. and C. J. Ziemer. 1993. Consider value, cost when selecting nonforage fiber. Feedstuffs. 65(2):14.

57 Sudweeks, E. M. 1977. Chewing time, rumen fermentation and their relationship in steers as affected by diet composition. J. Anim. Sci. 44:694.

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

59 Sudweeks, E. M., L. O. Ely, and L. R. Sisk. 1980. Effect of intake on chewing activity of steers. J. Dairy Sci. 63:152.

60 Sudweeks, E. M., S. E. Law, L. O. Ely, M. E. McCullough, and L. R. Sisk. 1979. Development and application of a roughage value index for formulating dairy rations. Bulletin No. 238 Georgia Agric. Exp. Stn.

61 Swain, S. M., K. K. Vaughan, and L. E. Armentano. 1991. Determining effectiveness of fiber in by-product feeds compared to alfalfa silage. J. Dairy Sci. 74(1):220.(Abstr.)

62 Tyrrell, H. F. and J. T. Reid. 1965. Prediction of the energy value of cow's milk. J. Dairy Sci. 48:1215.

63 VandeHaar, M., H. Bucholtz, R. Beverly, R. Emery, M. Allen, C. Sniffen, and R. Black. 1992. Spartan dairy ration evaluator/balancer: an agricultural integrated management software microcomputer program. Michigan State Univ. Cooperative Ext., East Lansing, MI.

64 VanHorn, H. H., B. Harris, Jr., M. J. Taylor, K. C. Bachman, and C. J. Wilcox. 1984. By-product feeds for lactating dairy cows: effects of cottonseed hulls, sunflower hulls, corrugated paper, peanut hulls, sugarcane bagasse, and whole cottonseed with additives of fat, sodium bicarbonate, and Aspergillus oryzae product on milk production. J. Dairy Sci. 67:2922.

65 VanSoest, P. J. 1982. Nutritional Ecology of the Ruminant. Comstock Publishing Associates, Ithaca, NY.

66 VanSoest, P. J., J. B. Robertson, and B. A. Lewis. 1991. Methods for dietary fiber, neutral detergent fiber and nonstarch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74:3583.

67 Vaughan, K. K., S. M. Swain, and L. E. Armentano. 1991. Effectiveness of NDF from ground corn cobs and wheat middlings compared to alfalfa silage. J. Dairy Sci. 74(1):220.(Abstr.)

68 Wagner, K. M., J. L. Firkins, M. L. Eastridge, and B. L. Hull. 1993. Replacement of corn silage with wheat middlings and calcium chloride or sodium bicarbonate for lactating dairy cows. J. Dairy Sci. 76:564.

69 Welch, J. G. 1982. Rumination, particle size and passage from the rumen. J. Anim. Sci. 54:885.

70 Welch, J. G., and A. P. Hooper. 1988. Ingestion of feed and water. Page 108 *in* The ruminant animal: digestive physiology and nutrition. D. C. Church, ed. Prentice Hall, Englewood Cliffs, NJ.

71 Welch, J. G., and A. M. Smith. 1969. Influence of forage quality on rumination time in sheep. J Anim. Sci. 28:813.

72 Welch, J. G., and A. M. Smith. 1969. Effect of varying amounts of forage intake on rumination. J. Anim. Sci. 28:827.

73 Welch, J. G., and A. M. Smith. 1970. Forage quality and rumination time in cattle. J. Dairy Sci. 53:797.

74 Welch, J. G., and A. M. Smith. 1971. Physical stimulation of rumination activity. J. Anim. Sci. 33:1118.

75 Welch, J. G., A. M. Smith, and K. S. Gibson. 1970. Rumination time in four breeds of dairy cattle. J. Dairy Sci. 53:89.

76 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.

77 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.