DEFINING EFFECTIVE FIBER CONTENT OF DAIRY RATIONS

by

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Chapter I

INTRODUCTION

Ration physical form affects rumen health and function and partitioning of nutrients between rumen and lower digestive tract. However, all-forage rations produce normal rumen health and function but limit energy intake necessary for maximum milk production. All-concentrate rations provide maximum energy intake for milk production but do not provide bulk or "scratch" necessary for normal rumen health. Optimum dairy rations provide energy and bulk for milk production and cow health.

Attempts to evaluate physical form have not produced a routine method for quantitation of feedstuff or ration physical form. Roughage Factor, Effective Fiber, Roughage Value Index, or Bulk Density measurements have attempted to correlate these physical form evaluations to milk fat test and production, but have not been developed to a routine procedure. These evaluations may be important since maintaining milk fat test can be detrimental to ruminant health and production.

Ration physical form also affects partitioning of nutrients between rumen and lower digestive tract by effecting changes in rumen fluid dilution rate (RFD). Increased

RFD has been associated with increasing forage component of rations. Soluble ration components, small particles, and some microbial cells flow with the fluid phase of rumen digesta, therefore a faster RFD carries more of these components to the lower tract. Reduced rumen residence time decreases digestibility of these components in the fluid phase hence, rumen by-pass occurs. Increased RFD has the disadvantage of reducing digestibility of those components best digested in the rumen such as fiber. Increased RFD can produce changes in the microbial population favoring rapidly growing organisms with lower maintenance requirements and produce a fermentation favoring acetate rather than propionate production. Accurate physical form evaluation would allow formulation of rations for optimum partitioning of nutrients as well as maintaining ruminant health.

Since corn silage is the major forage in dairy cattle rations in Virginia evaluation of corn silage physical form would be beneficial. Feeding corn silage as the only forage in the ration requires more careful management than when other forage sources such as hays are included with the corn silage. Therefore evaluation of cow response to fiber sources supplemented to corn silage-based rations has merit.

Objectives of these experiments were to: Experiment I, 1) determine influence of added amounts of orchardgrass (OG), alfalfa (ALF), or cottonseed hulls (CSH) to corn silage-based rations on intake, nitrogen balance, rumen fermentation, and rumen fluid and solids dilution rates. Experiment II, 2) compare 9% added OG, ALF, or CSH to corn silage-based rations on intake, chewing time, rumen fermentation, and rumen fluid and solids dilution rates. Experiment III, 3) evaluate a fine chop corn silage-based ration supplemented with 0, 9, or 18% chopped OG on intake, rumen fermentation, and rumen fluid and solids dilution rates.

Chapter II

LITERATURE REVIEW

FIBER AND ANIMAL HEALTH

Evaluating the roughage component of a dairy ration has become more important since high grain feeding has been shown to increase milk production. High-level grain feeding has resulted in metabolic disorders such as milk fat depression, liver damage, founder, bloat and indigestion, and physiological disorders such as stiffness of joints and possibly abomasal displacement (Kesler and Spahr, 1964). Most of these disorders cause cows to go off feed and reduce milk production. Inclusion of roughage or fiber sources in the ration has been shown to prevent or correct these metabolic and physiological disorders. Although maintaining cow health and preventing off-feed problems is most important, other benefits of roughage in a ration have been observed. Among those observed are optimum nutrient intake, increased rate of passage of digesta, altered rumen fermentation pattern, enhanced digestion of some components and increased animal performance (Kesler and Spahr, 1964).

Consideration of forage:concentrate ratio was first studied by Ronning and Laben (1966), in a California study. They judged that a 60:40 ratio of alfalfa hay:concentrate resulted in best performance for first-lactation cows after peak of lactation. In the same experiment a 90:10 ratio depressed milk yield because cows were unable to consume enough energy. In 30:70 ratio and 0:100 dietary ratio diets cows consumed excess energy and became over-conditioned. Milk fat percent was depressed with the 0:100 ratio diet. Health problems were not reported in this study.

Kesler and Spahr (1964) indicated that maximum nutrient intake occurred in high producing dairy cows when concentrates made up 50% to 60% of a ration containing corn silage and alfalfa-grass hay. Later, Spahr and Harshbarger (1971) showed that when corn silage was the only forage in a complete feed containing 45% to 50% concentrates, milk production of 30 kg per day could be supported. Coppock et al. (1974) showed that during the second trimester of lactation dry matter intake was higher for a 45:55 forage:concentrate ratio compared to a 30:70 ratio. Energy balance was negative for the first trimester of lactation but reached equilibrium during the second trimester. Increasing the concentrate portion of the ration reduced the time for animals to reach energy equilibrium.

Studies by Moe et al. (1971) and Coppock et al. (1974) have shown that high producing dairy cows in the first trimester of lactation are unable to consume enough feed to maintain energy balance even with rations composed of up to 80% concentrates. Dairy cows reach energy equilibrium in the second trimester but as energy requirements taper off, cows do not regulate their feed intake according to physiological requirements. Cows in third trimester will overconsume energy and become overconditioned unless ration changes are made. Rations composed of silages and high quantities of concentrate should be modified during various stages of lactation to control energy intake to reflect changing lactation requirements (Coppock et al., 1974).

PHYSICAL FORM

Metabolic and physiological problems associated with high concentrate feeding have been observed by pelleting or fine grinding of forage or entire ration. It has been advantageous to alter the physical form of many feedstuffs, especially low quality crops or crop residues to optimize their intake.

Milk fat depression may be the first noticeable symptom from feeding a pelleted or finely ground ration. Powell in 1939 first reported the relationship between physical form and milk fat depression. O'Dell et al. (1968) at Clemson studied the effect of grinding and pelleting of coastal bermudagrass in relation to milk fat test and milk production. Using forage ground to different fineness (0.16cm, 0.32 cm, 0.64 cm, and 0.95 cm) and pelleted (0.64 cm) or not, they determined that the critical grind size in relation to milk fat depression was approximately 0.64 cm. Individual animal variation precluded an exact measurement. Milk production was not affected by physical form alterations. Milk fat depression was not as great for groups receiving ground hay rations as compared to groups receiving the same rations pelleted. Their observation was that pelleting of forage or ration appears to further reduce particle size.

Miller et al. (1969) at Virginia showed that when cows consumed finely chopped corn silage considerable milk fat depression occurred. Milk fat percentage declined from 3.5 to 3.0 over a 10 week period but there was no influence on milk yields. From this study a recommended knife setting for the field chopper was 1.0 to 1.3 cm to avoid milk fat depression in cows consuming corn silage as the sole forage source.

Jorgensen et al. (1978) showed that alfalfa silage should not be less than 0.64 cm theoretical length of cut (TLC) when used as the only source of forage. Furthermore this may not be adequate for dry cows and the period immediately after calving for prevention of off-feed problems and displaced abomasum. Cows fed finely chopped silage (0.48 cm TLC) gained significantly more body weight compared to cows fed a medium chopped silage (0.64 cm TLC). Finely chopped silage fed at 33:67 forage:grain ratio depressed milk fat test (3.0%) and produced higher milk production per day. When the finely chopped silage was fed at 50:50 forage:grain ratio, milk fat test was not depressed.

Feeding pelleted coastal bermudagrass to Clemson dairy cows resulted in milk fat depression (O'Dell et al., 1964; Chalupa et al., 1969). Supplementing pelleted rations with baled hay or corn silage prevented declines in milk fat test. Baled hay supplemented at 2.27 kg daily increased milk fat from 3.5 to 3.7%. Corn silage (6.8 kg) supplemented to the pelleted rations also increased milk fat 0.2 percentage units. O'Dell et al. (1964) fed pelleted coastal bermudagrass to six cows for 56 days, then divided the cows into groups and supplemented 2.27 kg baled alfalfa per cow per day or fed the pelleted ration 4 times per day. Supplementing the baled hay (2X feeding) prevented further milk fat depression maintaining a 3.0 fat test. Four-times-daily (4X) feeding of the pellets increased milk fat from 1.9% to 2.3%. These studies indicated that 4X feeding of pelleted rations or supplementing baled hay or corn silage to pelleted rations was effective in preventing milk fat depression.

Dry matter intake was affected by alfalfa hay addition to corn silage rations (Waugh et al., 1955). Alfalfa hay was offered at 1.00, 0.50, 0.25, and 0.00% of live weight daily, separate from the grain and corn silage. The higher level of hay (1.00%) increased total dry matter intake. Maximum fat corrected milk (FCM) production was not observed with the highest hay level but at 0.50% level. Silage intake per day increased as amount of hay supplemented decreased. At the 0.50% level, utilization of silage hay, and grain dry matter was maximum as reflected in FCM production. Although hay increased intake of dry matter, silage dry matter was more valuable for milk production than hay dry matter. Total digestible nutrients (TDN) of alfalfa hay was 54 to 59% (dry-basis) while corn silage was 64 to 67% (dry-basis). Silage provided more energy for milk production.

In a review Hemken and Vandersall (1967) suggested possible problems when silage was the only source of forage: a) nutrient deficiency, such as vitamin A or a mineral deficiency, b) difficulty in maintaining forage intake because cattle tire of the ration and c) possible physiological effects from the absence of dry roughage. They suggest that in addition to calcium, phosphorus, and salt, iodine may also be a problem. Possible problems with goiters in calves, retained placentas or other breeding problems can also occur. The higher nitrate levels of silage may inhibit thyroid activity and cause the iodine deficiency. Addition of iodine apparently overcomes the problem.

Vitamin A could be a potential problem in some areas (Hemken and Vandersall, 1967). Blood vitamin A levels were lower in Maryland as compared to Michigan. There was not a clear relation in blood vitamin A levels between cows fed all silage and those supplemented with hay. A poor conversion of carotene to vitamin A may be a potential reason for lower blood levels. Supplementation with carotene or vitamin A may be necessary in some areas.

Addition of fiber sources to corn silage rations increases the acid detergent fiber (ADF). Average corn silage with 27-30% ADF mixed in a silage:grain ratio of 60:40 would provide 16-18% ration ADF. Supplementing silage with fiber sources in lieu of a portion of silage would maintain 21% ADF in the total ration. This level of ADF has been suggested as the requirement to support milk fat synthesis (NRC, 1978).

The importance of ADF in the dairy ration was demonstrated by Lofgren and Warner (1970). In cows susceptible to milk fat depression, ADF had a correlation coefficient of +.072 with fat test change for each percentage dry matter change. Other fiber components such as crude fiber (r = +0.49), cell wall constituents (r = +0.31), hemicellulose (r = -0.10), cellulose (r = +0.44), and lignin (r = -0.15) had lower correlation coefficients than ADF. ADF was the best index of the ability of a diet to increase milk fat percentage. In this study, 17.5% ADF maintained fat test at an average of 3.3%.

ACID DETERGENT FIBER IN RATIONS

The ADF content of a ration is related to net energy (NE) content. Chandler and Walker (1972) showed that crude fiber (CF) content of a ration was negatively correlated (R^2 = 0.785) with NE(lact.). In this equation a lower limit of 14% CF (dry-basis) was set thereby restricting NE(lact.) to 1.904 Mcal/kg dry matter. Crude fiber was used in this equation because ADF content of many feedstuffs was not available. CF of a feed is related to ADF content. Several relationships between ADF and CF have been established: New York equation CF = 0.79 ADF, Clemson equation CF = 0.75 ADF + 3.56, and Penn State equation CF = 0.967 ADF - 3.80 (Coppock, 1975).

Another relationship was established (Jahn and Chandler, 1976) between ADF in a ration and response to added protein. The response to increasing protein of a ration depended on the ADF content of that ration. Protein increases above 14.5% resulted in declines in dry matter intake when ration ADF was 11 and 25%. However, at 18% ADF the intake continued to increase as protein increased above 14.5%.

FIBER AND RUMEN FERMENTATION

It is difficult to distinguish between physical and chemical effects of a feedstuff or ration. The physical aspect appears to be necessary for normal rumen function and health but also affects rate of solid and liquid passage and subsequently the type of rumen fermentation. The chemical aspect appears to affect rate of digestion, microbial activity, and fermentation end products. The physical-chemical parameters that affect digestion of a ration in the dairy cow influence partition of ration energy between body weight and milk production. Partition of energy appears to be highly correlated to the type of rumen fermentation produced by feeding a ration. Type of rumen fermentation can be classified as high acetate, high propionate, or occassionally high butyrate. High acetate fermentation appears to be related to partition of energy into milk fat. A high propionate ration appears to be related to partitioning energy into body stores and reflecting lower energy in milk by depressing fat content.

A very descriptive concept of type of rumen fermentation and its influence on partition of energy has been proposed by Orskov (1975). The concept develops a ratio of non-glucogenic to glucogenic volatile fatty acids (VFA) produced by rumen fermentation. Non-glucogenic VFA are acetic and butyric which can not be used to synthesize glucose. The major glucogenic VFA is propionic which can be used to synthesize glucose. The non-glucogenic ratio (NGR) is defined as:

$$\text{NGR} = \frac{\text{acetic} + 2\ \text{butyric} + \text{valeric acid}}{\text{propionic} + \text{valeric acid}}$$

where VFA are expressed as moles/100 moles. Valeric acid appears in both numerator and denominator because valerate produces 1 mole of acetic and 1 mole of propionic acid upon oxidation. The NGR at which milk fat depression occurs is not well defined and may vary with stage of lactation and breed of animal. For efficient utilization of energy the NGR should be below 4 but if the NGR falls below 3 milk fat synthesis may be depressed because energy may be partitioned to body tissues. Orskov (1975) suggested that much of the apparent disagreement among results from different laboratories could be resolved by using the concept of NGR.

The most comprehensive data on the relation between NGR and energy utilization was evaluated by Orskov (1975) from data of Coppock et al. (1964) and Flatt et al. (1969a, b) for lactating dairy cows. Utilization of metabolizable energy (ME) is maximum with an NGR between 2.25 and 3.0. When NGR is above 4.0 utilization of ME will begin to decrease. Unless NGR is above 3.5 there is a definite effect on partition of energy to favor body fat synthesis and decrease in milk fat synthesis. An NGR between 3.5 and 4.0 would produce most efficient utilization of ME and support milk fat synthesis.

RATE OF PASSAGE

The rate of passage of material through the digestive tract affects how much of the ration is degraded in the rumen and how much escapes ruminal degradation to be digested in the lower tract. Liquid rate of passage or dilution rate is a major factor affecting microbial species in the rumen, efficiency of microbial growth and type of fermentation. In an animal with a low rumen fluid dilution rate, ration protein and soluble carbohydrates may be extensively degraded in the rumen allowing very little to enter the lower tract. A faster fluid dilution rate may allow a portion of the ration protein and soluble carbohydrate to enter the lower tract undegraded.

Bypass protein has a higher biological value when digested postruminally (Little and Mitchell, 1967). Soluble carbohydrate is utilized 11 to 30% more efficiently when digested postruminally rather than in the rumen. One disadvantage of increasing fluid dilution rate is a depressed digestion of those components primarily digested in the rumen (Mertens, 1977).

Much research on rate of passage has been done with sheep and beef cows. Only a few researchers have studied rate of passage in dairy cows where intake is multiples of maintenance. Bauman et al. (1971a) measured rumen fluid dilution rate with dairy cows using polyethylene glycol. A ration containing 57% alfalfa hay was compared to a high-grain ration with 10% alfalfa hay. Cows fed the control ration (57% hay) had a dilution rate of 20.6%/hr while the cows fed the high-grain ration (10% hay) had only 9.6%/hr. A slightly larger rumen fluid volume was observed for the control cows (47.6 l) compared to high-grain cows (44.9 l). Dry matter intake was 15.6 kg/d for control and 17.4 kg/d for high-grain cows. Higher rumen fluid dilution rate of the controls was associated with decreased rumen propionate. Molar proportions of acetate, propionate and butyrate for control and high-grain cows were 69, 21, 10, and 45, 47, 8, respectively. The increased propionate concentration was associated with milk fat depression (1.9%) observed with high-grain cows. The control ration supported milk fat synthesis (4.0%).

Harrison et al. (1975) demonstrated with sheep that as rumen fluid dilution rate increased, molar proportion of propionic decreased in the rumen. Dilution rate was increased by infusion of sodium bicarbonate or artificial saliva solution. Infusion of water had no effect on dilution rate. They also observed an increase rumen bypass of organic matter, alpha-linked glucose, total amino acids, and total microbial amino acids with increasing dilution rate.

Many inferences of the effect of dilution rate on microbial synthesis and microbial products entering the lower tract have been obtained using continuous culture techniques. Several excellent reviews (Owens and Isaacson, 1977; Bull et al.,1979) have been published that deal with the impact of dilution rate on microbial synthesis from in vitro continuous culture. Increasing dilution rate tends to increase bacterial efficiency. Bacterial efficiency is described by Y-ATP, grams of cells per mole ATP. The Y-ATP increases with dilution rate which appears to be due to a decreased energy expenditure for maintenance of the bacterial population. Isaacson et al. (1975) demonstrated that increasing dilution rate with a constant energy (glucose) supply decreased maintenance energy, decreased the fermentor population but increased the yield of cells from 263 to 462 mg/day. Efficiency of bacterial growth increased from 0.25 to 0.44 grams of cells per gram of glucose metabolized. Y-ATP increased from 7.5 to 16.7 as dilution rate increased from 2 to 12%/hr.

Data of Hespell (1979) indicates a theoretical Y-ATP of about 32 for bacterial growth on preformed monomers. However for bacterial growth on glucose and inorganic salts Y-ATP would be about 21. Hespell (1979) indicates that under optimal feeding in which equal amounts of cells are derived from glucose-salts and preformed monomers, a theoretical Y-ATP for rumen bacterial population would be about 26.

Owens and Isaacson (1977) concluded that accelerating fluid dilution rate will increase the efficiency of bacterial growth and the use of non-protein nitrogen. Increasing fluid dilution would increase microbial protein, soluble feed protein, and soluble carbohydrate to the lower tract. However, there may be a decrease in total-tract fiber digestion because of decreased rumen retention. Increased dilution rate will increase acetate:propionate ratio, which in turn may alter ruminal and animal energetics.

STARCH DIGESTION

The NGR concept proposed by Orskov (1975) is an important parameter relating energy utilization to rumen fermentation. However any material escaping degradation in the rumen and which can be digested postruminally and absorbed as glucose will affect the NGR. Factors affecting the extent of degradation of starch in the rumen will have an important effect. Extent of degradation and rate of passage of starch through the rumen are the major factors involved.

The extent of starch degradation in the rumen depends on the processing and physical form of the grain (Waldo, 1973). The main sources of starch in feedstuffs are barley, corn, and sorghum. Barley starch digestion at the abomasum or duodenum was 94% ± 2.4 and was not affected by processing or by total intake. Corn grain starch digestion was 78% ± 12.5 at the abomasum or duodenum. Processing of corn grain, ground vs. flaking, increased rumen digestibility from 82.8 to 95.1 for sheep. Increasing the level of corn in a ration decreases the percentage digested in the rumen. Sorghum starch digestibility was 76% ± 22.4 at the abomasum. Sorghum starch is digested less in rumen of cattle than sheep. Moist heat treating of sorghum starch increases rumen digestion equivalent to barely starch.

Feed intake has a significant effect on starch digestion. Wheeler et al. (1975) showed that starch digestion was 96% at maintenance intake level whereas at feed intakes of 2.5 to 3.2 multiples of maintenance, the digestibility of starch was 84.7 to 88.1%. Considerable quantities of starch were escaping fermentation in the reticulorumen, and substantial amounts reaching the small intestine were not digested. Decreased starch digestion in the rumen could be due to increased rate of passage or an unfavorable environment in lower tract. Amylolytic activity in small intestine may be reduced due to intestinal pH below optimum (6.9) for enzymatic activity which decreases starch digestion.

PHYSICAL FORM EVALUATIONS

It appears that a descriptive definition of the influence of ration physical form on health, digestive efficiency and production is needed. There have been several attempts to define the influence of ration physical form and establish requirements for production of meat and milk and maintaining animal health.

Effective Fiber

One method which combines the chemical analysis and physical form of rations and feedstuffs was developed and proposed by Harris (1975). This procedure used the term "effective fiber" to describe the ability of feedstuffs to support milk fat synthesis. All feedstuffs were compared to cottonseed hulls as a standard. Harris indicated that dairy cow rations should supply 17% effective fiber. Any ingredient finely ground and pelleted would contain less than 10% effective fiber. A fair measure of effective fiber can be obtained by placing pelleted or chopped products in water and examine the length of the fiber particles. If the product contains many fibers .64 to1.27 cm in length, it may be used with a fair degree of success.

Relatively few feedstuffs have been evaluated through feeding trials and assigned values for effective fiber. The Dairy Cattle Feed Formulation System (1979) contains many feedstuffs which have been assigned values but not actually tested. These values are then used to formulate rations containing a required effective fiber level. This effective fiber procedure does not provide a rapid laboratory evaluation to determine effective fiber values of feedstuffs. The usefulness of the procedure is limited because of the variability of feedstuff physical form, especially processed feedstuffs.

Roughage Factor

Another method for evaluating physical form requirements was proposed by McCullough (1973). McCullough used the term "roughage factor" to rate feedstuffs on their ability to contribute true fiber or bulk to complete dairy rations. The roughage factor for each feedstuff was compared to a standard such as silage or long hay. A minimum roughage factor (units/wt) for complete rations was established based on milk production per day. For cows producing less than 18.2 kg of milk per day, 1000 units per ton of air dry ration would be required. For 18.2 to 27.3 kg production, 800 units would be required and greater than 27.3 kg production would require 600 units. The evaluation procedure is not clearly defined and only a few feedstuffs have been assigned values. This procedure is limited because of the variability of feedstuff physical form.

Chewing Time

A third method of evaluating physical form was proposed by Balch (1971). This is based on time an animal spends chewing as an index of "fibrousness" of that feedstuff. Balch had observed that as roughage increased in a ration or coarseness increased, so did the time the animal spent chewing. Sudweeks (1979) at Georgia has evaluated feedstuff for dairy cows and found that 31.4 minutes of chewing time per kilogram of feed would maintain 3.5% milk fat test. The R^2 for this regression equation was only 0.37.

Jorgensen et al. (1978) at Wisconsin evaluated alfalfa silage at 3 theoretical lengths of cut (TLC) for lactating dairy cows. In a 33:67 (forage:grain ratio) ration, milk fat was depressed with the fine (.46 cm) TLC. Chewing time per 24 hr was only 7.4 hours. With a medium (.64 cm) TLC milk fat tested was 3.6% and chewing time was 9.4 hr per 24 hr. Roughage index, minutes chewing per lb dry matter intake (DMI), was 8.2 for fine TLC and 10.3 for medium TLC. Jorgensen et al. (1978) predicted that when chewing time drops below 9.4 to 9.8 hr/24 hr or 10.3 to 10.5 minutes per pound of DMI, energy may be partitioned to body weight gain and milk energy (fat) reduced.

Jorgensen et al. (1978) found that chewing time was associated with intake of cell wall constituents (CWC) and particle size. Welch and Smith (1969) also found that CWC intake was highly correlated (r = +0.99) with time spent chewing in sheep. Jorgensen (1979) summarized the importance of the "roughage index" value (time chewing/lb DMI) to physical form of a ration since total chewing time relates to saliva flow, rumen pH, acetic:propionic acid ratio, and subsequently energy output as milk or tissue.

Bulk Evaluation

A routine analysis has been developed by Clancy et al. (1976) for measuring bulk density of as-fed feedstuffs and rations. Bulk density of rations was considered in McCullough's (1973) roughage factor system. Studies on the influence of bulk density (weight/unit of volume) on intake and animal performance have demonstrated that intake regulation is related to bulk and digestibility. In a study by Bull et al. (1975) it was demonstrated that a diet with caloric density of 0.68 Mcal digestible energy/liter was the point above which physiological regulation was employed by dairy cows. Physical limitation to intake occurred with diets having a caloric density of 0.58 and 0.63. This offers a technique to regulate intake in late lactation or the dry period. It should be possible to formulate rations to maximize utilization of forages in rations with digestible energy density close to the point where physical and physiological factors converge in the regulation of energy intake. It may be necessary to establish this relationship for different types of roughages because of differences in rumen and lower tract retention times.

Intake of bulk density was greater for a ration containing orchardgrass compared to a ration containing alfalfa (Kilmer et al., 1979). Digestible energy (DE) intake was not different for the 2 rations fed to lactating dairy cows.

Intake of dry matter (DM) was higher for the alfalfa ration compared to the orchardgrass ration. There also was no difference in neutral detergent fiber (NDF) intake. Digesitibility of dry matter and NDF was significantly higher for the orchardgrass diets. The authors associated the higher volume intake for orchardgrass with the higher digestibility coefficients for DM and NDF compared to alfalfa.

Mertens (1980) has suggested that NDF should be used as an index to measure effective density of dairy rations. Mertens points out that NDF has been shown to be highly correlated to digestibility (r = -0.65), rumination (r = +0.99), and intake (r = -0.65). It appears that NDF content is similar among different qualities of hay and would provide a more accurate measure of maximum productivity of a ration compared to acid detergent fiber (ADF) or crude fiber (CF) analysis. An optimum NDF content for maximum dry matter intake and maximum solid-corrected milk production has been demonstrated. However differences may exist among sources of NDF because of rate of passage or bulk density variability. More work is needed on this concept and a major obstacle is method for measuring bulk density.

SUMMARY

Adequate methods to evaluate the effective fiber content of a ration have not been developed. Effective fiber content of a ration or feedstuff can be defined as the influence that a feedstuff has on the intake, digestion and utilization of ration components for production and health of ruminants. Attempts to evaluate physical form which is closely related to effective fiber content has met with some success but as feedstuffs are highly processed, such as by-products, a more critical evaluation will be necessary. From the literature it appears that rate of passage of liquid and solid material through the digestive tract has the greatest influence on type of rumen fermentation and site of digestion of the major components. Physical form of feeds influences rate of passage but may be more important in supplying needed bulk to maintain rumen integrity and overall animal health.

Chapter III

EXPERIMENT I

PROCEDURES

Experimental Design

A split plot design was utilized with three types of added fiber plus a Control of 9% orchardgrass and three amounts of each type. This design had two cows assigned to each type of fiber and the control. Each level was fed for 3-wk periods with days 14 through 21 for data coll ection. Statistical design, model and animal assignments are shown in Appendix table 1. This design allows comparison of a basal corn silage ration to rations containing additional fiber sources: orchardgrass hay (OG), alfalfa hay (ALF), or cottonseed hulls (CSH). Regression coefficients for each variable on amounts increasing of each fiber source were calculated and compared. Orthogonal contrasts of 0% added fiber (basal) versus 9% added (OG and ALF plus 5.5% CSH) and rations containing Hays (OG and ALF at 9 and 18%) versus CSH (5.5 and 11%) can be made. CSH at 5.5% provides an equalivalent amount of ADF as OG or ALF, therefore this treatment was included in 9% treatment contrast. Since the Control ration was 9% added orchardgrass for all periods it was not included in slope calculations.

Ration Formulation and Analysis

Alfalfa and orchardgrass additions to the corn silage-based ration were 0, 9, and 18% of the corn silage dry matter, whereas cottonseed hulls were added at 0, 5.5, and 11%. Alfalfa and orchardgrass hays were chopped to give an average particle length of 10 cm. The corn silage was a medium to coarse chop with a theoretical length of cut (TLC) of 1.27 cm. The rations were formulated to have a 60:40 forage:concentrate ratio, 15.5% crude protein and 18-22% acid detergent fiber (ADF). The concentrate portion of the ration consisted of the herd concentrate mix and dry corn grain. The concentrate mix is detailed in table 1. The ration compositions are shown in table 2. The added fiber, corn silage, concentrate mix and dry corn were mixed prior to each feeding. The cows were fed twice daily at 0700 and 1400. Weighback (orts) was taken daily at 0900. The rations were offered to have 2.5-3.8 kg orts daily.

Feed and Ort Analysis

Feed and orts were dried at 60 C to a constant weight and ground through a 2.0 mm screen and analyzed for cell wall constituents by the neutral detergent fiber (NDF) procedure of Robertson and Van Soest (1978) and acid detergent fiber (ADF) by Goering and Van Soest (1970). Crude protein was analyzed by Kjeldahl. Dry matter (DM) was

Table 1. Composition of dairy concentrate B.

Ingredient	Concentration[a]	Specifications
	%	
Dried molasses	1.25	--
Wet molasses	3.00	3% CP
Distillers grains	2.50	25% CP
Wheat	5.75	10% CP
Pellet binder[b]	2.00	8% CP
Trace mineral salt	1.75	--
Ground limestone	2.50	--
Dicalcium phosphate	3.50	--
Sodium sulfate	.75	--
Magnesium oxide	.75	--
Methionine hydroxy analog	.35	--
Vitamin mix	.50	$12x10^6$ IU A and D
Soybean meal	75.40	--
Total	100.00	35% CP

[a]Calculated on as-fed basis.
[b]Pelleted with a .40-cm die.

Table 2. Ration formulations and specifications used to determine the influence of added fiber on corn silage-based rations.

Ingredients[a] % Added Fiber:	Basal	Orchardgrass		Alfalfa		Cottonseed hulls	
	0	9	18	9	18	5.5	11
	%	%	%	%	%	%	%
Corn silage	60.0	51.0	42.0	51.0	42.0	54.5	49.0
Orchardgrass hay[b]	--	9.0	18.0	--	--	--	--
Alfalfa hay[b]	--	--	--	9.0	18.0	--	--
Cottonseed hulls[c]	--	--	--	--	--	5.5	11.0
Concentrate B	24.8	24.0	23.2	22.5	20.2	25.2	25.6
Cracked corn	15.2	16.0	16.8	17.5	19.8	14.8	14.4
Specifications:							
Dry matter[d]	54.9	58.3	62.1	58.2	61.9	57.0	59.2
Crude protein[d]	15.5	15.5	15.5	15.5	15.5	15.5	15.5
Acid detergent[d] fiber	18.1	19.5	20.8	19.2	20.3	20.4	22.7
NE_1[e]	150	151	152	150	149	148	145

[a]Calculated on dry matter basis.

[b]Hay chopped to produce average particle size of 10 cm.

[c]Donated by National Cottonseed Products Assoc., Memphis, Tenn.

[d]%.

[e]Mcal/kg (estimated NRC, 1978).

determined by oven drying at 60 C to a constant weight (approximately 72 h).

Data Collection

Rations and orts were sampled each feeding for 5 d beginning at 14 d of each period. Total collection procedures were conducted for 5 d beginning at 14 d. Feces and urine (via catheter) were collected, weighed, mixed, sampled (.22% urine, and 2.2% wet feces), and frozen for analysis. Milk was sampled (.22% volume) at each milking and frozen. Rumen fluid samples were taken 2 h post-feeding on 21 d using a metal suction strainer described by Raun and Burroughs (1962) and transported to the laboratory in a stoppered flask.

Feces, urine, and milk were analyzed for nitrogen by Kjeldahl. Feces were oven dried at 60 C to a constant weight for NDF and ADF analysis by procedures already described. Rumen fluid was measured for pH and a 5 ml aliquot of rumen fluid was pipetted into a tube containing 1 ml of 3 N sulfuric acid, mixed and frozen (-15 C) for volatile fatty acid analysis. Volatile fatty acids were analyzed by gas chromatography (Ottenstein and Bartley, 1971) using the internal standard (isocaproic acid) procedure for quantitation.

Rate of Passage Measurements

Rate of passage was measured using the lithium salt of cobalt ethylenediaminetetraacetic acid (CoEDTA) and Ytterbium chloride (Yb) markers. CoEDTA was prepared by the procedure of Uden et al. (1978). Yb solution was prepared by adding 3 g Ytterbium chloride to 30 ml of water. Acetic acid was added to reduce the pH to below 4.5 and then the total volume was made to 50 ml (Hart, 1981). CoEDTA was given orally in 2 gelatin capsules (12g each) and 3g of Yb (50ml solution) was sprayed on a portion of the ration at the 1400 h feeding.

Markers were given at the beginning of total collection. Fecal samples (approximately 100g) were taken at time zero for background and at 4-h intervals to 28 h and 6-h intervals to 120 h post-dosing. Fecal samples were mixed and an aliquot dried at 100 C for marker analysis. Dried fecal samples were ground through a 2.0 mm screen in a Wiley mill for analysis. Samples were prepared for marker analysis by atomic absorption (CoEDTA) and atomic emission (Yb) by procedures described by Hart (1981).

Statistical Analysis

Data from this experiment were analyzed by the Statistical Analysis System.[1] Analysis of the treatments was by the general linear model procedure of SAS using the model:

Y = Ration Cow Period

All experimental rations were grouped as seven rations. These were as follows: 0% Added, 9% OG, 18% OG, 9% ALF, 18% ALF, 5.5% CSH, 11% CSH. These ration groups are shown by the dotted-line boxes in Appendix table 1A. The model above refers to the seven rations. Orthogonal contrasts were made between 0% Added (group 1) versus 9% OG (groups 2, 4, and 6) and Hays (groups 2, 3, 4, and 5) versus CSH (groups 6 and 7).

Slopes were calculated for response per % added (as-fed) fiber source. Test of slope differences for types used the model:

Y = Type Period Cow(Type) Type*Period

Models used in this experiment are further described in Appendix table 1. All-pairs comparisons of the three slopes were made and tested by Bonferroni F test. Rate of passage was determined by fitting the marker excretion data to a two compartment model described by Ellis et al. (1979) using a SAS program described by Hart (1981). Passage rate esti-

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[1]SAS Institue Inc., Raleigh, NC, 1979.

mates were statistically analyzed by models described above.

RESULTS AND DISCUSSION

Ration Analysis

Rations were formulated to be isonitrogenous but variation was observed (table 3). Crude protein was slightly below the 15.5% formulated value with added fiber rations tending to be highest. Variation in DM and CP observed with ration analysis may have been caused by difficulty in obtaining representative ration samples. Coarseness of the silage and chopped hays make sampling these rations difficult. However the 18% OG, 18% ALF, and 11% CSH ration analysis (table 3) agree with the calculated DM and CP values (table 2). ADF analysis of the complete rations was higher for all rations which may relate to filtering problems with the concentrate portion of the samples. Cell wall constituents (CWC) and acid detergent fiber (ADF) were higher for added fiber rations compared to 0% rations. Recommended ADF for lactating cow rations is a minimum of 17% (NRC, 1978) which is slightly lower than the 0% rations. Adding these fiber sources may increase ADF and provide a margin of safety for supporting milk fat synthesis in lactating dairy cows.

Table 3. Analysis of rations used to determine influence on lactating cows of added fiber to corn silage-based rations.

	Basal	Orchardgrass		Alfalfa		Cottonseed hulls	
Component[a] % Added Fiber:	0	9	18	9	18	5.5	11
Dry matter	56.8	60.3	62.3	61.3	61.9	59.6	59.6
Crude protein	14.1	13.9	15.4	13.9	15.1	14.3	15.1
Acid detergent fiber	18.9	22.5	23.9	22.9	24.7	22.6	26.1
Cell wall constituents	34.3	40.3	43.0	36.5	42.6	41.5	42.0

[a]Calculated on dry matter basis.

Intake and Digestibility

Intake of dry matter (DM), cell wall constituent (CWC), and acid detergent fiber (ADF) is shown in table 4. Adjusting DM intake for the ration sampling error by using calculated DM content of the total rations did not greatly affect intake pattern (table 4) or statistical analysis (table 5). Most cows during the second period of the experiment apparently experienced digestive disturbance. This is reflected in lower DMI for control cows during period 2 (figure 1). Cows experienced some degree of diarrhea and may have been irritated by loss and replacement of catheters. These problems were not as evident during periods 1 and 3, however the statistical model accounts for a period effect.

Orthogonal contrasts for intake and digestibility are shown in table 5. Although intake was greater for 9% and CSH rations the contrasts were not significant. Intake adjusted for body weight did not affect the statistics, indicating comparable body weights for each group. Differences in intake of CWC approached significance and would be expected to be higher for 9% and CSH rations because of slightly higher CWC content. ADF intake was slightly higher ($P<.11$) for 9% compared to 0% rations. Higher ADF content of CSH rations increased ($P<.01$) ADF intake compared to rations containing Hays. Digestibility of DM, CWC, and ADF

Table 4. Dry matter (DM), cell wall constituents (CWC), and acid detergent fiber (ADF) intake and digestibility for Experiment I.

Ration	Period	% Added fiber	Intake[a]			Digestion Coefficients		
			DM[b]	CWC	ADF	DM	CWC	ADF
Control	1	9	19.7(19.2)	7.8	4.7	66.2	49.6	53.9
	2	9	17.7(16.8)	7.7	4.1	67.5	55.2	50.1
	3	9	19.2(18.9)	7.3	4.3	66.1	50.0	49.7
Orchard-grass hay	1	0	21.7(20.8)	7.4	4.6	65.0	43.6	50.7
	2	9	21.1(20.3)	9.2	4.5	68.0	56.4	49.9
	3	18	19.3(19.2)	8.3	4.5	67.1	52.3	50.7
Alfalfa hay	1	0	19.3(18.6)	6.6	4.0	66.9	45.0	49.9
	2	9	19.0(18.0)	6.9	3.9	66.1	44.1	41.6
	3	18	18.8(18.8)	8.0	4.6	66.4	52.5	53.5
Cottonseed hulls	1	0	19.1(18.4)	6.5	4.0	68.2	49.2	53.0
	2	5.5	18.3(17.4)	7.6	3.7	65.5	46.7	33.0
	3	11	22.2(22.1)	9.3	5.8	65.3	43.6	45.4
S. E. M.			.9	.4	.2	.9	1.9	2.0

[a]kg/d. CWC and ADF calculated on dry matter basis.

[b]Intake calculated from dry matter content of rations in Table 2 are shown in parathesis.

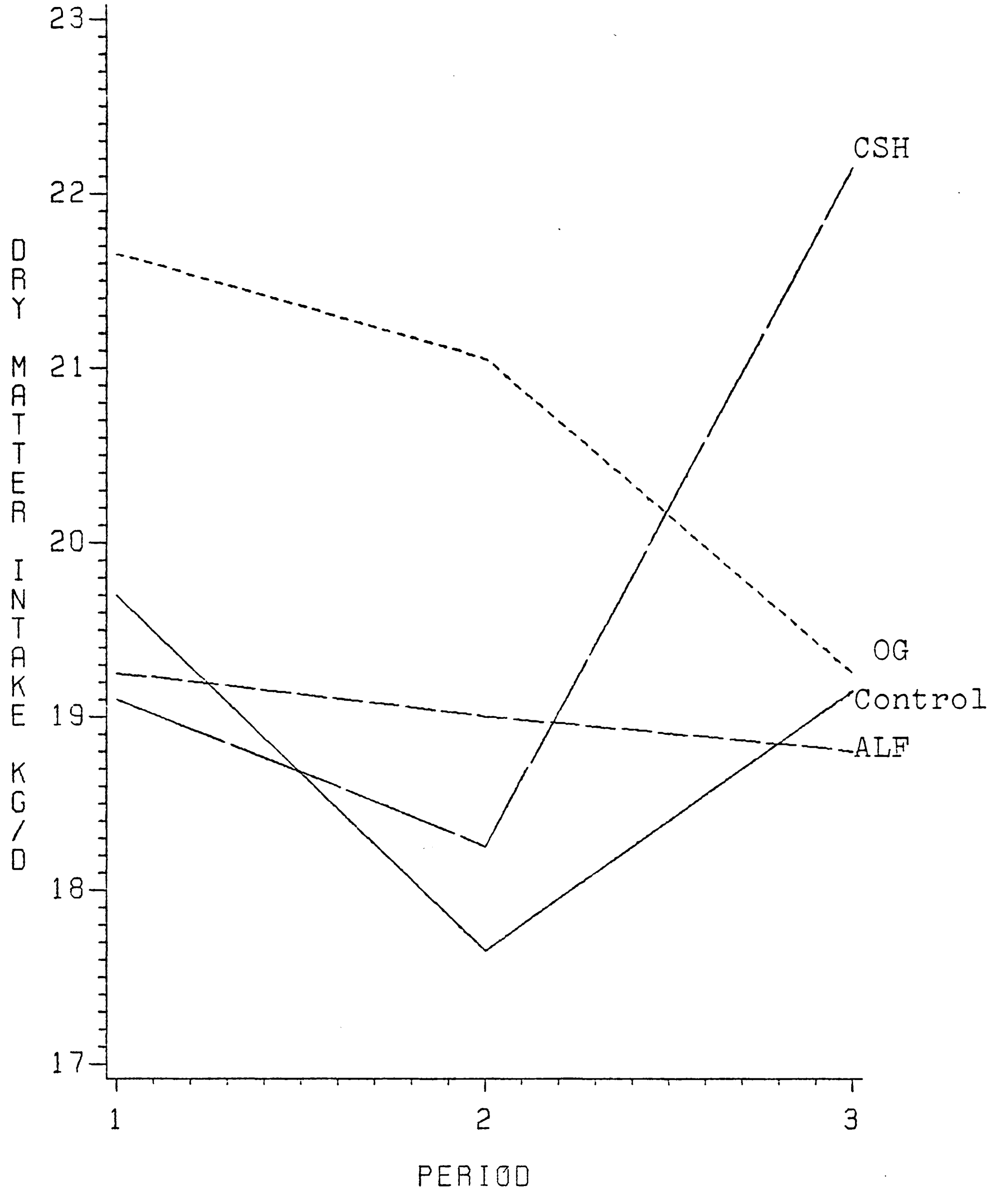

Figure 1. Dry matter intake for Experiment 1.

Table 5. Orthogonal contrasts of 0% versus 9% rations and rations containing Hays versus Cottonseed hulls (CSH) for intake and digestibility.

Variable	Orthogonal Contrast[d]					
	0% vs 9%			Hays vs CSH		
	-- Mean --		P<	-- Mean --		P<
Intake of:						
Dry matter[ae]	18.7 (17.9)	20.2 (19.6)	.33 (.21)	19.1 (18.6)	21.1 (20.6)	.16 (.12)
Dry matter[b]	3.3	3.6	.29	3.4	3.8	.17
Cell wall constituents[a]	6.4	7.5	.11	7.8	8.6	.20
Acid detergent fiber[a]	3.9	4.3	.11	4.4	5.2	.01
Digestibility of:						
Dry matter[c]	66.6	65.1	.33	66.9	63.1	.02
Cell wall constituents[c]	47.0	44.5	.44	51.1	40.0	.02
Acid detergent fiber[c]	48.4	42.6	.20	51.1	38.7	.01

[a]kg/d.

[b]% of body weight/d.

[c]%.

[d]Observations for each treatment are: 0% = 6, 9% = 12, Hays = 14, and CSH = 4.

[e]Values in parathesis were calculated using formulated ration values dry matter from Table 2.

was similar for 0% and 9% rations (table 5). Significantly lower DM, CWC, and ADF ($P<.02$, .02, and .01, respectively) digestibility was observed for rations containing cottonseed hulls compared to rations containing orchardgrass or alfalfa. Villavicencio et al. (1968) also observed lower DM and crude fiber (CF) digestion for cottonseed hulls rations compared to alfalfa or grass hay rations for dairy cows.

Comparing responses to increasing amounts of fiber types, DMI decreased .13 $kg \bullet d^{-1} \bullet \%^{-1}$ added orchardgrass whereas DMI increased .27 $kg \bullet d^{-1} \bullet \%^{-1}$ added cottonseed hulls (table 6). Response to added alfalfa was slightly negative (-.03 $kg \bullet d^{-1} \bullet \%^{-1}$). These results of feeding Alf do not agree with the data of Waugh et al. (1955) where total DMI and DMI as corn silage increased by supplementing alfalfa hay with corn silage.

Intake adjusted for body weight did not affect the relative differences in slope or statistical comparisons (table 6). Intake of CWC increased per % added fiber for the three sources. However, ADF intake decreased slightly for added orchardgrass and increased for added alfalfa and cottonseed hulls. In all categories of intake CSH produced the most positive response. Adding cottonseed hulls to corn silage-based rations would most effectively increase DM, CWC, and ADF intake. This would be especially important

Table 6. Regression coefficients[a] for increasing fiber type on intake and digestibility.

Variable	Ration		
	OG	ALF	CSH
	----- per % added -----		
Intake of:			
Dry matter[b]	-.13[e]	-.03	.27[e]
Dry matter[c]	-.02[e]	.00	.05[e]
Cell wall constituents[b]	.04	.07	.25
Acid detergent fiber[b]	-.01[e]	.03	.10[e]
Digestibility of:			
Dry matter[d]	.11	-.02	-.27
Cell wall constituents[d]	.48	.42	-.51
Acid detergent fiber[d]	.00	.20	-.69

[a]Per % added fiber type on dry matter basis.

[b]kg/d.

[c]% of body weight/d.

[d]%.

[e]Contrasts in rows tested by Bonferroni F Test at $P<.05$ level of significance.

where ration fiber would be minimal. McCoy et al. (1966) reported that rations containing 30% CSH were consumed greater than rations containing alfalfa hay or corn cobs as the sole roughage. Villavicencio et al. (1968) compared 30% CSH rations to 30% alfalfa rations and 30% native grass hay rations and observed significantly higher intake for CSH rations with Holstein cows.

CSH effectively increased intake but had a negative effect on digestibility (table 6). This is consistent with data of Villavicencio et al. (1968), and McCoy et al. (1966), in dairy cows and Cole et al. (1976a, b) for steers. Digestibility of DM and CWC increased for OG but ADF digestion was not affected. ALF had no effect on DMD, but increased CWC and ADF digestibility. This is in agreement with data of White et al. (1971, 1974) whereas roughage in the ration increases, digestibility of energy, DM, organic matter, and nitrogen-free extract decreased while crude fiber digestibility increased.

Nitrogen balance

Nitrogen intake (NI) was lower (18%) during period II for Control cows reflecting abnormal conditions observed with the cows (table 7). However, NI was not greatly affected for added fiber rations during period II. Control

Table 7. Nitrogen balance data for Control and added fiber rations.

Ration	Period	Level	Nitrogen Variable					
			Intake[b]	Fecal	Urine	Milk	Tissue[b]	Production[ab]
			g/d					
Control	1	9	449.9(472.5)	169.6	164.3	143.0	-30.0(-4.4)	113.1(138.6)
	2	9	367.3(412.0)	147.6	170.8	110.4	-61.5(-16.8)	48.9(93.6)
	3	9	456.9(465.5)	158.0	174.3	121.9	2.8(11.4)	124.7(133.3)
Orchardgrass hay	1	0	477.3(513.0)	189.5	167.4	153.9	-33.5(2.3)	120.5(156.2)
	2	9	449.7(498.5)	176.2	186.0	132.2	-44.7(4.2)	87.5(136.4)
	3	18	491.2(472.5)	154.3	192.3	109.8	34.8(16.2)	108.2(126.0)
Alfalfa hay	1	0	429.9(456.5)	161.5	147.4	145.8	-24.8(1.9)	121.0(147.7)
	2	9	422.9(441.5)	178.9	170.3	140.9	-67.1(-48.5)	73.8(92.4)
	3	18	455.9(464.0)	171.4	166.2	124.5	-6.1(2.0)	118.4(126.5)
Cottonseed hulls	1	0	424.5(453.5)	124.3	152.4	153.4	-38.1(23.5)	115.4(176.9)
	2	5.5	423.0(425.5)	146.2	152.9	120.6	3.4(5.9)	124.0(126.5)
	3	11	544.4(542.5)	170.9	194.5	136.7	42.4(40.5)	179.0(177.2)
S. E. M.			17.5(19.6)	10.5	12.9	5.5	12.2(11.5)	14.7(12.5)

[a]Sum of milk and tissue nitrogen.

[b]Values in parathesis were calculated using formulated values (Table 2) for ration analysis.

cows apparently recovered during period III with NI about equal to period I, whereas the added fiber ration cows show an increase in NI for period III. Mean values for fecal, urine, milk, tissue, and production nitrogen are also shown in table 7, however, interpetations of these values are made by orthogonal contrast and slope comparisons in tables 9 and 10, respectively.

Nitrogen quality indexes represented by digested nitrogen (DN) and biological value (BV), are shown in table 8. Lower values for BV during period II are indicative of the abnormal situation. DN was not affected to the same degree as BV. It appears the CSH cows were affected less than cows on the other rations.

Biological value (BV) of ration nitrogen would indicate quality of the nitrogen entering the lower digestive tract. Changes that may occur in the rumen such as type of fermentation, microbial population, or rate of passage, can affect the quality of nitrogen, especially amino acids entering the lower digestive tract. Increasing roughage in rations has been shown to increase rumen-bypass feed of protein and/or microbial protein in steers (Topps et al., 1968; Cole et al., 1976a, b). Interpetation of DN and BV are made by orthogonal contrast and slope comparisons in tables 9 and 10, respectively.

Table 8. Nitrogen quality indexes of digestibility (DN) and biological value (BV) for Experiment I.

Ration	Period	% Added Fiber	BV[a]	DN[b]
Control	1	9	41.0	62.2
	2	9	20.9	59.7
	3	9	41.8	65.4
Orchardgrass hay	1	0	41.2	60.2
	2	9	32.0	60.9
	3	18	43.0	68.6
Alfalfa hay	1	0	44.8	62.4
	2	9	29.6	57.6
	3	18	41.1	62.3
Cottonseed hulls	1	0	48.3	70.4
	2	5.5	43.8	65.1
	3	11	48.4	68.4
S. E. M.			4.2	1.2

[a]Retained N ÷ absorbed N x 100.

[b]Digestion coefficient.

Table 9. Orthogonal contrasts of 0% versus 9% rations and rations containing Hays versus cottonseed hulls (CSH) for nitrogen balance data.

Nitrogen Variable	Orthogonal Contrast[e]					
	0% vs 9%			Hays vs CSH		
	---- Mean ----		P<	----Mean ----		P<
Intake[af]	406.4 (439.9)	477.0 (481.2)	.04 (.23)	445.6 (458.0)	503.5 (504.2)	.06 (.15)
Intake[b]	71.8	85.3	.04	79.3	89.8	.06
Fecal[a]	147.8	178.5	.11	159.3	198.9	.04
Urine[a]	160.4	167.8	.73	173.4	173.4	.99
Milk[a]	128.4	141.4	.19	132.2	130.5	.84
Tissue[af]	-36.2 (3.4)	-8.8 (-18.8)	.21 (.62)	-37.6 (-27.6)	24.1 (2.7)	.01 (.04)
Production[af]	92.2 (131.7)	132.4 (134.9)	.13 (.90)	94.7 (125.3)	154.6 (131.9)	.03 (.74)
Digested N[c]	63.2	62.6	.79	64.0	59.3	.03
Biological[d] value	34.7	45.1	.16	37.7	42.2	.50

[a]g/d.

[b]% of body weight/d.

[c]%.

[d]Retained N ÷ absorbed N x 100.

[e]Observations for each treatment are: 0% = 6, 9% = 12, Hays = 14, and CSH = 4.

[f]Values in parathesis were calculated using formulated values (Table 2).

Table 10. Regression coefficients[a] for increasing fiber type on nitrogen balance data.

	Ration[f]		
Nitrogen Variable	OG	ALF	CSH
Intake[b]	.78	1.44	10.9
Intake[c]	.11	.38	1.9
Fecal[b]	-1.96	.54	4.2[g]
Urine[b]	1.39	1.04	3.8
Milk[b]	-2.46	-1.19	-1.5
Tissue[b]	1.78	1.03	7.3
Production[b]	-.68	-.14	5.8
Digested N[d]	.004	.00	-.002
Biological value[e]	.10	-.21	.007

[a]Per % added fiber type on dry matter basis.

[b]g/d.

[c]g/100 kg body weight/d.

[d]%.

[e]Retained N ÷ absorbed N x 100.

[f]Contrasts tested by Bonferroni F Test at $P<.05$ level of significance.

[g]Contrast CSH and OG significant ($P<.05$).

Orthogonal contrasts indicate adding 9% equivalent fiber increases (P<.04) NI but this was concurrent with slightly higher DMI. Slightly higher (P<.04) fecal nitrogen was observed for 9% rations compared to 0% ration which is related to increased NI but had no effect on DN. Higher (P<.13) production nitrogen (milk N plus tissue N) observed for 9% rations is reflected in slightly higher (P<.16) BV of 9% rations.

Nitrogen intake was higher (P<.06) for CSH rations compared to Hays due mainly to higher DMI for CSH rations. Adjusting N intake for the ration sampling error by using calculated N content reduced significant differences for N intake between 0% versus 9% rations (table 9). N intake tended to parallel DM intake (table 5) after these adjustments were made. Tissue N was calculated by difference between intake, fecal, urine, and milk N, therefore adjustments in N intake using calculated values decreased contrast differences for tissue N (table 9) and reversed the trend for contrast 0% versus 9%. Using ration analysis values (table 3) NI was higher for CSH rations, fecal nitrogen increased (P<.04) resulting in decreased DN (P<.03). Lower CP digestion for CSH rations compared to alfalfa hay rations was observed by Villavicencio et al. (1968) for lactating dairy cows. Cole et al. (1976b) observed greater apparent N absorption for rations containing 14 and 21% CSH compared to 0% and 7% CSH rations in steers. Higher production nitrogen for CSH compared to Hays reflected the positive tissue balance for CSH whereas milk nitrogen was similar for the rations. Biological value was slightly higher for CSH but was not statistically significant. However, the positive tissue balance observed for cows fed CSH suggest the biological value difference would be highly significant to the dairy cows.

Response to increasing amounts of each fiber type indicates CSH rations produce the most favorable nitrogen balance (table 10). CSH rations had the greatest effect on NI due to the DMI response. NI increased similarily for OG and ALF but much less (P<.06 and .09, respectively) than CSH. Fecal and urinary N increased for CSH but digested nitrogen and biological value responses were essentially zero. Production N increased for CSH while OG and ALF were slightly negative responses. Although response to CSH was overwhelming compared to OG or ALF, response to these added fiber sources coarseness of the corn silage and relatively similar ADF content of the rations. was favorable as indicated by relatively small changes in DN and BV.

Rumen Fermentation

Molar proportions of acetate and propionate were not affected by the additions of fiber sources (table 11). Some variance occurred with APR but the differences were not significant as indicated by contrast in tables 12 and 13. Increasing roughage in rations has been demonstrated to increase APR in dairy cows (Bauman et al., 1971a) and sheep (Hodgson and Thomas, 1975). Calculated NGR which considers a ratio of the four major VFA varied, but no differences for rations were observed indicating a relatively stable rumen fermentation. Rumen pH was also stable across rations. Fermentation responses to added fiber in this experiment may have been precluded by the

Orthogonal contrasts (table 12) show that total VFA concentrations were higher (P<.11) for rations containing 9% added fiber compared to 0% rations. Similar means for the other variable contrast are indicated by relatively high probability values.

Total VFA increased with added fiber rations but was not significant between fiber types (table 13). Slopes for other fermentation variables were essentially zero, therefore contrast probabilities were not significant.

Table 11. Volatile fatty acid proportions, acid ratios, and rumen pH for Control and added fiber rations.

Ration	Period	% Added Fiber	Volatile Fatty Acids					Ratio		Rumen pH
			Ac	Pr	Bu	Val	TVFA[a]	APR[b]	NGR[c]	
			----- moles/100 moles -----				mm/liter			
Control	1	9	63.8	19.6	14.0	2.6	113.2	3.3	4.3	6.5
	2	9	62.0	21.5	12.6	4.0	110.5	2.9	3.6	6.7
	3	9	61.7	21.4	13.8	3.2	116.2	2.9	3.8	6.4
Orchardgrass hay	1	0	60.1	21.4	13.1	5.5	83.6	2.8	3.4	6.3
	2	9	60.4	21.3	13.9	4.4	129.6	2.8	3.6	6.5
	3	18	59.4	21.0	14.1	5.5	116.2	3.0	3.6	6.4
Alfalfa hay	1	0	59.1	20.0	16.8	4.0	105.3	2.9	4.0	6.6
	2	9	59.5	22.0	16.8	3.8	131.6	2.7	3.6	6.5
	3	18	58.6	23.2	14.3	3.9	130.8	2.5	3.4	6.3
Cottonseed hulls	1	0	56.7	23.2	14.6	4.9	90.1	2.4	3.2	6.2
	2	5.5	57.5	23.2	14.6	4.9	146.1	2.3	2.9	6.3
	3	11	56.6	23.8	14.4	4.9	121.0	2.4	3.2	6.3
S. E. M.			2.6	1.4	1.3	.9	15.3	.3	.3	.3

[a]Total volatile fatty acids.

[b]Acetate:propionate ratio.

[c]Non-glucogenic ratio = (Ac + 2 Bu + Val) ÷ (Pr + Val).

Table 12. Orthogonal contrasts of 0% versus 9% rations and rations containing Hays versus Cottonseed hulls (CSH) for rumen fermentation.

	Orthogonal Contrast[c]					
Variable	0% vs 9%			Hays vs CSH		
	--- Mean ---		P<	---- Mean ---		P<
Acetate[a]	58.1	60.4	.60	59.9	60.4	.92
Propionate[a]	22.9	22.3	.78	22.2	22.1	.93
Butyrate[a]	13.5	13.9	.85	13.6	13.3	.85
Valerate[a]	5.5	3.5	.21	4.2	4.3	.92
Total VFA[b]	86.0	131.4	.11	118.4	129.2	.65
APR[d]	2.5	2.8	.64	2.8	2.8	.96
NGR[e]	3.1	3.6	.30	3.5	2.8	.96
Rumen pH	6.4	6.3	.81	6.4	6.6	.62

[a]moles/100 moles.

[b]mm/liter.

[c]Observations for each treatment are: 0% = 6, 9% = 12, Hays = 14, and CSH = 4.

[d]Acetate:propionate ratio.

[e]Non-glucogenic ratio = (Ac + 2 Bu + Val) ÷ (Pr + Val), where VFA are expressed as molar percentages.

Table 13. Regression coefficients[a] for increasing fiber types on volatile fatty acids, ratios, and rumen pH.

	Ration[f]		
Variable	OG	ALF	CSH
Acetate[b]	-.04	-.03	-.02
Propionate[b]	-.02	.18	.01
Butyrate[b]	.06	-.14	-.02
Valerate[b]	.00	-.01	-.03
TVFA[c]	1.81	1.42	2.80
APR[d]	.01	-.02	.00
NGR[e]	.01	-.04	.00
Rumen pH	.00	-.02	.02

[a]Units are per % added fiber type on dry matter basis.

[b]moles/100 moles.

[c]Total volatile fatty acids, expressed as mm/liter.

[d]Acetate:propionate ratio.

[e]Non-glucogenic ratio = (Ac + 2 Bu + Val) ÷ (Pr + Val).

[f]No significant differences (P>.05) for contrasts by Bonferroni F Test.

Rumen Dilution Rates

Rumen fluid dilution (RFD) rates tended to vary more than the rumen solids dilution (RSD) rates (table 14). Unexpectedly RFD for Control cows increased from 7.8 in the first period to 12.9 %/hr during the second period. Since intake was lower during the second period for Control cows, RFD would be expected to be lower. RFD for OG and ALF did decreased during this period whereas CSH appeared to be stable during this period. RSD did not appear to be affected by the situation.

Orthogonal contrasts show lower ($P<.01$) RFD occurred for the 9% added fiber rations compared to 0% rations (table 15). Adding "long hay equivalents" to rations should increase RFD but the 9% rations were fed primarily during the second period when intake was lower than the first period (figure 1). Also RFD decreased for OG and Alf during period 2 plus Control RFD for period 1 and 3 were the lowest means observed. Means for CSH were slightly higher ($P<.13$) than means for Hays.

Increasing amounts of cottonseed hulls or alfalfa hay increased RFD while increasing orchardgrass hay decreased RFD. However, these differences were not significant between fiber types as indicated in table 16. Cole et al. (1976b) observed increased RFD with CSH additions to rations

Table 14. Rumen dilution rates of liquid and solid phases for Control and added fiber rations.

Ration	Period	% Added Fiber	Dilution Rate Liquid	Dilution Rate Solids
			------- %/hr	-------
Control	1	9	7.8	6.4
	2	9	12.9	6.4
	3	9	7.9	4.8
Orchardgrass hay	1	0	14.5	7.8
	2	9	9.6	6.3
	3	18	13.4	7.1
Alfalfa hay	1	0	16.1	7.2
	2	9	11.5	6.6
	3	18	16.8	8.2
Cottonseed hulls	1	0	11.9	6.6
	2	5.5	11.2	7.3
	3	11	13.8	7.7
S. E. M.			1.2	.6

Table 15. Orthogonal contrasts of dilution rates for Control and added fiber rations.

Dilution Rate	Orthogonal Contrasts					
	0% vs 9%			Hays vs CSH		
	-- Mean --		P<	-- Mean ---		P<
Phase:						
Fluid	16.7	8.3	.01	11.7	14.8	.13
Solids	6.8	6.4	.66	7.2	8.6	.16

[a]Observations for each treatment are: 0% = 6, 9% = 12, Hays = 14, and CSH = 4.

Table 16. Regression coefficients[a] for increasing fiber type on dilution rates.

Dilution Rate	Ration[b] OG	ALF	CSH
	---------- %/hr ----------		
Phase:			
Liquid	-.06	.04	.17
Solids	-.04	.05	.11

[a]Per % added fiber type on dry matter basis.

[b]No significant differences (P>.05) for contrasts by Bonferroni F Test.

for steers. Expected response to added alfalfa or orchardgrass would be increased RFD. Hodgson and Thomas (1975) showed increased RFD with a forage ration compared to a concentrate ration for sheep. However, Cole et al. (1976b) observed reduced RFD in a trial with steers fed 21% CSH. Other factors may be involved with RFD and roughage additions since RFD response to added fiber has also been shown to be negative.

RSD was slightly lower for 9% rations compared to 0% rations (table 15). RSD would be lower for 9% rations because of the less digestible nature of the hays or cottonseed hulls compared to the corn silage. Hays or hulls would remain in the rumen longer and have lower dilution rates. CSH is relatively less digestible than the hays but the smaller particle size would pass out of the rumen faster as indicated by the contrast of Hays vs CSH (table 15).

Solids dilution rate tended to parallel RFD. This can be explained in lieu of recent evidence that spraying YbCl on feed may exceed binding capacity of the feed particles and the excess YbCl could wash off in the rumen (Ellis et al. 1979). This allows some of the YbCl to migrate with the fluid phase from the rumen. It is necessary to soak feedstuffs to be marked in YbCl solution then rinse the excess from the feedstuff. This procedure allows any solid feedstuff or phase (such as fine particles) to be marked and estimated for dilution rate. Therefore RSD data must be evaluated with this in mind.

Chapter IV

EXPERIMENT II

PROCEDURES

Experimental Design

A latin square design was utilized with four treatments and two replicates. The design had eight cows assigned to the four treatments with four periods of 3 wk each. Two weeks of each period was for adjustment to rations and 1 week for data collection. Statistical design and animal assignments are shown in Appendix table 2.

Ration Formulation and Analysis

Three rations were formulated to provide 9% (dry-basis) of orchardgrass, alfalfa, or cottonseed hulls in a corn silage-based ration. A control ration was formulated with corn silage as the only forage. Corn silage was medium to coarse chopped with a TLC of 1.27 cm. Alfalfa and orchard-grass were chopped to have an average particle length of 10 cm. The rations were formulated to a 60:40 for-age:concentrate ratio with 15.5% crude protein, ADF then ranged from 18-22%. Added fiber was substituted for a portion of the corn silage dry matter.

Concentrate portion of the ration consisted of the herd concentrate mix and high moisture corn grain. The concentrate mix is detailed in table 17. Ration compositions are shown in table 18. The added fiber, corn silage, concentrate mix and high moisture corn grain were mixed prior to each feeding. Cows were fed twice daily at 0700 h and 1400 h. Orts were taken daily at 0900 h. Rations were offered to have 2.5-3.8 kg orts daily.

Feed and orts were oven dried at 60 C to a constant weight, ground through a 2.0 mm screen and analyzed for neutral detergent fiber (NDF) by the procedure of Robertson and Van Soest (1978). Acid detergent fiber was determined on an aliquot separate from the NDF analysis by the procedure of Goering and Van Soest (1970). Crude protein was analyzed by Kjeldahl.

Density Measurements

Density of the rations was measured by a modification of the procedure of Clancy et al. (1976). A plexiglass box 15.0 cm square and 14.0 cm deep with centimeter graduations on the side was used. A 2.5 kg weighted lid was placed on top of approximately 300 g of the ration and after 2 min for settling, the volume was determined. Dry density was calculated using the dry matter weight of the ration. Density was determined six times for each ration during each period.

Table 17. Composition of dairy concentrate A.

Ingredient	Concentration[a]	Specifications
	%	
Dried molasses	1.25	--
Wet molasses	3.00	3% CP
Distillers grains	2.50	25% CP
Wheat	3.75	10% CP
Pellet binder[b]	2.00	8% CP
Trace mineral salt	1.75	--
Ground limestone	2.50	--
Dicalcium phosphate	3.50	--
Sodium sulfate	.75	--
Magnesium oxide	.75	--
Vitamin mix	.50	$12x10^6$ IU A and D
Soybean meal	75.75	--
	100.00	35% CP

[a]Calculated on as-fed basis.

[b]Pelleted with a .40-cm die.

Table 18. Ration formulations and specifications used to determine effective fiber of feed sources added to corn silage-based rations.

Ingredient[a]	Ration designation: Control	Orchard- grass	Alfalfa	Cottonseed hulls
	-------	-------	% -------	-------
Corn silage	60.0	51.0	51.0	50.5
Orchardgrass hay	--	9.0	--	--
Alfalfa hay	--	--	9.0	--
Cottonseed hulls	--	--	--	9.5
Concentrate A	24.8	24.0	22.5	25.5
High moisture corn	15.2	16.0	17.5	14.5
Specifications:				
Crude protein[b]	15.5	15.5	15.5	15.5
Acid detergent fiber[b]	18.1	19.5	19.2	22.1
NE_1[c]	150	151	150	146

[a]Calculated on dry matter basis.

[b]%.

[c]Mcal/kg (estimated NRC, 1978).

Chewing Time

Jaw motion was monitored by a bellows pneumograph and a four channel physiograph[2] similar to Law and Sudweeks (1975). The bellows was attached to a halter on the side of the head and protected by being encased inside a rubber hose. A string encircled the end of the nose with one end tied to the halter and the other end to the bellows. Time spent eating was distinguished from cud chewing by the pattern produced by the bellows and observation by the attendant. Four animals were monitored simultaneously, for a 48-h period minus four milking periods of 2 h. Time spent eating and cud chewing was then calculated as minutes per 24 h. After observing the cows waiting to be milked and during milking, it appeared that little or no cud chewing occurred during this time.

Data Collection

Rations and orts were sampled each feeding for 3 d during week 3 of each period. Samples were also taken for density measurements at this time. Rumen fluid samples were taken 2 h post-feeding on day 21 using a metal suction strainer described by Raun and Burroughs (1962) and transported to the laboratory in a stoppered flask. Rumen fluid

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[2]Narco Biosystems, Inc., Houston, TX.

was measured for pH as described for Experiment I.

Rate of Passage Measurements

Rate of passage was measured using the same markers and dosing procedures described for Experiment I. Fecal samples were taken as grab samples instead of aliquots from total collection. Cows were induced to defecate when possible and the latter portion of the discharge taken as a sample (approximately 100 g). Samples were taken at time zero for background and at 4 h intervals from 8 h to 28 h and 6 h intervals to 94 h post-dosing. Fecal samples were prepared and analyzed as described for Experiment I.

Statistical Analysis

Data from this Experiment were analyzed by the Statistical Analysis System.[1] Analysis of the treatments was by the general linear model procedure of SAS using the model:

Y = Type Period Cow

Model for this experiment is further described in Appendix table 2. Rate of passage was determined as described for Experiment I.

RESULTS AND DISCUSSION

Ration analysis

Rations were formulated to be isonitrogenous, however, some variation was observed (table 19). Adding fiber sources increased ration dry matter (DM) and acid detergent fiber (ADF). Cell wall constituents (CWC) varied but did not increase as might be expected by adding these fiber sources. Addition of orchardgrass (OG) or alfalfa (ALF) hay decreased ration density (table 20). Cottonseed hulls (CSH) addition had essentially no effect on ration density. Dry densities of the rations were similar. A 4% difference in dry matter between Control and added fiber rations decreased the magnitude of the differences. Control rations were approximately 46% DM while added fiber rations were approximately 50% DM.

Intake

DMI was highest for CSH rations (table 21). Orthogonal contrast showed that CSH mean was (P<.06) higher than the average DMI for Hays (table 22). No difference was observed between OG and ALF. Wheeler et al. (1979) observed higher DMI for rations containing CSH compared to rations containing orchardgrass hay, corn stover or barley straw as the forage for steers. They observed rumen digesta dry matter

Table 19. Analysis of rations for Experiment II.

Component[a]	Ration Designation			
	Control	Orchard-grass	Alfalfa	Cottonseed hulls
Dry matter	45.8	49.8	49.6	49.8
Crude protein	15.2	14.5	15.5	14.6
Cell wall constituents	36.0	37.2	35.1	36.5
Acid detergent fiber	21.9	23.5	22.7	26.1

[a]Calculated on dry matter basis.

Table 20. Influence of added fiber on density of corn silage-based rations.

Ration	Density	
	g/ml	g DM/ml[c]
Control[a]	.310	.14
Orchardgrass hay[b]	.253	.13
Alfalfa hay[b]	.283	.14
Cottonseed hulls[b]	.305	.15

[a]Corn silage as the only forage.

[b]Substituted hay at 9% and hulls at 9.5% for corn silage dry matter.

[c]Corrected for dry matter of ration.

Table 21. Influence of added fiber on intake of dry matter (DM), cell wall constituents (CWC), and acid detergent fiber (ADF).

Ration	DMI	CWCI	ADFI
	------------	kg/d	------------
Control	18.2	7.4	4.0
Orchardgrass hay	18.5	8.0	4.4
Alfalfa hay	18.2	7.8	4.2
Cottonseed hulls	19.5	8.4	5.1
S. E. M.	.4	.2	.1
Ration F Test	P<.06	P<.01	P<.01

Table 22. Orthogonal contrasts of intake and chewing time variables for Experiment II.

	Orthogonal Contrasts								
Variable	Control vs Added		P<	CSH vs Hays		P<	OG vs ALF		P<
Intake of:									
Dry matter[a]	18.2	18.7	.18	19.5	18.4	.02	18.5	18.2	.52
Cell wall constituents[b]	7.4	8.1	.01	8.4	7.9	.01	8.0	7.8	.50
Acid detergent fiber[b]	4.0	4.5	.01	5.1	4.3	.01	4.4	4.2	.15
Chewing time as:									
Eating[c]	385.5	369.0	.31	372.8	367.2	.74	375.0	358.6	.38
Cud chewing[c]	375.5	372.6	.89	385.9	366.0	.39	386.0	346.0	.15
Total[c]	761.0	741.7	.33	758.6	733.2	.23	761.8	704.6	.03
Eating[d]	21.3	19.8	.12	19.2	20.1	.40	20.4	19.8	.63
Cud chewing[d]	20.5	19.9	.66	19.7	20.0	.82	21.4	18.6	.10
Total[d]	42.1	39.9	.14	39.0	40.4	.38	42.0	38.7	.08

[a]kg/d.

[b]Calculated on dry matter basis.

[c]min/d.

[d]min/kg DMI.

was highest (21.6%) for CSH which may have contributed to higher intake.

CWC intake was (P<.01) higher for added fiber rations compared to Control and also higher (P<.01) for CSH compared to Hays. ADF intake was higher (P<.01) for added fiber rations compared to Control with significance similar to CWC intake. With higher intake for CSH and higher CWC and ADF content of added fiber rations these differences would not be unexpected. Intake of ADF is important to milk fat synthesis. Control ration was only 18.7% which may be minimal in most dairy cow rations to support milk fat. Therefore, supplementing 9% of these or comparable feedstuffs may supply a margin of safety for preventing metabolic disorders.

Chewing time

Time per day the cows spent eating and cud chewing was not significantly different (table 23) for the four rations. Cows on Control ration spent the most time (386 min) eating, whereas those fed ALF ration spent the least amount of time (359 min) eating.

Cud chewing did not differ between rations (table 23). Lowest cud chewing time was ALF whereas OG and CSH were similar. Freer and Campling (1965) observed with sheep that less time eating was compensated for by increased rumination

Table 23. Influence of added fiber on the time spent eating, cud chewing, and total chewing per day.

Ration	Eating	Cud chewing	Total
	-------------	min/d	------------
Control	386	376	761
Orchardgrass hay	376	386	762
Alfalfa hay	359	346	705
Cottonseed hulls	373	386	759
S. E. M.	14	19	17
Ration F Test	P<.58	P<.40	P<.07

time. This was not the case for ALF fed to dairy cows in this trial. Total chewing time is the total time spent eating plus cud chewing. ALF ration showed a slightly lower (P<.07) total chewing time compared to OG. There was a 56 min per day reduction in total chewing time by adding alfalfa hay to the ration. No justification is evident for reduced chewing time observed by adding chopped alfalfa hay to corn silage-based rations. Sudweeks and Ely (1980) indicate that long alfalfa hay would stimulate chewing less than long orchardgrass hay. Based on their roughage value indexes (RVI) alfalfa hay is only 61.5 while orchardgrass hay is 74.0.

Total chewing per kg of DMI (RVI) was not different for the rations (table 24). RVI values were 42 for Control and OG while ALF and CSH were 39. Orthogonal contrast of RVI for ALF and OG suggest that OG is greater (P<.08) and would support milk with higher milk fat percent (table 22). Extensive research conducted at Georgia (Sudweeks and Ely, 1980) regressing roughage value index on % milk fat shows that a value of 39 or 42 would maintain milk fat at 3.7% and 3.8%, respectively. Balch (1971) indicated that mean differences of 10% in the RVI obtained in change-over trials (accounting for cow variance) were likely to be meaningful. However, RVI values of 39 and 42 are well above the 31

Table 24. Influence of added fiber on time spent eating, cud chewing, and total chewing per kilogram of dry matter intake.

Ration	Eating	Cud chewing	Total
	-----------	min/kg·DMI	---------
Control	21	21	42
Orchardgrass hay	20	21	42
Alfalfa hay	20	19	39
Cottonseed hulls	19	20	39
S. E. M.	0.8	1.1	1.3
Ration F Test	P<.33	P<.38	P<.12

necessary to maintain normal milk fat of 3.5% (Sudweeks et al., 1979). A 10% variance around RVI of 31 may be critical for preventing the metabolic disorders associated with inadequate roughage. Although an exact relationship between RVI and rumen health and function has not been established it can be assumed from data on reduced milk fat test.

Rumen fermentation

Rumen volatile fatty acid (VFA) patterns are shown in table 25. Molar proportions of acetate and propionate were not affected by added fiber sources. Acetate was 3 percentage units higher for OG while propionate was lowest for ALF ration. Expected response to added fiber would be lower rumen propionate and possibly increased acetate with a subsequent increase in acetate:propionate ratio (APR). However, coarseness of the corn silage (TLC=1.27 cm) used in this experiment may have precluded a significant response to added fiber. Chalupa et al. (1969) increased APR from 1.9 to 2.8 by supplementing a ration containing pelleted coastal bermudagrass hay with 10% long baled coastal bermudagrass hay.

Butyric acid was ($P<.01$) higher for ALF by orthogonal comparison with OG (table 26). Variation observed for valeric acid was not significant. Total volatile fatty acid

Table 25. Influence of added fiber on rumen fermentation parameters.

Ration	Ac	Pr	Bu	Val	TVFA
	-----	moles/100	moles	-----	mm/ liter
Control	56.2	26.5	14.9	2.4	121.0
Orchardgrass hay	59.1	26.1	12.9	1.9	79.0
Alfalfa hay	56.7	24.2	16.5	2.5	97.3
Cottonseed hulls	56.6	26.3	14.1	3.0	83.9
S. E. M.	1.0	1.5	0.6	0.3	5.1
Overall F Test	P<.23	P<.72	P<.01	P<.14	P<.01

Table 26. Orthogonal contrasts of rumen fermentation and dilution rates for Experiment II.

Variable	Orthogonal Contrasts								
	Control vs Added		P<	CSH vs Hays		P<	OG vs ALF		P<
Volatile fatty acids:									
Acetate[a]	56.2	57.5	.32	56.6	57.9	.32	59.1	56.7	.12
Propionate[a]	26.5	25.5	.61	26.3	25.2	.55	26.1	24.2	.41
Butyrate[a]	14.9	14.5	.56	14.1	14.7	.41	12.9	16.5	.01
Valerate[a]	2.4	2.5	.81	3.0	22.4	.06	1.9	2.5	.16
Total[b]	121.0	86.7	.01	83.9	88.2	.51	79.0	97.3	.02
Rumen pH:	6.3	6.3	.74	6.2	6.4	.18	6.4	6.3	.49
APR[c]	2.2	2.3	.55	2.2	2.4	.28	2.4	2.4	.99
NGR[d]	3.2	3.3	.72	3.0	3.4	.21	3.2	3.5	.42
Rumen dilution[e]:									
Fluid	11.1	11.0	.94	12.9	10.1	.01	11.3	8.9	.04
Solids	6.0	5.6	.62	5.4	5.7	.75	5.7	5.6	.87

[a]moles/100 moles.

[b]mm/liter.

[c]Acetate:propionate ratio.

[d]Non-glucogenic ratio = (Ac + 2 Bu + Val) ÷ (Pr + Val).

[e]%/hr.

concentration was (P<.01) higher for Control ration compared to added fiber rations. This may reflect the slightly higher energy of the Control ration. However, Bauman et al. (1971) observed higher VFA concentrations in dairy cows fed limited roughage, high-grain (15:85) rations compared to a control ration of 55:45 roughage:grain ration but could not explain the increase by digestible energy intake.

Acetate:propionate ratios were not significantly different (table 27). Control and CSH rations were 2.2 while the OG and ALF rations were 2.4. Non-glucogenic ratios (NGR) of rumen VFA proposed by Orskov (1975) were not significantly different for the four rations. Highest NGR was for ALF at 3.5, CSH had the lowest at 3.0 while Control and OG were intermediate at 3.2. According to the data of Orskov (1975) NGR values in this range correspond to efficient utilization of ration energy and favor partition of energy to milk secretion. Means for rumen pH ranged from 6.2 to 6.4 but were not significantly different across rations.

Rumen dilution rates

Rumen fluid dilution (RFD) rates were significantly (P<.01) different (table 28). Mean for Control was not significantly different from the mean of added fiber rations

Table 27. Influence of added fiber on acetate:propionate (APR) and non-glucogenic (NGR) ratios and pH of rumen fluid.

Rations	APR	NGR[a]	pH
Control	2.2	3.2	6.3
Orchardgrass hay	2.4	3.2	6.4
Alfalfa hay	2.4	3.5	6.3
Cottonseed hulls	2.2	3.0	6.2
S. E. M.	0.2	0.2	0.1
Overall F Test	P<.67	P<.49	P<.48

[a]NGR = (Ac + 2 Bu + Val) ÷ (Pr + Val), where VFA are expressed as molar percentages.

Table 28. Influence of added fiber on rumen fluid dilution rate.

Ration	No. Cows	Rumen Fluid Dilution
		%/hr
Control	8	11.1
Orchardgrass hay	8	11.3
Alfalfa hay	8	8.9
Cottonseed hulls	8	12.9
S. E. M.		.8
Overall F Test		P<.01

(table 26). CSH ration had the highest RFD and was significantly higher than the average of mean for OG and ALF rations. Increased RFD for CSH may be related to the higher intake. Villavicencio et al. (1968) observed increased DMI with CSH rations and implicated increased RFD because of their small particle size. Cole et al. (1976a, b) suggested an increased rumen rate of passage by feeding CSH because of decreased DM and cellulose digestion for steers. There was also a significant (P<.04) difference between OG and ALF rations where ALF was 2.4%/hr lower than OG ration. Lower RFD for ALF may be related to the reduced chewing time observed with this ration. Jorgensen et al. (1978) indicated chewing time was postively related to saliva flow and Harrison et al. (1975) infused artificial saliva into the rumen of sheep and increased rumen dilution rate. It is possible that feeding ALF reduced saliva flow decreasing RFD but probably would not be the only factor involved.

No significant differences occurred between rations for rumen solids dilution (RSD) rate (table 29). There was a tendency for RSD rate to decrease with addition of hays or hulls. Added fiber sources may be comparatively less digestible than corn silage. If we consider the added fiber as a less digestible residue, it would remain in the large particle pool of the rumen longer. Therefore mean rumen reten-

Table 29. Influence of added fiber on rumen solids dilution rate.

Ration	No. Cows	Rumen Solids Dilution
		%/hr
Control	8	6.0
Orchardgrass hay	8	5.7
Alfalfa hay	8	5.6
Cottonseed hulls	8	5.4
S. E. M.		.6
Overall F Test		P<.94

tion time would be longer producing these slightly lower fractional turnover rates. However, because of the technique used for solid phase marking the data must be evaluated carefully.

Chapter V

EXPERIMENT III

PROCEDURES

Experimental Design

Analysis of covariance was used with animals adjusted to a finely chopped corn silage-based ration. Eighteen lactating Holsteins were used with two periods of 3 wk each. Periods consisted of 14 d for adaptation to rations and 7 d for data collection. Statistical design and animal assignments are shown in Appendix table 3.

Ration formulation and analysis

Three rations were used with a 60:40 forage:concentrate ratio. A control ration was formulated with 60% finely chopped corn silage (TLC=.64 cm) and 15% high moisture corn and 25% concentrate mix. Chopped orchardgrass hay (same as Experiment II.) was substituted at 9 and 18% for corn silage dry matter. Concentrate mix was the same as that in Experiment II. The rations were calculated to be 14.8-14.6% crude protein and 16.7-20% ADF. Ration formulations and specifications are shown in table 30. Rations were mixed and fed using the procedures described in Experiment I.

Table 30. Ration formulations and specifications used to determine effect of added orchardgrass hay to fine chop corn silage.

Ingredient[a]	Added Orchardgrass 0%	9%	18%
	---------- % ----------		
Corn silage	60.0	51.0	42.0
Chopped orchardgrass	--	9.0	18.0
Concentrate A	25.0	25.0	25.0
Dry cracked corn	15.0	15.0	15.0
Specifications:			
Crude protein[b]	14.8	14.7	14.6
Acid detergent fiber[b]	16.8	18.4	20.0
NE_1[c]	167.8	163.4	159.0

[a]Calculated on dry matter basis.

[b]%.

[c]Mcal/kg (estimated NRC, 1978).

Data collection

Procedures are the same as described in Experiment II. Rations and orts were analyzed as described in Experiment I. Density measurement procedures are described in Experiment II. Rate of passage determinations are described in Experiment II except a 4-h fecal grab sample was taken and fecal grab samples were taken to 64 h post-dosing.

Statistical analysis

Data from this experiment were analyzed by the Statistical Analysis System.[1] Analysis of the treatments was by the general linear model procedure of SAS using the model:

Y = Ration Covariate

Model for this experiment is further described in Appendix table 3. Contrast for linear and quadratic effects of treatments were made. Rate of passage was determined as described for Experiment I.

RESULTS AND DISCUSSION

Ration Analysis and Density

Ration analyses are shown in table 31. Crude protein was higher than calculated for all rations. Acid detergent fiber content was similar for rations and did not increase as expected for rations with added OG.

Table 31. Ration analysis for covariate and experimental periods.

	Added Hay			
Component	0%[a]	0%	9%	18%
Dry matter	47.8	50.3	54.6	59.4
Crude protein	14.8	15.8	16.2	16.8
Cell wall constituents	42.1	42.2	42.4	43.9
Acid detergent fiber	20.0	19.6	19.5	20.4

[a]Covariate ration.

Densities of rations are shown in table 32. Added orchardgrass hay decreased ration density with each added increment. Density was 35.5% lower for 18% ration and 14.5% lower for 9% ration compared to 0% ration. By comparison 0% ration (table 32) was 11.7% more dense than Control ration used in Experiment II (table 20) which used a medium to coarse chop corn silage.

Dry matter, cell wall constituent, and acid detergent fiber intake

Intake of DM, CWC, and ADF are shown in table 33. DM intake tended to increase with 9% and 18% rations, but the difference was not significant. However, intake of CWC and ADF increased linearly ($P<.06$) with added OG.

Unadjusted means for intake of DM, CWC, and ADF are shown in figure 2. Means for the covariate period were very similar. Trends for these variables are not unexpected. DMI would be expected to decrease as cows remain on the finely chopped corn silage ration. Addition of hay to the ration should maintain the DMI or produce a slight increase in intake. Slight differences in DMI and fiber content for rations produced significant CWC and ADF intake for rations fed during the experimental period. Since covariate period allowed only 2 weeks for adaptation to 0% ration, differ-

Table 32. Density of fine chop corn silage based rations with added chopped orchardgrass hay.

Added Orchardgrass	Density	
	g/ml	g DM/ml[a]
0	.35	.18
9	.30	.16
18	.23	.14

[a]Corrected for dry matter of ration.

Table 33. Intake of dry matter (DM), cell wall constituents (CWC), acid detergent fiber (ADF) of fine chop corn silage-based rations with added chopped orchardgrass hay.

Added Orchardgrass	DM	CWC	ADF
	-------------	kg/d	-------------
0%	19.1	8.1	3.7
9%	19.6	8.3	3.8
18%	19.8	8.7	4.0
S. E. M.	.4	.2	.1
Ration F Test	P<.46	P<.06	P<.06
Contrast: P<			
Linear	.23	.02	.23
Quadratic	.81	.76	.48

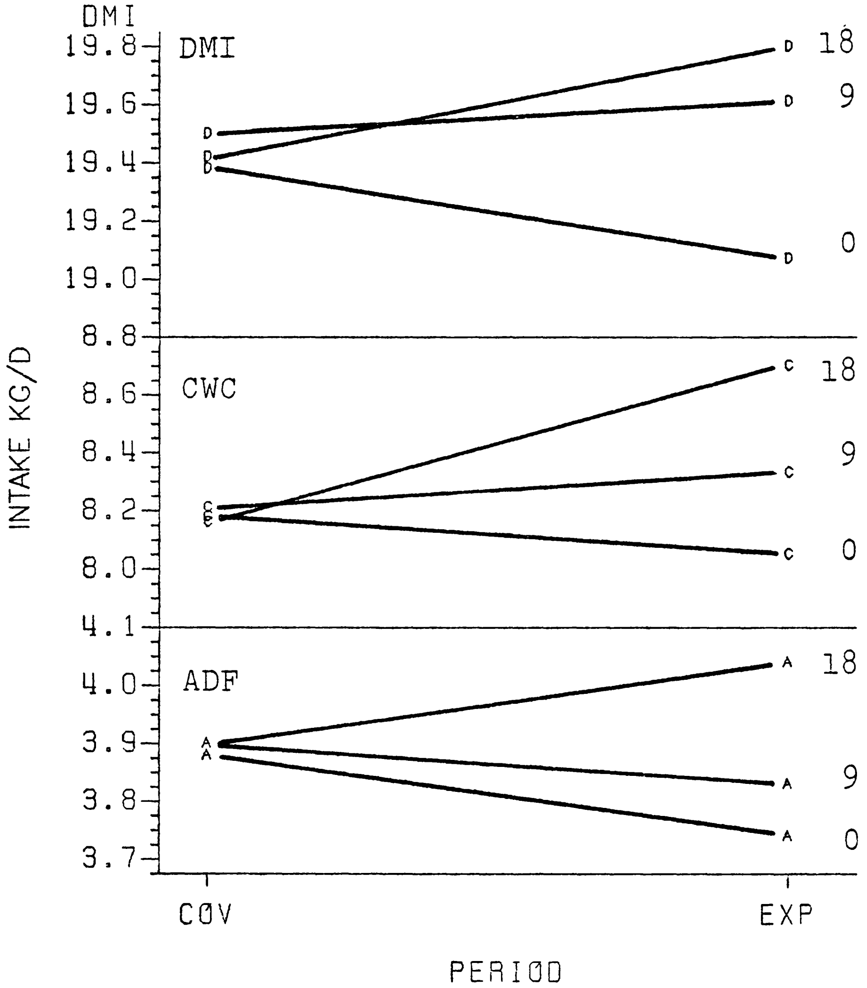

Figure 2. Intake of dry matter, cell wall constituents, and acid detergent fiber for Experiment 3.

ences for DMI were not as great as expected. A longer adaptation period for covariate as well as experimental period may have demonstrated larger differences for intake.

Chalupa et al. (1969) demonstrated DMI decreases as milk fat depression progresses. Milk fat test decreased from 3.5 to 3.0% in 42 d on a ration of pelleted coastal bermudagrass (PCB). After 84 d on rations containing PCB, milk fat decreased to 2.4% while intake decreased from 19.2 kg/d to 17.4 kg/d. Supplementing the PCB with 1.4 or 2.8 kg/d corn silage maintained intake at 19.5 and 19.2 kg/d, respectively, which is comparable to intake of 19.2 kg/d after 42 d on PCB ration. However supplementing 2.1 kg/d of baled coastal bermudagrass hay increased intake to 20.9 kg/d.

Volatile fatty acids

Molar proportions of rumen volatile fatty acids (VFA) are shown in table 34. Molar proportion of acetate increased linearly (P<.09) with added orchardgrass hay. There was a downward trend for propionate with added hay however, this was not significant. Molar proportion of butyric acid was (P<.04) reduced with 9% and 18% rations. Valeric acid was not affected by added hay. Total VFA concentration decreased (P<.08) with 9% and 18% rations com-

Table 34. Rumen fermentation parameters for experimental period for fine chop corn silage rations with chopped orchardgrass hay.

Added orchardgrass	Ac	Pr	Bu	Val	APR[a]	NGR[b]	TVFA[c]	Rumen pH
	-------- moles/100 moles --------						mm/liter	
0%	58	21	18	03	2.8	4.1	88.5	6.4
9%	61	20	16	03	3.1	4.2	72.9	6.3
18%	62	19	16	03	3.3	4.5	76.1	6.6
S. E. M.	1	1	1	1	.16	.20	4.8	.2
Ration F Test	P<.09	P<.27	P<.04	P<.87	P<.18	P<.36	P<.08	P<.10
Contrast: P<								
Linear	.04	.12	.03	.68	.07	.17	.09	.08
Quadratic	.54	.81	.18	.76	.90	.73	.14	.21

[a]Acetate:propionate ratio.

[b]Non-glucogenic ratio = (Ac + 2 Bu + Val) ÷ (Pr + Val).

[c]Total volatile fatty acids.

pared to 0% ration. Miller et al. (1969) reported slightly higher molar proportion of propionate (25.4 vs 22.3) and similar acetate (57.7 vs 57.2) for fine chop corn silage compared to the same corn silage with coarser chop. Data of Chalupa et al. (1969) show propionate increased from 20.3 moles/100 moles for dairy cows fed a control ration of corn silage:alfalfa hay as the roughage to 36.3 mole/100 moles after 84 d on a ration containing pelleted coastal bermudagrass as the roughage. Acetate decreased from 62.7 to 48.6 moles/100 moles during the same period. Supplementing the pelleted forage with corn silage or baled coastal bermudagrass produced acetate and propionate molar proportions comparable to control ration values.

Acetate:propionate (APR) and non-glucogenic ratios (NGR) were not significantly affected by treatment but there was a tendency for ratios to increase with added hay. Observed VFA patterns are the expected results of adding hay to high-concentrate, low-fiber rations for dairy cows. Slight increase in acetate and slight decrease in propionate as well as an increase in APR and NGR values agrees with other research. APR reported by Miller et al. (1969) was 2.2 for finely chopped corn silage compared to 2.6 for coarsely chopped corn silage. Bauman et al. (1971b) indicated that changes in APR when high-grain, low-fiber rations are fed result primarily from increased propionate production and relatively small changes in acetate production.

Rumen fluid dilution rate

Least square means for rumen fluid dilution rate are shown in table 35. There was a trend for increasing dilution rate with added hay rations but the trend was not significant. Much of the data detailing effects of ration physical form on RFD has been with extremes, such as high fiber versus high concentrate rations. Limited data is available for minor ration variations such as rations used in these experiments. However, increased RFD is expected by increasing roughage or fiberousness of a ration and agrees with data for dairy cows (Bauman et al., 1971a), steers (Topps et al., 1968), and sheep (Hodgson and Thomas, 1975). Grovum and Williams (1977) have shown with sheep that increasing intake decreases rumen retention time of Cr-EDTA, hence a greater RFD. Therefore much of the data on ration effects on RFD may be confounded by changes in intake.

Unadjusted means for covariate and experimental period are shown in figure 3. Dilution rate increased for all treatments. Cow 1180 had a dilution rate of 32.4%/hr during the covariate period while only 16.3%/hr during the experimental period on the 18% ration. This one value increased

Table 35. Adjusted means for rumen dilution rate of experimental period for fine chop corn silage-based rations with added orchardgrass hay.

Added orchardgrass	Dilution Rate	
	Fluid	Solids
	------- %/hr ---------	
0%	13.8	4.6
9%	14.4	5.7
18%	15.1	5.9
S. E. M.	1.9	.7
Ration F Test	P<.90	P<.25
Contrasts: P<		
Linear	.66	.15
Quadratic	.99	.36

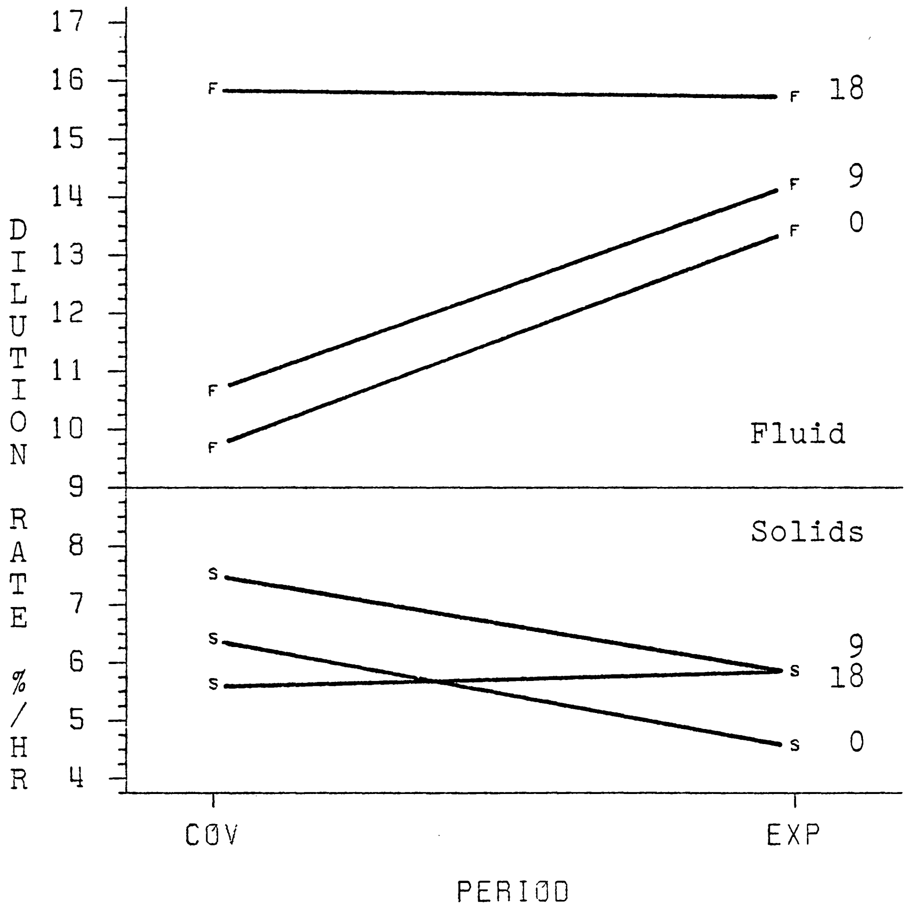

Figure 3. Rumen dilution rates for Experiment 3.

mean RFD for covariate from 12.5%/hr to 15.9%/hr. If cow 1180 is deleted from covariate mean then response to ration changes appears to parallel 0% and 9% slopes. Deleting 1180 from the experimental period had very little effect on 18% mean (15.7 with, and 15.6 without).

Rumen solids dilution rate

Least square means for rumen solids dilution (RSD) are shown in table 35. RSD tended to increase with 9% and 18% rations but the trend was not significant. This increase may be partly due to the slight increase in DMI observed for 9% and 18% between covariate and experimental periods. Data of Grovum and Williams (1977) show shorter transit times for solid phase as intake increased from 400 to 1300 g/d for sheep. Van Soest (1966) has observed increased fecal particle size as intake increased in dairy cows suggesting a faster RSD.

Unadjusted means for covariate and experimental period are shown in figure 3. 0% and 9% showed decreasing rates while the 18% ration showed a slight increase in solids dilution rate. However the technique used to estimate RSD precludes any detailed interpretation.

Chapter VI

SUMMARY AND CONCLUSIONS

Three experiments were conducted to determine the influence of added fiber sources such as chopped orchardgrass (OG) and alfalfa (ALF) hays or cottonseed hulls (CSH) to corn silage-based rations for dairy cows. Variables measured included intake, digestibility, nitrogen balance, rumen fluid and solids dilution rates, chewing time, and rumen fermentation patterns.

In Experiment I, three rations were formulated with 0, 9, and 18% of ration dry matter as OG or ALF, and 0, 5.5, and 11% CSH substituted for corn silage dry matter. A Control ration of 9% OG was used to monitor normal changes over the 12 wk experimental period. Two lactating Holsteins were assigned to each treatment and Control. Total collection procedures were conducted for 5 d during each of three experimental periods. Fecal samples were taken for estimation of rumen dilution rates using CoEDTA (fluid) and YbCl (solid) markers. Rumen fluid samples were taken after 14 d adaptation to rations for pH and volatile fatty acid (VFA) analysis. Dry matter intake (DMI) was higher with added fiber rations with an additional increase for CSH rations. Dry matter, cell wall constituents (CWC), and acid detergent fiber (ADF) digestibilies were lower for added fiber rations with a significant depression for CSH. Nitrogen balance data indicated that significantly more nitrogen was absorbed and utilized for production by addition of CSH, although nitrogen digestibility of CSH rations was significantly reduced. Rumen pH was not affected by treatments. Adding fiber sources did not effect significant changes in rumen VFA patterns although total VFA concentrations were slightly higher when fiber was added. Rumen fluid dilution (RFD) rates were higher for CSH compared to OG and ALF rations. An abnormal situation occurred with most of the cows during period 2 of this Experiment which was indicated by lower intake for Control cows.

From Experiment I, it was concluded that: 1) adding fiber sources to corn silage-based rations increases intake of DM, CWC, and ADF, 2) favorable nitrogen balance results from added fiber with an increased advantage for CSH addition, 3) rumen fermentation patterns are not affected by fiber addition to relatively coarse chopped (TLC=1.27 cm) corn silage, 4) CSH effects an increase in rumen fluid dilution rate more than OG or ALF addition.

Data from Experiment I indicated that several important advantages of adding fiber sources to corn silage-based rations are possible, especially with CSH addition.

Expected responses to added OG or ALF were not observed possibly due to coarseness of Control ration or unaccounted animal variation. Substitution of 9 or 18% OG or ALF for corn silage DM appeared not to affect digestibility as greatly as 5.5 or 11% CSH. Addition of CSH had a pronounced favorable effect on nitrogen balance and rumen fluid dilution rate. However complications during the second period of the experiment as well as the number of observations in the design may have diminished significance of some responses to the increasing fiber additions. These observations above were considered in the design and objectives of Experiment II.

In Experiment II, a replicated latin square arrangement was used to evaluate 9% added OG, ALF, or CSH to corn silage-based rations. Variables measured included intake, chewing time, rumen fluid and solids dilution rates, and rumen fermentation patterns. Added OG or ALF decreased ration density whereas CSH had very little effect on density compared to Control. Dry matter intake was highest for CSH rations while DMI for OG and ALF was comparable to Control. Added fiber rations produced significant increases in intake of CWC and ADF. Total chewing time per day was significantly reduced with ALF addition. Roughage Value Index (RVI) was also lower for ALF compared to OG ration. Total

VFA concentration was lower for added fiber rations compared to Control ration. Acetate:propionate (APR) and non-glucogenic (NGR) ratios were not affected by fiber additions. RFD rate was significantly lower for ALF compared to OG, but RFD was significantly higher for CSH compared to OG and ALF.

From Experiment II, it was concluded that: 1) adding 9% OG or ALF hay to a relatively coarse chopped corn silage (TLC=1.27 cm) does not affect intake although 9% CSH addition significantly increases intake, 2) adding 9% OG, ALF, or CSH does not affect rumen VFA or pH, 3) reduced chewing time was associated with reduced RFD for ALF addition, 4) adding "long hay equivalents" to coarsely chopped corn silage may alter RFD but response depends on source, 5) effectiveness of cottonseed hulls may be related to increased intake and RFD.

Data from Experiment II indicated that increasing ration bulk with OG or ALF does not affect intake. CSH addition increased intake but did not affect ration bulk. Increasing ration bulk did not increase chewing time of OG or ALF ration as expected, but ALF reduced chewing time per day. Reduced RFD for ALF may have been associated with reduced chewing time per day. Data from this experiment supports observations from experiment I that CSH addition increases DMI and RFD. Slight differences in RVI occurred between ALF and OG, but these values of 39 and 42, respectively, were well above the critical value of 31 suggested by Sudweeks et al. (1979) as necessary to support 3.5 milk fat. Rumen fermentation parameters were not affected as expected by the fiber additions. Significant responses to added fiber in Experiments I and II may have been precluded by the coarseness of the silage used, whereas a finely chopped corn silage may allow better evaluation of fiber additions. A third experiment was designed with finely chopped corn silage-based rations using analysis of covariance to account for cow variation.

In Experiment III, 18 lactating Holsteins were assigned to rations of finely chopped corn silage (TLC=.64 cm, roughage component) or a similar ration supplemented with 9 or 18% (dry-basis) chopped orchardgrass hay. Analysis of covariance was performed using the finely chopped corn silage-ration observations as the covariate. Variables measured included intake, rumen fermentation, and rumen fluid and solids dilution rates. Ration density decreased with 9 and 18% addition of OG. Dry matter intake increased with added OG but the trend was not significant. Intake of CWC and ADF was significantly higher for added OG rations. Cows with no added hay during experimental period showed a slight decrease in DMI from covariate period. Molar proportion of rumen acetate increased linearly with added OG while propionate showed a decreasing trend. Total VFA were lower for 9 and 18% added OG rations, however APR increased with added OG. Rumen pH was highest for 18% OG ration. RFD was highest for 18% added OG although RFD increased for all treatments from covariate to experimental periods.

From Experiment III, it was concluded that: 1) adding OG hay to finely chopped corn silage decreased ration density, 2) slightly higher DMI occurs by adding OG hay to finely chopped corn silage, 3) rumen acetate and APR increase while rumen propionate may decrease with fiber additions, 4) higher RFD can occur by adding OG hay to finely chopped corn silage-based rations.

In summary, the results of these experiments show that adding fiber sources to corn silage-based rations has some advantages. CSH addition consistently increased DMI and produced an increased RFD. Increased RFD may be affected through increased DMI but both parameters may be beneficial in optimizing nutrient intake and partitioning nutrients between rumen and lower digestive tract.

Benefits of adding OG or ALF were not realized in Experiments I and II and this may have been due to coarseness of the corn silage. OG and ALF increased ration bulk however the corn silage may have provided adequate bulk.

Since bulk density is rather easy to measure it may warrant more research to determine influence on ruminant health and production and possibly establish requirements for bulk in dairy rations.

Rumen fluid dilution rate affects site of digestion of nutrients but also affects changes in rumen environment. Increased RFD can produce changes in the microbial population favoring rapidly growing organisms with lower maintenance requirements and produce a fermentation favoring acetate rather than propionate production. CSH addition increases RFD through a mechanism which appears to differ from that produced by chopped hay addition. CSH has a small particle size which should pass from the rumen faster than chopped hay. Increased ration bulk should stimulate rumination and saliva flow which may increase RFD. CSH increased RFD but had no affect on ration bulk, whereas ALF decreased RFD but increased ration bulk. More research needs to be done on physical and chemical factors which stimulate or reduce rumination and RFD.

Rumen fermentation parameter responses were not realized in these experiments. This may relate to coarseness of the corn silage in the first two experiments and length of the adaptation period in all three experiments. Carry-over effects from treatments, especially rations with coarse particles of silage or hay, may have masked some important responses. Longer retention time for coarse particles in the digestive tract may necessitate 3 to 4 week adaption periods for finer particle rations to effect changes in rumen fermentation parameters as well as other parameters.

Future research should use a negative control such as a finely chopped corn silage to determine effectiveness of fiber sources. Importance of this technique relates to situations where fiber sources such as corn silage have been finely chopped or by-products have been processed to a fine particle size. In this case physical form or effective fiber must be supplied by supplementing "long hay equivalent" sources such as hay. Quantitative measurement of potential "long hay equivalent" sources must be available to formulate rations with adequate effective fiber. This allows optimum use of available feedstuffs and would minimize purchased feedstuffs to supplement effective fiber when necessary.

Two techniques for quantitation of physical form are available and appear to merit further development. Density measurements using a technique similar to that employed in these studies are simple and rapid. It would lend itself to on-farm use or as a forage testing routine measurement. However a standardized procedure must be developed and relate to animal response, health and production. The other physical measurement is particle sizing using a series of screens to partition the feedstuff. There is a standard procedure for this technique but the procedure is time consuming and may not be suitable for routine use in feed analysis. These two procedures plus feed quality analysis such as crude protein, fiber and mineral analysis may provide adequate quantitation of effective fiber. Current definition for effective fiber relates to a feedstuffs ability to support milk fat synthesis compared to the standard of cottonseed hulls. Supporting milk fat synthesis is important to cow health and production. This definition should be expanded to also relate to partitioning of feed components between rumen and lower digestive tract. Lower maintenance of the rumen microbial population, optimum production of microbial products, and effecient use of feedstuffs such as non-protein nitrogen and fiber sources could also be predicted.

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APPENDIX

Appendix Table 1. Statistical design, models, and expected mean squares for Experiment I.

A. Statistical arrangement and cow assignment.

Ration Designation	Periods 1	2	3	Cow No.
Control	9%	9%	9%	H-1029 SH-1270
Orchardgrass hay	0%	9%	18%	H-1284 SH-0947
Alfalfa hay	0%	9%	18%	H-1084 SH-1263
Cottonseed hulls	0%	5.5%	11%	H-1151 CH-1267

B. Model and expected mean squares for analysis of rations in Experiment I.

$$Y = \mu + L_i + P_j + C_k + E_{(ijk)}$$

where L = Ration groups i = 1 through 7

P = Periods j = 1, 2, 3

C = Cows k = 1 through 8

E = Residual component

Source	Expected Mean Square
Rations	$\sigma^2_e + k_1 \Sigma L_i{}^2/6$
Periods	$\sigma^2_e + k_2 \Sigma P^2_j/2$
Cows	$\sigma^2_e + k_3 \sigma^2_c$
Residual	σ^2_e

Appendix Table 1. (continued)

C. Model for slope (regression) calculations for each fiber type with increasing levels.

$$Y = a + T_i + \beta_4 P_j + C_{(i)k} + \sum_{i=3}^{3} \beta_i P_j + E_{(ijk)}$$

where a = intercept

T = Type of fiber i = 1, 2, 3

P = Periods j = 1, 2, 3

C = Cows k = 1 through 6

β_4 = Overall slope of observation across periods

β_i = Deviation from overall slope for each fiber type

Source	Expected Mean Squares
Type	$\sigma^2_e + K_1 \alpha^2_c + K_2 \Sigma T_i/2$
Period(β)	$\sigma^2_e + \beta_4^2 \sum_{j=1}^{3} (P_j - \bar{P})^2$
Cow(Type)	$\sigma^2_e + k_1 \sigma^2_c$
Type x Period	$\sigma^2_e + k_2 \sum_{i=1}^{3} \beta_i^2 (T_i \sum_{j=1}^{3} (P_j - \bar{P}))^2/2$
Residual	σ^2_e

Appendix Table 2. Statistical design, model, and expected mean squares for Experiment II.

A. Statistical arrangement and cow assignment.

		Ration Designation			
		Control	Orchard-grass	Alfalfa	Cottonseed hulls
Periods	1	1115 1262	1280 1275	1259 1288	987 1298
	2	987 1298	1115 1262	1280 1275	1259 1288
	3	1259 1288	987 1298	1115 1262	1280 1275
	4	1280 1275	1259 1288	987 1298	1115 1262

B. Model for Latin Square arrangement.

$$Y = \mu + R_i + P_j + C_k + E_{(ijk)}$$

where R = Rations $i = 1 - 4$
P = Periods $j = 1 - 4$
C = Cows $k = 1 - 8$
E = Residual component

Appendix Table 2. (continued)

Source	Expected Mean Square
Type	$\sigma^2_e + k_1 \Sigma L_i^2/3$
Period	$\sigma^2_e + k_2 \Sigma P_j/3$
Cow	$\sigma^2_e + k_3 \sigma^2_c$
Residual	σ^2_e

Appendix Table 3. Statistical design and model for Experiment III.

A. Statistical arrangement and cow assignment.

Periods		
Covariate		Experimental
	cow #	Percentage OG substituted for corn silage
3 wk period no OG	1232 1252 1350 1353 1301 1365	0%
	1233 1167 1159 1335 1363 1349	9%
	1133 1244 1180 1362 1352 1331	18%

B. Model for Analysis of Covariance.

$$Y = a + R_i + \beta_1 C_j + E_{(ijk)}$$

where a = intercept

R = Rations $i = 1 - 3$

C = Covariate observation

E = Residual component

Appendix Table 3. (continued)

Source	Expected Mean Square
Ration	$\sigma^2_e + b \sum_{i=1}^{3} T_i^2/5$
Covariate	$\sigma^2_e + \beta_1^2 \Sigma(C_j - \bar{C})^2$
Residual	σ^2_e

Appendix Table 4. Analysis of Variance for Experiment I.

A. Analysis of Variance for intake and digestibility

		Mean Squares						
		Intake				Digestion Coefficient		
Source	df	DM[a]	DM[b]	CWC[a]	ADF[a]	DM	CWC	ADF
Rations	6	3.91	.13	1.40	.67	3.61	44.23	47.32
0% vs 9%	1	3.65	.12	.58	.46	12.67	108.41	135.57
Hays vs CSH	1	1.65	.07	1.00	.16	1.65	4.67	25.52
Period	2	2.25	.09	.18	.16	1.22	19.77	11.02
Cow	7	18.27	.30	2.85	.74	5.93	23.83	31.80
Error	8	1.50	.05	.30	.05	1.53	6.98	13.20
Total	23	6.98	.14	1.60	.50	2.89	27.44	47.57

[a]kg/d.

[b]kg/100 kg body weight/d.

[c]%.

Appendix Table 4. (continued)

B. Analysis of Variance for nitrogen balance data.

		Mean Squares							
		Nitrogen Component							
Source	df	Intake[a]	Fecal[a]	Urine[a]	Milk[a]	Tissue[a]	Production[a]	Digestion[b]	BV[c]
Rations	6	1961.51	699.99	235.45	234.41	758.93	878.37	0.11	32.44
0% vs 9%	1	2981.21	1393.04	0.00	2.72	3378.42	3189.34	0.20	17.46
Hays vs CSH	1	3740.04	707.64	41.63	123.52	565.13	1217.06	0.00	81.44
Period	2	497.38	243.36	52.05	548.21	2061.06	3329.28	0.17	279.22
Cow	7	8572.92	1222.48	641.15	641.21	800.10	1978.82	0.21	67.27
Error	8	610.84	219.96	331.36	61.21	300.08	434.50	0.03	34.54
Total	23	4187.34	524.25	502.63	417.71	1251.81	1647.62	0.18	88.22

[a] g/d.

[b] %.

[c] BV = Biological Value
Retained N ÷ absorbed N x 100.

Appendix Table 4. (continued)

C. Analysis of Variance for rumen parameters.

		Mean Squares									
		Volatile Fatty Acids					Ratio		Rumen	Dilution Rate	
Source	df	Ac[a]	Pr[a]	Bu[a]	Val[a]	Total[b]	APR[c]	NGR[d]	pH	Liquid[e]	Solid[e]
Ration	6	0.01	0.02	0.02	0.01	347.07	0.05	0.12	0.03	0.15	0.02
0% vs 9%	1	0.00	0.00	0.00	0.00	103.68	0.00	0.00	0.05	0.08	0.02
Hays vs CSH	1	0.04	0.00	0.00	0.03	1545.87	0.04	0.18	0.01	0.55	0.00
Period	2	0.03	0.03	0.01	0.01	15.98	0.09	0.25	0.07	0.17	0.02
Cow	7	0.11	0.10	0.05	0.01	237.02	0.21	0.33	0.11	0.05	0.00
Error	8	0.14	0.04	0.03	0.02	466.21	0.18	0.15	0.17	0.03	0.01
Total	23	0.12	0.07	0.03	0.01	496.76	0.19	0.25	0.10	0.09	0.01

[a]moles/100 moles.

[b]mm/liter.

[c]Acetate:propionate ratio.

[d]Non-glucogenic ratio = (Ac + 2 Bu + Val) ÷ (Pr + Val).

[e]%/hr.

Appendix Table 5. Analysis of Variance for Experiment I.

A. Analysis of Variance for regression of fiber types on level for intake and digestibility

		Mean Squares						
		Intake				Digestion Coefficients		
Source	df	DM[a]	DM[b]	CWC[a]	ADF[a]	DM[c]	CWC[c]	ADF[c]
Type	2	8.48	0.23	1.29	0.87	4.84	36.91	10.91
Period	1	0.01	0.00	8.42	1.84	0.56	37.28	5.47
Cow(Type)	3	25.77	0.58	4.07	0.82	9.68	33.56	70.78
Period*Type	2	7.63	0.25	0.95	1.02	6.13	62.43	32.07
OG vs Alf	1	1.90	0.06	0.15	0.26	3.13	0.64	6.48
OG vs CSH	1	14.85	0.48	1.79	1.98	12.25	101.03	28.13
Alf vs CSH	1	6.13	0.19	0.91	0.80	3.00	85.61	61.61
Error	9	1.68	0.05	0.49	0.24	1.88	16.71	64.47
Total	17	6.81	0.16	1.82	0.53	3.48	28.07	58.83

[a]kg/d.

[b]kg/100 kg body weight/d.

Appendix Table 5. (continued)

B. Analysis of Variance for regression of fiber types on level for nitrogen balance data.

		Mean Squares							
		Nitrogen Component							
Source	df	Intake[a]	Fecal[a]	Urine[a]	Milk[a]	Tissue[a]	Production[a]	Digestion[b]	BV[c]
Type	2	2845.43	2508.25	228.42	120.23	161.77	405.67	0.005	20.35
Period	1	8512.01	151.23	2456.74	2252.28	5715.97	792.19	0.001	1.23
Cow(Type)	3	11749.40	641.18	962.66	228.80	1707.98	3154.26	0.001	67.46
Period*Type	2	3366.60	1676.44	146.67	215.60	1056.82	1708.11	0.003	7.89
OG vs ALF	1	73.21	1012.50	18.61	261.06	87.78	46.08	0.004	15.00
OG vs CSH	1	5618.00	3341.53	148.78	375.38	1176.13	2880.41	0.005	1.38
Alf vs CSH	1	4408.61	675.28	272.61	10.35	1906.53	2197.85	0.000	7.28
Error	9	1196.54	194.43	314.87	126.08	771.29	867.61	0.001	68.13
Total	17	3859.60	568.63	579.19	270.90	1420.07	1544.70	0.002	64.78

[a] g/d.

[b] %.

[c] BV = Biological Value
Retained N ÷ absorbed N x 100.

Appendix Table 5. (continued)

C. Analysis of Variance for regression of fiber types on level for rumen parameters.

		Mean Squares									
		Volatile Fatty Acids					Ratio		Rumen	Dilution Rate	
Source	df	Ac[a]	Pr[a]	Bu[a]	Val[a]	Total[b]	APR[c]	NGR[d]	pH	Liquid[e]	Solids[e]
Type	2	0.028	0.071	0.062	0.003	85.1	0.124	0.329	0.101	0.034	0.007
Period	1	0.001	0.027	0.009	0.000	2637.3	0.022	0.079	0.000	0.006	0.007
Cow(Type)	3	0.213	0.193	0.066	0.008	153.9	0.434	0.546	0.035	0.030	0.004
Period*Type	2	0.000	0.037	0.034	0.000	13.7	0.089	0.409	0.067	0.023	0.103
OG vs Alf	1	0.000	0.061	0.066	0.000	25.2	0.168	0.390	0.065	0.016	00.014
OG vs CSH	1	0.000	0.000	0.008	0.000	1.5	0.014	0.038	0.010	0.044	0.017
Alf vs CSH	1	0.000	0.047	0.028	0.000	14.3	0.084	0.185	0.125	0.007	0.000
Error	9	0.124	0.037	0.032	0.018	812.1	0.160	0.142	0.145	0.083	0.006
Total	17	0.121	0.080	0.004	0.014	644.6	0.214	0.257	0.097	0.066	0.006

[a] moles/100 moles.

[b] mm/liter.

[c] Acetate:propionate ratio.

[d] Non-glucogenic ratio = (Ac + 2 Bu + Val) ÷ (Pr + Val).

[e] %/hr.

Appendix Table 6. Analysis of Variance for Experiment II.

A. Analysis of Variance for intake and chewing time.

		Mean Squares								
		Intake			Chewing Time			Chewing Time		
Source	df	DM[a]	CWC[a]	ADF[a]	Eat[b]	Cud Chewing[b]	Total[b]	Eat[c]	Cud Chewing[c]	Total[c]
Type	3	2.89	1.49	1.90	987.8	2852.1	6248.9	6.7	11.2	28.4
Control vs added	1	1.90	2.89	1.82	1625.3	49.6	2242.8	14.7	2.1	29.8
Hays vs CSH	1	6.36	1.48	3.72	165.0	2106.8	3451.0	4.0	0.5	10.5
Alf vs OG	1	0.42	0.09	0.17	1173.1	6400.0	13053.1	1.3	30.9	45.0
Period	3	0.14	1.80	1.03	1993.0	559.9	1742.8	4.0	2.2	5.4
Cow	7	4.55	0.62	0.49	5361.4	13134.0	30554.6	22.6	30.1	84.3
Error	18	0.99	0.20	0.07	1467.2	2758.4	2279.6	5.5	10.2	12.8
Total	31	1.89	0.57	0.44	2351.0	4897.6	8996.5	9.3	14.0	29.7

[a]kg/d.

[b]min/d.

[c]min/kg DMI.

Appendix Table 6. (continued)

B. Analysis of Variance for rumen parameters.

		Mean Squares									
		Volatile Fatty Acids					Ratio		Rumen	Dilution Rate	
Source	df	Ac[a]	Pr[a]	Bu[a]	Val[a]	Total[b]	APR[c]	NGR[d]	pH	Liquid[e]	Solids[e]
Type	3	0.137	0.087	0.180	0.014	2821.0	0.113	0.332	0.045	0.223	0.004
Control vs added	1	0.089	0.051	0.009	0.000	7026.4	0.078	0.052	0.006	0.000	0.008
Hays vs CSH	1	0.091	0.072	0.018	0.027	96.9	0.262	0.668	0.102	0.440	0.003
Alf vs OG	1	0.228	0.137	0.527	0.015	1339.6	0.000	0.277	0.026	0.230	0.001
Period	3	0.019	0.053	0.023	0.015	28.3	0.043	0.112	0.262	0.200	0.061
Cow	7	0.181	0.266	0.031	0.014	263.2	0.429	0.804	0.185	0.008	0.040
Error	18	0.087	0.190	0.025	0.007	2210.2	0.213	0.398	0.051	0.047	0.033
Total	31	0.106	0.184	0.042	0.010	457.2	0.235	0.456	0.101	0.086	0.035

[a] moles/100 moles.

[b] mm/liter.

[c] Acetate:propionate ratio.

[d] Non-glucogenic ratio = (Ac + 2 Bu + Val) ÷ (Pr + Val).

[e] %/hr.

Appendix Table 7. Analysis of Variance for Experiment III.

A. Analysis of Covariance for intake.

		Mean Squares			
		Intake			
Source	df	DM[a]	DM[b]	CWC[a]	ADF[a]
Ration	2	0.88	0.01	0.66	0.11
Linear	1	1.70	0.01	1.30	0.28
Quadratic	1	0.06	0.00	0.02	0.02
Covariate	1	22.22	1.06	4.06	0.87
Error	14	1.06	0.05	0.19	0.04
Total	17	2.28	0.10	0.47	0.10

[a]kg/d.

[b]kg/100 kg body weight/d.

Appendix Table 7. (continued)

B. Analysis of Covariance for rumen parameters.

		Mean Squares									
		Volatile Fatty Acids					Ratio		Rumen	Dilution Rate	
Source	df	Ac[a]	Pr[a]	Bu[a]	Val[a]	Total[b]	APR[c]	NGR[d]	pH	Liquid[e]	Solids[e]
Ration	2	0.224	0.043	0.061	0.002	404.4	0.297	0.247	0.134	0.020	0.038
Linear	1	0.411	0.082	0.091	0.003	435.9	0.589	0.472	0.181	0.038	0.056
Quadratic	1	0.031	0.002	0.030	0.001	3337.1	0.002	0.028	0.084	0.000	0.022
Covariate	1	0.439	0.187	0.083	0.021	578.1	0.605	0.551	0.190	0.111	0.010
Error	14	0.078	0.030	0.015	0.015	135.6	0.152	0.225	0.049	0.191	0.025
Total	17	0.026	0.050	0.025	0.238	202.1	0.237	0.286	0.069	0.174	0.025

[a] moles/100 moles.

[b] mm/liter.

[c] Acetate:propionate ratio.

[d] Non-glucogenic ratio = (Ac + 2 Bu + Val) ÷ (Pr + Val).

[e] %/hr.

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DEFINING EFFECTIVE FIBER CONTENT OF DAIRY RATIONS

by

Terry Lee Maddox

(ABSTRACT)

Cottonseed hulls (CSH), chopped orchardgrass (OG) or alflafa (ALF) hays were added to corn silage-based rations to determine effects on dry matter intake (DMI), nitrogen balance (NB), rumen volatile fatty acids (VFA), and rumen fluid (RFD) and solids (RSD) dilution rates. DMI was highest for added fiber rations and higher for CSH than hay rations. Digestibility of DM was depressed for added fiber rations with lowest for CSH. Most favorable NB was for CSH rations. Rumen VFA were not altered by fiber additions. Highest RFD was for 0% rations and lowest for 9% rations, however CSH had greatest postive influence on RFD. RSD trend was similar to that for RFD.

In Experiment II, 4 corn silage-based rations containing 9% OG, ALF, or CSH plus a Control (9% OG) were compared for effect on DMI, rumen VFA, chewing time (CT), RSD, and RFD. Ration density decreased with OG and ALF whereas CSH had no effect compared to Control. DMI was higher for CSH compared to OG and ALF. Total CT (min/d) and Roughage Value Index (CT/kg DMI) were reduced for ALF compared to OG. Total VFA were lower for added fiber rations compared to Control.

Acetate:propionate (APR) and non-glucogenic (NGR) ratio were not affected by fiber additions. RFD was reduced for ALF compared to OG whereas CSH was higher than OG and ALF. Reduced RFD was associated with reduced total CT for ALF. RSD was not affected by fiber additions.

Chopped OG was supplemented at 0, 9, or 18% of ration DM in a finely chopped corn silage-based ration. Analysis of covariance was performed using 18 lactating Holsteins. Ration density decreased with each increment of OG. DMI was highest for 18% OG ration. Cows on 0% showed decreased DMI whereas cows on 9 and 18% rations increased DMI from covariate period. Rumen acetate, APR and NGR increased while propionate and total VFA decreased with increasing OG. RFD and RSD increased with increasing OG supplementation.

Response to 9 and 18% supplementation of OG, ALF, or CSH to corn silage-based rations appears to follow similar pattern as when all-forage rations were compared to all-concentrate rations for lactating dairy cows. A more quanitative evaluation of physical form is needed for dairy rations and feedstuffs leading to an acceptable routine evaluation procedure.