# CORN VERSUS SOYBEAN HULL SUPPLEMENTS FOR BEEF COWS FED LOW-QUALITY NATIVE GRASS HAY

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1985

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
May, 1992

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# ACKNOWLEDGEMENTS

First, I wish to express my most sincerely gratitude to my major adviser, Dr. Charles A. Hibberd, for his inspiration in my coursework, instructions and real help in this experiment and patience in replying the weird and superficial questions that I asked. During these three years, I appreciate for his helpfulness and counsel in my adapting to new culture and environment. I regard him as my mentor and psychiatrist and cherish the friendship that we own.

I am also thankful to Dr. Fredric N. Owens and Dr. Robert Teeter for serving on my graduate committee.

Without the assistance of my dear colleague, Ronald Scott, and laboratory technicians, Kathryn Swenson and Shaban Janloo, this experiment can not be accomplished. I also want to thank my colleague, Paula Dubeski, for her morale encouragement. To the gentlemen working in Nutrition and Physiology Barn, thank you for taking care with the animals during the experimental periods.

My deepest appreciation is extended to my grandmother, Sau-Wan Ho; father, Yun-Pong Chan; mother, Kwen-Yin Li and brother, Willis Chan, for their love, encouragement and financial support.

I would like to dedicate this thesis to my family and my major advisor.

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# CHAPTER I

# INTRODUCTION

In nature, solar energy is stored primarily in the form of coal and oil, cellulose, hemicellulose and lignin. Animals such as cattle and sheep and insects such as termites can utilize cellulosic materials because cellulolytic microbes exist in their gastrointestinal tracts.

Ruminants contribute to human food supplies by transforming fibrous feeds of little or no human value into nutritious food. They can utilize nonarable land such as pastures and meadows and some of the forests, waste by-products and crop residues to produce meat and milk for human consumption. Low quality pastures, however, may not provide enough nutrients for ruminants; therefore, additional quantities of supplemental nutrients must be provided to sustain productivity.

Cereal grain supplementation is frequently utilized in the United States. Cereal grains are inexpensive sources of energy and may be fed economically to cattle (Loerch, 1990). However, forage digestion is depressed when energy supplements are fed at high levels (Chase and Hibberd, 1987). In addition, human population growth in this century has exerted pressure on world food supplies causing some to suggest that feeding grain to ruminants should be minimized.

Cellulose digestion can be enhanced when cattle grazing low-quality grass are supplemented with small quantities of energy or protein supplements (Kartchner, 1981; Martin and Hibberd, 1990). However, when the level of grain supplement is increased, cellulose digestion may be depressed (van der Linden et al., 1984; Chase and Hibberd, 1987). The starch contained in cereal grain supplements has been suggested to be one of the major factors depressing cellulose digestion (Burroughs et al., 1949; Mertens and Loften, 1980). Whether depressed cellulose digestion is due to reduced ruminal pH, inadequate ruminal ammonia or altered digesta flow kinetics remains uncertain. Optimally, supplementation should increase energy intake without disrupting fiber digestion of low-quality native grass hay. Low starch, highly digestible fiber feeds such as soybean hulls, corn gluten feed or wheat bran may be complementary, rather than detrimental, to grazed forage (Hsu et al., 1987; Anderson et al., 1988a). Few studies have directly compared the effects of starch vs digestible fiber supplements on forage intake and utilization. In addition, the effects of these supplements on ruminal fiber fermentation and microbial protein synthesis are not known. Consequently, the objective of this experiment was to compare the effects of starch vs digestible fiber supplements on intake, nutrient flow and digestion, microbial protein synthesis, digesta kinetics and ruminal environment of beef cows fed low-quality native grass hay.

# CHAPTER II

# LITERATURE REVIEW

## Factors Affecting Nutrient Requirements

The nutrient requirements of beef cows depend on their physiological needs for maintenance, reproduction, gestation and lactation. Although each of these physiological needs represents a unique nutrient requirement, these functions frequently overlap. Consequently, their effects on the total nutrient requirements of the cow are additive.

### Maintenance

Maintenance requirements are defined as "the combination of nutrients which are needed by the animal to keep its body functioning without any gain or loss in body composition or any productive activity" (Ensminger and Olentine, 1978). Factors such as exercise, weather, stress, health, body size and individual variation can affect the maintenance requirement. Consequently, the quantity of nutrients needed for basal metabolism can differ from individual to individual.

### Lactation

Beef cows lactate from parturition until weaning. The mechanism of lactation is complex and involves the interactions of several hormones including estrogen, progesterone and prolactin. During lactation, the nutrient requirements of beef cows increase dramatically compared with maintenance because the dams must continue to maintain their own biological function as well as repair tissue damage after parturition and produce milk for growth of the newborn.

### Reproduction

Nutritional factors play vital roles in the attainment of sexual maturity and in the course of the reproductive process. Specific nutrient deficiencies can result in injury and failure at specific stages of the reproductive process (Maynard et al., 1979). A normal plane of nutrition is necessary to obtain optimal reproductive function. Maynard et al. (1979) demonstrated that poor nutrition delays puberty and may cause retrogressive changes in reproductive organs. In contrast, overfeeding may cause dystocia.

### Gestation

An adequate nutrient supply is important for the female, especially during the last third of pregnancy, because most fetal growth occurs during that time. Also, pregnant females must store enough body reserves to meet the demands of milk production (Ensminger and Olentine, 1978). In conclusion, the nutrient requirements of animals differ depending on the physiological needs they encounter. In order to obtain optimum animal performance, nutrient requirements must be determined accurately and adequate nutrients must be supplied in a balanced diet.

## Nutrient Requirements

### Energy

Animals obtain chemical energy from their food. As ingested nutrients are oxidized, chemical energy is converted into mechanical or heat energy. The purpose of this conversion is for muscular activity, transport of substances against concentration gradients and synthesis of various compounds such as enzymes and hormones (McDonald et al., 1988). Chemical energy is obtained from oxidation of organic matter in the body. Compared with protein or fat, glycogen has the first priority for oxidation to provide needed energy for basal body function in a fasting animal.

When energy intake exceeds the maintenance requirement, excessive energy can be stored in the form of protein or fat or be transferred into milk or used for muscular work (McDonald et al., 1988).

## Protein

Many diverse biological processes are accomplished by different proteinaceous compounds. Protein is utilized for protein anabolism in body tissues, oxygen transport in the respiratory system, motion and support, immune system function and digestion and absorption. The determination of the protein requirement in ruminants is much more complicated than in nonruminants because of extensive dietary protein degradation and synthesis by microorganisms within the rumen. Therefore, the amount of protein available for digestion and absorption by the animal may differ considerably from that provided by food (Maynard et al., 1979). Microbial protein plays a very important role in the protein supply of ruminants. Also, ruminant needs may be satisfied with essential amino acids supplied by microbial fermentation. Hence, diets should be formulated to provide adequate protein for both microbial growth as well as any further physiological needs of the ruminant.

## Vitamins and Minerals

Vitamins and minerals are required by ruminants in very small amounts compared with other nutrients. Their major functions are as prosthetic groups of specific enzymes and coenzymes associated with biochemical pathways. In ruminants, B-complex vitamins and vitamin K can be synthesized by ruminal microorganisms (Huber, 1988). Therefore, the minimum daily requirement of vitamin A, D and E and minerals should be supplied to meet NRC recommendations in order to prevent deficiencies.

# Sources of Nutrients

## Forage

The largest proportion of nutrients supplied to ruminants come from forages. The nutrient content of a forage is dependent on factors such as species of forage, stage of maturity, climate, fertilization and leaf to stem ratio (Van Soest, 1982). Species and maturity greatly affect forage quality. Legume species often have higher nutritive value than grasses because they usually contain more crude protein. Forage quality is also affected by plant tissue structure. Cellulose, hemicellulose and lignin are the major fibrous components in forage. Lignin plays a role as an inhibitory factor of forage digestibility by cross-linking cellulose and hemicellulose in the plant cell wall resulting in more complex structures that are not easily broken down by microorganisms.

## Supplements

When forage nutrients cannot meet the nutrient requirements of the cow, supplementation may be necessary. Supplements may be energy or protein-based depending on the specific nutrient deficiency. Soybean meal and cottonseed meal are commonly used as protein supplements whereas energy supplements can be generally divided into two groups: cereal grain supplements, based on corn, milo or wheat, and highly digestible fiber feeds, based on soybean hulls, corn gluten feed or wheat middlings. Because the chemical composition of these feeds differs, their effects on digestive events may vary.

Protein Supplements. Protein supplements are feeds that contain more than 20 percent crude protein (Ensminger and Olentine, 1978). Traditionally, protein supplements have been composed of soybean meal or cottonseed meal. The primary reason to feed protein supplements to ruminants is to provide adequate nitrogen for microbial growth in the rumen. Ruminal protein degradation, however, can vary depending on the feed (Owens and Zinn, 1988). Protein supplements may be composed of processed oilseeds or by-products from grain milling, brewing and distilling. Protein content of by-products will vary with geographical area, the amount of product included and the method of processing (Ensminger and Olentine, 1978). Since protein feeds are the most expensive supplemental component of the grazing animal's diet, it is important to provide enough protein for the optimum performance, but to avoid feeding more than is necessary.

Soybean meal is used widely as a protein supplement in the United States. Almost all soybean meal that is marketed has been extracted with a fat solvent (hexane). Soybean meal normally contains 40-50 percent protein, depending on the content of hulls. Because its amino acid profile is well-balanced, protein from soybean meal has a better quality than most other protein-rich feeds of plant origin (Ensminger and Olentine, 1978). In addition, soybean meal protein is readily available to ruminal microbes with a ruminal degradation of about 74% (Owens and Zinn, 1988).

Cottonseed meal is commonly fed as a protein supplement, especially in the southwestern region of United States. The protein content of cottonseed meal ranges from 44.3 to 45.2% (NRC, 1984). Cottonseed meal protein degradation in the rumen is about 60% which is slightly lower than for soybean meal (Owens and Zinn, 1988).

<u>Energy Supplements</u>. Energy supplements contain less than 20% percent protein (Ensminger and Olentine, 1978). Cereal grains, such as corn, and by-product feeds, such as soybean hulls, corn gluten feed or wheat middlings, are used as components of energy supplements.

Cereal grains, such as corn, are frequently used in supplements to increase energy intake. The major chemical constituent of corn is starch which is highly digestible (86%) in beef cows (Chase and Hibberd, 1987). Corn has a high TDN value (91%), a low protein level (9%) and a relatively low extent of ruminal protein degradation (35%; NRC, 1984; NRC, 1985). High NDF (70 to 80%) and intermediate protein (11 to 21%) are the general characteristics of digestible fiber feeds such as soybean hulls, corn gluten feed and wheat middlings. These feeds are termed 'digestible fiber' because they are generally low in lignin (2 to 3%).

Soybean hulls, a by-product of the soybean milling industry, are obtained by removing the outer coating or bran of the soybean seed. Cellulose content ranges from 44.9% (Garleb et al., 1988) to 46% (NRC, 1984), crude protein ranges from 10.3% (Garleb et al., 1988) to 12.1% (Martin and Hibberd, 1990). In addition, they contain no starch and only 2% lignin (NRC, 1984). The TDN content based on NRC (1984) is estimated to be 64% although some reports indicate that TDN is much higher. Soybean hulls provide more digestible energy to ruminants (1,811 DE kcal/kg) than cottonseed hulls (1,633 DE kcal/kg; Jurgens, 1978). Compared with cottonseed hulls, soybean hulls produced twice as rapid weight gain in lambs (Streeter and Horn, 1983).

Corn gluten feed is composed of bran plus corn steep liquor obtained by soaking the corn with a dilute lactic acid solution followed by centrifugation (McDonald et al., 1988). Protein and crude fiber contents of corn gluten feed are 25.6% and 9.7%, respectively (NRC, 1984). About 80% of the protein in corn steep liquor is degradable in the rumen (Wagner, 1982).

Wheat middlings are a by-product of the flour milling industry comprising several grades of granular particles containing different proportions of endosperm, bran and germ, each of which contains a different percentage of fiber. Wheat middlings contain 16 to 18% crude protein and less than 9.5% crude fiber (Jurgens, 1978) but are low in calcium, carotene, and vitamin D (Ensminger and Olentine, 1978).

## Effect of Supplementation on Livestock Performance

Supplementation is necessary whenever nutrient requirements of the animal exceed the quantity or quality of nutrients supplied by the forage. If these deficiencies are not satisfied, livestock performance may suffer. In addition, performance responses will differ depending on the type and quantity of supplement that is fed.

## Protein Supplementation

Protein supplementation of beef cattle grazing low quality forage can improve performance and economic efficiency. Supplies of both ammonia for microbial growth and undegraded dietary protein are increased by protein supplementation resulting in increased protein flow to the small intestine and OM digestion in the rumen. Consequently, cow performance often is improved. Rittenhouse et al. (1970) suggested that increased weight gain induced by protein supplementation was related to the satisfaction of protein requirements plus higher OM intake. Reduced postpartum weight loss (Gonzalez et al., 1987; Lusby and Wagner, 1987; Hibberd et al., 1988; Miner et al., 1990), increased milk production (Hibberd et al., 1988) and higher body condition score (Clanton and Zimmerman, 1970; Hennessey et al., 1983; Gonzalez et al., 1987; Hunt et al., 1990; Miner et al., 1990) in beef cows were observed when protein was supplemented. Greater weight gain in suckling calves was also demonstrated when cows on native grass were supplemented with cottonseed meal (Gonzalez et al., 1987). Consequently, protein supplementation can reduce losses in weight and body condition of cows consuming low-quality forages.

## Energy Supplementation

Energy supplements may improve cow performance depending on the type and amount of supplement fed. Daily gain and gain:feed ratio of growing steers were increased when a mixture of oat straw and alfalfa hay was supplemented with a small amount of corn (1.05 or 2.1 kg/d; Anderson et al., 1988b). In contrast, body weight and condition score were not altered when low-quality native grass was supplemented with 1.4 kg of cracked barley compared to an unsupplemented group (Kartchner, 1981).

Cow performance can be improved when animals grazing low-quality native grass are supplemented with highly digestible fiber feeds such as soybean hulls. Trautman (1987) indicated that cows supplemented with soybean hulls lost less weight and body condition than cows supplemented with corn. In contrast, Brown et al. (1981) reported that average daily gain and gain:feed ratio were higher with corn compared to a soybean hull supplement fed at a level of 30% of a corn stalkage diet. At 12.5, 25 and 50% of the corn stalkage diet, no differences in average daily gain were noted between corn and soybean hulls (Brown et al., 1981).

### Comparison of Protein and Energy Supplementation

Cows grazing low-quality forage (4.3% CP) with ear corn supplying 1.16 kg TDN/d plus a protein supplement lost weight (-18 kg) while cows supplemented with protein alone gained weight (+6 kg) during a winter grazing period even though supplemental protein intake (290 g CP/d) was equalized (Sanson et al., 1990). In addition, calf birth weight and calf daily gain were increased more when cows received protein supplements than when cows received only the ear corn supplement. Fall-calving cows on native grass supplemented with .75 kg cottonseed meal or .7 kg soybean meal lost less body weight and maintained higher body condition scores than cows supplemented with barley (Kartchner, 1981). In contrast, Hibberd and Chase (1986) indicated that cows fed high energy supplements based on corn or soybean hulls lost less body weight and maintained higher body condition scores than a control group fed only cottonseed meal. In addition, calves suckling dams supplemented with either corn or soybean hulls gained more weight than calves suckling dams with only protein supplementation due to increased milk production by cows receiving supplemental energy.

## Effect of Supplementation on Forage Utilization

Both intake and digestibility of forage can be altered with energy or protein supplementation. Generally, grain supplementation depresses forage intake and digestibility (Chase and Hibberd, 1987; Hibberd et al., 1987b; Sanson et al., 1990) whereas protein supplementation usually increases forage intake and digestibility (DelCurto et al., 1990a; Pordomingo et al., 1991).

## Forage Intake

Protein Supplementation. Consumption of low quality forage usually increases when protein supplements are fed to cattle (Hennessy et al., 1983; McCollum and Galyean, 1985a; Guthrie and Wagner, 1988; Scott and Hibberd, 1990) or to goats (Lu and Potchoiba, 1990). Forage intake of steers consuming medium quality fescue hay (6.6% CP) was increased when 3 g CP/kg $BW^{.75}$ was supplied by cottonseed meal (Hunt et al., 1989). Forage intake increases because of an increased rate of digestion of low-quality forage (Barton and Hibberd, 1984; Chase et al., 1988; Scott and Hibberd, 1990), extent of OM digestibility (Pordomingo et al., 1991) and (or) digesta passage rate (McCollum and Galyean, 1985a; Delcurto et al., 1990a,b).

Interactions exist between protein and energy supplements with regard to low-quality forage utilization. Steers had higher forage intake and ruminal DM fill when high levels of protein (1.32 g CP/kg BW) and energy (18.4 kcal ME/kg BW) supplements were fed with low-quality (3.0% CP) grass hay (DelCurto et al., 1990a). In contrast, Clanton and Zimmerman (1970) reported that forage intake did not change when low protein, high energy supplements were fed with low-quality forage. Similar results were observed when energy or energy plus protein supplements were fed with low-quality forage (Cook and Harris, 1968).

Source of supplemental protein may have different effects on forage intake. For example, forage intake by Holstein cows was lower with urea than with soybean meal supplementation although CP supplied by these two supplements was similar (Poos et al., 1979). Substitution of corn gluten meal for soybean meal in a supplement decreased hay OM intake linearly when steers were fed low-quality native grass hay (Hibberd and Martin, 1990).

Energy Supplementation. Cereal grain supplements may decrease intake of low-quality forage (Hibberd and Chase, 1986). Elliot (1967) and Branine and Galyean (1985) reported that energy supplementation depressed forage intake most severely when forage protein was low. Even though the protein requirement of the animal was satisfied, addition of corn with low-quality forage decreased forage intake (Sanson and Clanton, 1989; Sanson et al., 1990). Hall et al. (1990)

reported that bermudagrass hay (12.9 to 14.3% CP) intake was decreased when ground corn was fed at .5 or 1.0% of body weight. As the quantity of corn was increased, hay and total DM intakes decreased (Chase and Hibberd, 1987). In contrast, Vanzant et al. (1990) indicated that supplementation with corn, wheat or sorghum grain (.37% of BW daily) did not alter forage intake or ruminal DM fill of beef steers consuming bluestem-range forage. Total DM intake, however, was increased. This response agrees with that of Lu and Potchoiba (1990) who indicated that an increased dietary ME density increased DM intake curvilinearly suggesting that ME intake is the most dominant factor controlling DM intake in goats.

High fiber feeds such as soybean hulls appear to be similar to corn in energy value for heifers grazing native range (Merrill and Klopfenstein, 1984; Hibberd et al., 1987b; Anderson et al., 1988a). Compared with similar levels of supplemental corn, total dietary intake was not different with soybean hull supplements by heifers and calves (Brown et al., 1987). Low levels of soybean hulls have been shown to increase forage intake (Anderson et al., 1988b; Highfill et al., 1987; Hsu et al., 1987). Consequently, soybean hulls may be useful as a substitute for corn in supplements without depressing forage intake and utilization.

## Forage Digestibility

Protein Supplementation. Protein supplementation typically increases digestibility of forage (Rittenhouse et al., 1970) and total diet DM (Abou Akkada and el-Shazly, 1958; DelCurto et al., 1990a). DelCurto et al. (1990a) reported that low-quality forage DM digestibility increased when the level of protein supplement was increased from .66 g CP/kg BW to 1.32 g CP/kg BW. In lambs, Caton et al. (1986) also found that total DM digestibility increased when 189 g of cottonseed meal was fed with prairie hay (5.8% CP). Protein supplementation may increase rate of digestion of low-quality forage (Barton and Hibberd, 1984; Chase et al., 1988) resulting in an increase in extent of forage DM digestion.

Energy Supplementation. Compared to a cottonseed meal control, corn supplementation of low-quality forage decreased forage OM digestibility (Chase and Hibberd, 1987). In contrast, Guthrie and Wagner (1988) showed that DM digestibility of prairie hay (4% CP) increased when corn was supplemented (1.41 kg) as compared with an unsupplemented control (a mineral-vitamin mix). Total protein content of the diet was as high as 13% CP, however, with corn supplementation. Vanzant et al. (1990) reported that total tract DM digestibility of bluestem-range forage supplemented with either corn, wheat or sorghum grain (.37% BW daily) was not improved when compared with a non-supplemented control.

Protein content of the diet could be the most important factor affecting forage DM and OM digestibility with grain-based supplements. Burroughs et al. (1949) reported that supplementing with four pounds of starch decreased the DM digestibility of corn cobs from 57% to 34.6%. In contrast, no significant effect of added starch was observed on DM digestibility of alfalfa hay (57.3%). Presumably, alfalfa hay supplied more essential nutrients for microbial growth than corn cobs. Dry matter and CP digestibilities of orchardgrass hay (11.3% CP) actually were improved with protein supplementation when 10% of starch was added into the diet (Solaiman et al., 1990). Organic matter digestibility of low-quality forage increased linearly in heifers when .27, .54 and .81 kg cottonseed meal (Hibberd et al., 1987a) or ammonium compounds ($NH_4Cl$ and $NH_4HCO_3$; Chase et al., 1988) were added with 1.8 kg corn-based supplements.

Soybean hulls are rapidly digested in the rumen. Compared with corn fiber and cottonseed hulls, soybean hulls had a higher ruminal DM digestibility (Streeter and Horn, 1983; Hsu et al., 1987). Anderson et al. (1988b) reported that increasing levels of soybean hulls increased forage DM digestibility. In addition, OM digestibility of low-quality forage increased linearly with soybean hull supplementation (Martin and Hibberd, 1990). In contrast to high starch feeds such as corn, soybean hull supplementation appears to increase forage digestibility.

## Digestible OM Intake

Perhaps the most important response to supplementation is energy intake. Forage intake and digestibility interact to affect digestible OM intake in ruminants.

Protein Supplementation. Guthrie and Wagner (1988) indicated that digestible DM intake was increased with soybean meal supplementation when steers consumed low-quality prairie hay. In addition, hay OM digestibility of low-quality (4.3% CP) meadow hay increased with protein supplementation (1.12 g CP/kg BW) compared to an unsupplemented group (Sanson et al., 1990). Rooke et al. (1986) observed that increasing quantities of soybean meal increased the digestible DM intake of medium quality forage (9.5% CP).

Energy Supplementation. Pordomingo et al. (1991) reported that small quantities of supplemental corn (.2% of BW) tended to increase forage digestible OM intake; however, forage OM intake decreased linearly when higher levels of corn were fed. They indicated that negative associative effects occurred when corn supplementation exceeded .2% of BW. Forage OM intake decreased with the addition of corn supplement (Hannah et al., 1990; Pordomingo et al., 1991) but total OM intake still was greater than for the unsupplemented group. Increased total OM intake was also observed in Hall et al. (1990) when steers consuming bermudagrass hay were supplemented with .24% or .74% BW corn.

Compared with corn, soybean hull supplements increased total OM and digestible OM intake of a low-quality native grass hay diet (Martin and Hibberd, 1990). Compared with a corn-based supplement, wheat middlings tended to increase hay DM intake and digestibility (Ovenell et al., 1990).

## Effect of Protein Supplementation on Digestive Function

### Ruminal Ammonia Concentration

Protein supplementation usually increases ruminal ammonia concentrations (Hunt et al., 1989; DelCurto et al., 1990a; Scott and Hibberd, 1990). Microbial growth in the rumen may benefit from an increased concentration of ruminal ammonia, especially with low-quality forages. A high rate of ammonia release within the rumen with protein supplementation may also play a role in supporting microbial growth. McCollum and Galyean (1985b) and Freeman et al. (1987) reported that ruminal ammonia nitrogen peaked about 1 hour postsupplementation when protein supplements were included with a low-quality native grass hay and this increase may be associated with an increased extent of forage digestion.

### Rate of Forage Digestion

Protein supplementation increases the rate of forage digestion (Barton and Hibberd, 1984). Hunt et al. (1989) showed that rate of ruminal NDF disappearance increased when steers fed fescue hay were supplemented with cottonseed meal. Rate of hay OM digestion increased when beef cows grazing low-quality native grass were supplemented with ruminally degraded protein from soybean meal (Scott and Hibberd, 1990). Because cellulolytic bacteria require ammonia for growth (Satter and Slyter, 1974), an increase in ruminal ammonia may increase cellulolytic activity. Consequently, rate of forage digestion may increase.

### Microbial Protein Synthesis

Protein reaching the small intestine of the ruminant represents the sum of protein that escapes ruminal fermentation plus yield of ruminal microbes. Microorganisms flowing from the rumen are digested in and amino acids are absorbed from the small intestine to provide amino acids to ruminants (Stern and Hoover, 1979). Protein supplementation may enhance microbial protein synthesis (Scott and Hibberd, 1990). Head (1953) indicated that microbial protein synthesis may be inhibited if levels of dietary protein or nitrogen are low enough to reduce ruminal ammonia concentrations. Okorie et al. (1977) showed that microbial protein synthesis peaked when ruminal ammonia concentration was 5 mg/dl whereas Hume et al. (1970) observed that microbial protein synthesis was maximum with 9 mg $NH_3$/dl.

Ration type affects extent of microbial protein synthesis. Zinn and Owens (1983), Wanderley et al. (1987) and Bas et al. (1989) indicated that the total yield of microbial protein from the rumen was greater with concentrate than with forage diets but, in contrast, the efficiency at which digested energy was converted to microbial protein was higher with the forage diet. This response may be due to lower OM fermented in the rumen with the forage diet. Stern and Hoover (1979) and Zorrilla-Rios et al. (1991) suggested that the efficiency of microbial protein synthesis would be lower if urea is included in the diet. Presumably, this response might be attributed to a deficiency of preformed amino acids. Argyle and Baldwin (1989) showed that microbial growth yields increased only slightly in mixed rumen bacterial cultures with ammonia as a sole nitrogen source. However, microbial growth yields reached the saturation of growth when amino acid and peptide mixtures were added into the culture. Owens and Zinn (1988) indicated that almost all of the nitrogen absorbed in the ruminant's small intestine was derived from microbial sources if non-protein nitrogen was the only supplemental protein source in the diet. Thus, increasing or adding non-protein nitrogen does not provide escape protein for digestion in and absorption from the small intestine if microbial protein synthesis is already maximized. van Gylswyk (1970) and McAllan and Smith (1983) also indicated that preformed protein is superior to urea for maintaining optimal growth of cellulolytic microorganisms.

Microbial protein supply is the major contributor to nitrogen absorption with low-quality forage diets that have a low nitrogen content. In this case, a large proportion of the nitrogen absorbed by ruminants will be derived from microbial protein. Although dietary protein may appear adequate to maximize microbial protein synthesis, other factors such as ruminal protein degradation, dietary sulfur and feeding frequency also should be considered (Stern and Hoover, 1979).

## NDF Digestibility

Forage NDF digestibility can be enhanced by protein supplements if protein content of the forage is low. Caton et al. (1986) showed that total tract NDF digestibility was increased when cottonseed meal was fed with prairie hay (5.8% CP) to lambs. DelCurto et al. (1990a) indicated that NDF digestibility in steers fed low-quality forage free choice was increased when the forage was supplemented with 28% and 41% CP from sorghum grain and soybean meal mixtures. However, when a 12% CP supplement was fed with prairie hay, NDF digestibility was lower (29.9%) than that of the non-supplemented group (37.9%). Wedekind et al. (1986) observed a linear decrease in ruminal NDF digestion when the concentrate, composed of soybean meal (7%) and corn starch (76%), was increased from 0 to 60% of the diet. Postruminal NDF digestion, however, was improved. In contrast, Hunt et al. (1989) reported no differences in total NDF digestibility when cottonseed meal was supplemented to fescue hay (6.6% CP) for steers even though DM and NDF intake were greater with than without supplementation. Increased fiber digestion from the rumen to the lower gut may compensate for any decrease in ruminal NDF digestion so that total tract NDF digestion remains unchanged. Based on the DelCurto et al. (1990) and Hunt et al. (1989) studies, perhaps the benefit of protein supplementation is greater if the CP content of the forage is low. Results by Kartchner (1981) agree, and indicate that NDF digestibility may increase when the protein content of forage is below 8%. Another consideration is that protein supplementation may not change ruminal NDF digestibility if extent of ruminal protein degradation is low. For example, low-quality hay disappearance in situ decreased when corn gluten meal was substituted for soybean meal in the supplement (Hibberd and Martin, 1990). Abou Akkada and el-Shazly (1958) detected no increase in cellulose digestibility of wheat straw when it was supplemented with fish meal, cottonseed meal, bean meal, meat meal or casein.

## Passage Rates

McCollum and Galyean (1985b), Caton et al. (1986) and Freeman et al. (1987) reported that adding protein supplements to low-quality forage will increase ruminal dilution rates in cattle. Particle passage rate increased when ruminants fed low-quality roughages were supplemented with protein (Ellis, 1978; Caton et al., 1986; Guthrie and Wagner, 1988; Solaiman et al., 1990). Although particle passage rates were increased with protein supplementation, extent of forage digestion may be reduced. Therefore, both rate and extent of forage digestion should be considered when evaluating the value of protein supplements with low-quality forage.

## Volatile Fatty Acid Concentrations

Volatile fatty acid concentrations often increase when protein supplements are fed with low-quality roughage (Lee et al., 1985; Pritchard and Males, 1982; Hunt et al., 1989; DelCurto et al., 1990a). Ruminal acetate concentration was reduced in steers supplemented with 12, 28 and 41% CP from soybean meal (DelCurto et al., 1990a). Total ruminal VFA concentration with protein supplementation peaks later than ruminal ammonia nitrogen concentration (Branine et al., 1986; Caton et al., 1986; Freeman et al., 1987). These authors reported that ruminal total VFA concentrations were increased at about 1 h postsupplementation when steers were supplemented with soybean meal or cottonseed meal while grazing blue grama pasture. This response may explain how protein supplements improve forage utilization. An increase in ruminal ammonia increases microbial activity which increases the rate of ruminal fermentation.

Increased VFA concentrations usually are accompanied by a lower ruminal pH. With protein supplementation, however, ruminal pH usually remains above 6. DelCurto et al. (1990a) reported that ruminal pH remained above 6.6 for 12 h when steers were fed soybean meal supplements. Hunt et al. (1989) detected no change in pH (pH=6.00 to 6.08) when steers fed fescue hay (6.6% CP) were supplemented with cottonseed meal (3 g/kg $BW^{.75}$).

## Effect of Energy Supplementation on Digestive Function

Energy supplements can be divided into two general categories: 1) cereal grain-based that contain corn, barley, wheat, oats or sorghum; 2) by-product-based that contain soybean hulls, corn gluten feed, wheat middlings or rice bran. Cereal grains contain a large amount of starch whereas by-products such as soybean hulls contain large quantities of NDF.

### Starch Effects

Type and Species of Bacteria. The proportion of roughage to concentrate and sources of forage and concentrate may influence the type and number of ruminal microorganisms (Bryant and Robinson, 1962; Bath and Rook, 1963; Erfle, et al., 1982). Oschio et al. (1987) found that Butyrivibrio fibrisolvens, Bacteroides ruminicola and Ruminococcus albus were the most predominant bacteria in the rumen when heifers were fed a high proportion of orchardgrass hay. Burroughs et al. (1949) indicated that an increased ratio of starch to roughage in the diet depressed extent of cellulolysis in batch cultures. They explained that depressed cellulolysis with starch addition may be due to the lack of essential nutrients for the growth of roughage-digesting microorganisms. Depression of forage digestibility due to a preference by ruminal microorganisms for starch rather than cellulose or hemicellulose was proposed by el-Shazly et al. (1961).

For cellulose digestion, mutualisms or interactions between cellulolytic and non-cellulolytic bacteria probably are involved. Scheifinger and Wolin (1973) reported that Selenomonas ruminantium and Bacteroides succinogenes S85 could be co-cultured in cellulose medium even though S. ruminantium alone is not able to utilize intact cellulose. Dehority and Scott (1967) indicated that extent of cellulose digestion was enhanced by co-culture of non-cellulolytic with cellulolytic bacteria. Dry matter disappearance and total VFA production were increased when Treponema bryantii, a non-cellulolytic spirochete, was co-cultured with Bacteroides succinogenes S85 or Ruminococcus albus (Kudo and Cheng, 1987).

Attachment of cellulolytic bacteria to the fiber must precede fiber digestion (Akin and

Barton, 1983; Hoover, 1986; Morris, 1988). Hoover (1986) indicated that lag time and extent of attachment of bacteria to fiber are involved in cellulose digestion. Components of the plant cell wall, such as the epidermis and mesophyll, can affect lag time and extent of bacterial attachment (Latham et al., 1978). Mertens and Loften (1980) proposed that differences among forages in fiber digestion with starch addition were due to different structures of plant cell wall and attachment to particles by different types of cellulolytic bacteria. In an in vitro study, they showed that although CP content of alfalfa hay (16.4% CP) was the same as that of coastal bermudagrass hay, lag time of fiber digestion was shorter (.86 h) for alfalfa hay than for coastal bermudagrass (3.05 h) when purified corn and wheat starch were added. Ruminal pH (Cheng et al., 1984; Morris, 1988) and ammonia concentration (McAllan and Smith, 1983; Hoover, 1986) were reported to be involved with the extent of bacterial attachment to fiber. A similar reponse was observed by Smith et al. (1973); they suggested that attachment of cellulase to the cellulose substrate may be reduced due to low ruminal pH. In contrast, Pell and Schofield (1991) reported that ruminal pH did not affect the attachment of cellulolytic bacteria to fiber.

Depressed cellulolysis frequently accompanies a decreased ruminal pH (Burroughs et al., 1949). Terry et al. (1969), Russell et al. (1979), Hiltner and Dehority (1983), Mould et al. (1983b) and Hoover (1986) indicated that a low pH depressed ruminal cellulolysis and decreased the numbers of cellulolytic bacteria. Some authors have alleviated the negative effects of grain supplementation on forage digestion by adding buffers or ammonium compounds (Orskov and Fraser, 1975; Mould and Orskov, 1984; Mould et al., 1983ab; Wedekind et al., 1986; Chase et al., 1988). In contrast, Sanson et al. (1990) indicated that although ruminal pH was below 6.0 when .26% or .52% of BW corn was included with low-quality forage, neither cellulose digestibility nor hay DM and OM digestion were depressed.

Slyter (1986) conducted an experiment to determine whether pH 5.5-selected cellulolytic bacteria have a higher ability to digest fiber in an acid environment than pH 6.5-selected cellulolytic bacteria. He found more viable cellulolytic bacteria selected from a pH 6.5 environment when incubated at pH 5.5 than bacteria selected from pH 5.5. In addition, more NDF was digested in a pH 5.5 culture by pH 6.5-selected than by pH 5.5-selected bacteria. Hence, low ruminal pH alone appears unrelated to the decreased numbers of cellulolytic bacteria because, even though the most adaptable cellulolytic bacteria in pH 5.5 environment were used, their multiplication and ability to digest cellulose did not exceed that of the pH 6.5-selected bacteria. Hence, depressed forage digestion accompanied with low ruminal pH may not be due solely to a decreased number of cellulolytic bacteria. Hiltner and Dehority (1983) indicated that exposure of bacteria to low pH did not improve their ability to digest cellulose in an acid environment. Therefore, improved gene expression for cellulose digestion cannot be accomplished by altering pH. Erfle et al. (1982) found that total count of viable bacteria increased when pH was dropped from 7 to 5.5 in mixed ruminal cultures in vitro; they inferred that the number of viable cellulolytic bacteria had increased. Because cellulolytic bacteria comprise only a very small proportion of the total viable bacteria (1.2 to 3.6%; Erfle et al., 1982), determining the change of numbers of cellulolytic bacteria in different pH may not be easy.

Studies exploring the effect of pH on cellulose digestion have not demonstrated whether the low pH observed with depressed cellulose digestion is a cause or a result. During in vitro studies (Terry et al., 1969), pH of ruminal liquor was adjusted to 6.8, 6.0 and 5.5 to evaluate pH effects on cellulose digestion. They found that the extent of cellulolysis was decreased when pH was controlled at 5.5 and 6.0; this may be out of the pH range for optimum growth of cellulolytic bacteria. This also agreed with the results of Russell et al. (1979) showing that the growth rates of Butyrivibrio fibrisolvens and Selenomonas ruminantium decreased in vitro when pH dropped below 6.0. Numbers of viable cellulolytic bacteria, however, were not evaluated in Terry et al. (1969).

Burroughs et al. (1949) indicated that various other biological processes or mechanisms of the ruminal microorganisms may be the cause of decreased fiber digestion in ruminants when starch is fed. When concentrates are added to a roughage-based ration, growth of the cellulolytic bacteria may not be inhibited; instead, the environment simply may favor non-cellulolytic bacteria. This can be inferred from the increase in counts of total viable non-cellulolytic bacteria by Erfle et al. (1982). As time passed, more non-cellulolytic bacteria were produced although the rate of multiplication of cellulolytic bacteria did not change. Therefore, the total proportion of cellulolytic bacteria in the total viable counts may be lower (<1.2 to 3.6%) compared with that of a non-supplemented group. In this situation, the probability of cellulolytic bacteria attachment to fiber substrate decreases due to their lower proportion of the total bacterial population compared to the proportion of non-cellulolytic bacteria. Collision probability, therefore, may be involved in cellulose digestion mechanisms in vivo. When concentrate is fed, non-cellulolytic bacteria will have a greater chance to collide with cellulose than the cellulolytic bacteria. As a result, the extent of cellulose degradation may be decreased.

The collision hypothesis is supported by Varel and Dehority (1989) where the numbers of cellulolytic bacteria were not markedly different in ruminal samples obtained from animals fed 100% ground alfalfa, 75% alfalfa-25% corn or 50% alfalfa-50% corn rations. Similar results have been observed by others (Latham et al., 1971; Mackie et al., 1978; Van der Linden et al., 1984). Varel and Dehority (1989) indicated that the number of cellulolytic bacteria peaked with high levels of concentrate in the diet. They found that cellulose digestibility was maximum with the 50% alfalfa-50% corn diet as compared to 100% alfalfa and 75%:25% alfalfa-corn diet. These authors also suggested that a low ruminal pH did not affect the numbers of cellulolytic bacteria. In addition, Van der Linden et al. (1984) indicated that the depression of forage digestion with corn supplementation did not affect numbers of cellulolytic and hemicellulolytic bacteria. As bacteria multiply, VFA and acidic waste products are released which reduce ruminal pH until it finally reaches the crucial level where bacterial growth is retarded or even terminated. At this point, a lower pH may be a phenomenon that accompanies depressed cellulose digestion rather than its cause. Several studies support the concept that the depression in cellulose digestion is due to a "carbohydrate effect" rather than to a direct effect of pH (el-Shazly et al., 1961; Smith et al., 1973; Mould and Orskov, 1984; Hoover, 1986).

Rate of Fiber Digestion. Mertens and Loften (1980) proposed that the depression of fiber digestion by starch has at least three factors involved: (1) increased lag time of digestion, (2) decreased rate of NDF digestion, (3) decreased potential extent of fiber digestion. Rates of digestible hay and NDF disappearance decreased linearly in cows fed a low-quality hay diet when the level of corn was increased from 1 to 3 kg/d in a low-quality hay diet (Chase and Hibberd, 1987). Microbes may attack starch faster than roughage (Burroughs et al., 1949; el-Shazly et al., 1961). Perhaps, a bacterial preference for soluble carbohydrate rather than the rigid cell wall of forages may explain why lag time is increased and rate of NDF digestion is decreased. Miller and Muntifering (1985) indicated that when corn starch decreased the fiber digestibility of fescue hay, the response was not due to reduced rate of fiber digestion. Further, a prolonged lag time did not exert much effect on the depressive effects of starch on fescue hay digestion suggesting that other factors, such as a decrease in the potential extent of fiber digestion, might be involved. In contrast, Hall et al. (1990) reported that the rate of digestion of potentially digestible NDF increased from 5.11%/h to 6.00%/h and 5.82%/h when 0, .5 and 1.0% of BW corn, respectively, were fed with bermudagrass hay. Lag time and extent of fiber digestion, however, were not examined. Elevating the CP level of alfalfa haylage to as high as 23% did not avoid the decreased rate of alfalfa DM digestion caused by corn supplementation (Hannah et al., 1990). No significant differences in rate of fiber digestion were observed when different sources of starch were added to alfalfa, coastal bermudagrass, fescue and orchardgrass hays (Mertens and Loften, 1980). Energy supplementation of different types and quality of forages had different effects on rate of fiber digestion which is also interrelated with lag time and rate and extent of fiber digestion.

Extent of Fiber Digestion. Extent of ruminal fiber digestion was decreased when starch in the diet was increased (Head, 1953; el-Shazly et al., 1961; MacRae and Armstrong, 1969; Mertens and Loften, 1980; Aitchison et al., 1986) which in turn depressed forage intake (Hoover, 1986) and resulted in ruminal accumulation of NDF (Solaiman et al., 1990).

In wethers, when a basal ration containing ground, pelleted oat straw and urea was supplemented with more than 20% wheat starch, cellulose digestibility was decreased; depression was maximized (18%) with the addition of 30% starch (Mulholland et al., 1976). Similarly, when

Brink and Steele (1985) increased the proportion of corn fed to steers from 50% to 90%, total tract NDF digestibility decreased from 77.4% to 74.5%. Although post-ruminal NDF digestion can play a compensatory role, total tract NDF digestibility still was decreased due to an extreme depression in ruminal fiber digestion.

Extent of cellulose and hemicellulose digestion in vivo decreased when corn was added to either corn stover (Henning et al., 1980) or low-quality (4.2% CP) native grass hay (Chase and Hibberd, 1987) suggesting that NDF digestibility in low-quality forage may be decreased due to either low nitrogen content of forage, high starch content in cereal grains or insufficient quantities of ruminal degraded protein. DelCurto et al. (1990a) noted that high amounts of supplemental energy (18.4 kcal/kg BW) depress NDF digestibility. Depressed cellulolysis with the addition of barley in vitro also was observed (Stewart, 1977).

Burroughs et al. (1949) suggested that corn starch will increase the protein requirement needed to maintain roughage digestion. Mould et al. (1983a) and Vanzant et al. (1990) indicated that depression of fiber digestibility will be much more affected by grain supplementation in warm-season forages than cool-season forages and suggested that fiber digestion will be depressed if forage CP is below 4.2%. With a 13% CP forage, Hall et al. (1990) found that total tract NDF digestibility did not decrease even though ruminal NDF disappearance decreased with added corn. In contrast, Head (1953) reported that the addition of various amounts of nitrogen-rich feeds, such as white fishmeal, decorticated groundnut meal or casein, could not prevent the depression of cellulose digestion when potato or corn starch were included in the diet. This agrees with reports by Sanson and Clanton (1989) and Sanson et al. (1990) that forage NDF and hemicellulose digestibility decreased when low-quality forage was supplemented with corn even when the protein requirement of the animal was satisfied. van der Linden et al. (1984) reported that even though a corn stover diet contained 13.8% CP, its intake, and the amount of cellulose and hemicellulose digested in the rumen were reduced when starch was added. el-Shazly et al. (1961) showed that the depression in cellulose digestion could be alleviated by urea supplementation when ratios of hay to corn were 2:1 and 1:1. These responses may be due to increased supply of ruminally degraded protein which will supply ammonia to satisfy the nitrogen requirement of ruminal microorganisms.

<u>End Product Inhibition</u>. End-products from ruminal fermentation also may depress cellulose digestion via cellulase inhibition. Ryu and Mandels (1980) indicated that the cellulase system consists of three major enzymatic components: endo-1,4-ß-glucanase, exo-1,4-ß-glucanase and β-glucosidase. Bonhomme et al. (1986) postulated that endo-1,4-β-glucanase first attacks crystalline cellulose, cleaves the β-1,4 linkage and exposes new chain ends for exo-1,4-ß-glucanase to catalyze. Exo-1,4-ß-glucanase then releases cellobiose or glucose units. Finally, β-glucosidase hydrolyzes cellobiose into glucose. Depressed cellulose digestion by starch may involve end-product inhibition. Henning et al. (1980) indicated that addition of starch inhibited ruminal cellulase and hemicellulase activity. Katz and Reese (1968), Sternberg et al. (1977) and Morris (1988) demonstrated that the cellulase system was inhibited by the presence of cellobiose and by high concentrations of glucose. Ruminal glucose from starch supplementation may depress forage digestion by inhibiting cellulolytic enzymes. Because fermentation is faster with starch than with low-quality forage, concentrations of end-products in the ruminal environment should be greater with starch addition; thereby, cellulose digestion could be decreased.

<u>Volatile Fatty Acid Concentration</u>. Chase and Hibberd (1987) indicated that total VFA concentrations were not altered when low-quality hay was supplemented with increasing levels of corn, however, corn supplementation decreased the molar proportion of acetate and the acetate:propionate ratio. In addition, Vanzant et al. (1990) reported that ruminal VFA concentrations did not change when steers grazing bluestem range forage (5.8% CP) were supplemented with .37 % BW of corn daily. In contrast to the report of Chase and Hibberd (1987), the acetate:propionate ratio did not change. Pordomingo et al. (1991) reported that corn supplementation did not affect VFA concentrations or the molar proportion of acetate even though butyrate increased. Ruminal VFA concentrations and ruminal pH were both decreased when Holstein heifers fed a hay-based diet were given a barley supplement (Oshio et al., 1987). In

contrast, ruminal pH was not affected when more corn was fed to steers grazing low-quality rangeland (Vanzant et al., 1990; Pordomingo et al.,1991).

Ruminal Ammonia. When compared with protein supplementation, corn supplementation reduced ammonia concentration in the rumen (McCollum and Galyean, 1985b). Pordomingo et al. (1991) also indicated that ruminal ammonia concentration decreased linearly when level of corn was added to the diet. Chase and Hibberd (1987) reported that ruminal ammonia nitrogen concentrations peaked 3 h postsupplementation but remained below 2 mg/dl when 1, 2 or 3 kg of corn was fed to cows consuming low-quality hay. These authors suggested that the decrease in ruminal fiber digestion may be due to an inadequate supply of ammonia nitrogen for growth of cellulolytic bacteria.

Cereal grain supplementation could cause a ruminal nitrogen deficiency for microbial growth because grain protein is relatively resistant to microbial attack (Stern and Hoover, 1979). Sanson et al. (1990) reported that the ruminal ammonia concentrations required for maximum microbial growth were higher than the recommended levels (2 to 5 mg/dl) suggested by Satter and Slyter (1974) when .25% or .52% BW of corn was fed with low-quality meadow hay (4.3% CP). In addition, Hoover (1986) demonstrated that the nitrogen requirement for ammonia and amino acids for microbial growth may increase when readily fermentable carbohydrate is added to a diet. When ammonium compounds such as $NH_4Cl$ or $NH_4HCO_3$ were dosed into the rumen, NDF digestibility, cellulose, hemicellulose and rate of in-situ dry matter disappearance increased when heifers were fed low-quality (4.8% CP) native grass hay (Chase et al., 1988).

These studies suggest that supplemental nitrogen should be included in low-quality native forage diets supplemented with cereal grains. Because of the low ruminal degradation of corn protein coupled with the poor digestibility of low-quality forage protein, a ruminal degraded protein source should be included in the supplement (Chase and Hibberd, 1987).

Microbial Growth Rate and Protein Synthesis. Stern and Hoover (1979) indicated that when microbial nitrogen needs are satisfied, energy supply limits microbial protein synthesis. In the absence of fermentable energy, significant death (60%) and lysis (30%) of ruminal bacteria occurred within 2 h due to starvation suggesting that energy supply is a major factor controlling microbial protein synthesis, especially with low-quality roughage diets (Hespell, 1979). Pordomingo et al. (1991) indicated that when the nitrogen requirement of microbes is satisfied, small quantities of supplemental corn can stimulate microbial protein production due to the additional energy supply; this will increase microbial protein flow to the small intestine and improve ruminal fiber digestion of low-quality forage (Chase and Hibberd, 1987; Jones et al., 1988).

Passage Rate. Chase and Hibberd (1987) indicated that particle passage rate from the rumen of beef cows fed low-quality hay decreased linearly when corn was supplemented. Pordomingo et al. (1991) reported that when .2, .4 and .6% BW of corn was fed with summer blue grama grass, particle passage rate was decreased. Decreased particle passage rate may be due to the decrease in forage intake with grain supplementation. In contrast, ruminal passage rate may increase with low levels of corn supplementation (McCollum and Galyean, 1985b) even though liquid passage rate was unaffected. Vanzant et al. (1990) showed that when bluestem range forage was supplemented with corn at levels as high as .37% BW daily, liquid passage rate was not changed.

Forage quality also may interact with level of grain supplementation to affect passage rate. Compared with a non-supplemented group, particle passage rate was increased when steers fed bermudagrass hay (12.9% CP) were supplemented with ground corn (.24% and .74% BW/d; Hall et al., 1990). Poore et al. (1990) indicated that when concentrate level was increased from 30 to 60% of a wheat straw-alfalfa hay mixed diet, ruminal passage rate was not altered. These authors suggested that ruminal passage rate will be affected much more with low-quality hay than with high-quality hay.

Microbial protein synthesis with low-quality forage diets should be increased if ruminal passage rate is increased (Hespell, 1979). Isaacson et al. (1975) reported that ruminal liquid passage rate is positively correlated with microbial efficiency. Van Soest (1982) agreed that liquid passage rate may have an effect on microbial efficiency, but suggested that an increased ruminal passage rate might not increase the availability of microbial protein to ruminants because microbial protein cannot be absorbed beyond the small intestine.

Corn supplementation exerted a larger effect on particle passage rate than on liquid passage rate (Chase and Hibberd, 1987). A decrease in particle passage rate with corn supplementation will increase forage retention time in the rumen which may decrease forage intake.

### Digestible Fiber Effects

Miller and Eisenhauer (1982) reported that a large amount of agricultural byproducts and residues, including 28 million tons of crop hulls, are produced annually in the United States. Energy supplements frequently are based on cereal grains such as corn. Recently, supplements based on digestible fiber feeds such as soybean hulls have been investigated. Effects of these two feed types on digestive events may be different.

Rate of NDF Digestion. Anderson et al. (1988b) reported that increasing the amount of soybean hulls fed linearly decreased rate of NDF digestion. No differences in rate of NDF digestion were detected when similar amounts of corn and soybean hull supplements were fed.

Extent of NDF Digestion. Anderson et al. (1988a) and Highfill et al. (1987) found that negative associative effects on fiber digestion were less with soybean hull than with corn supplements. Martin and Hibberd (1990) indicated that total tract NDF digestibility was not decreased when cows were fed soybean hull supplements. Compared to the same level of corn, soybean hull supplementation produced higher total tract NDF digestibility in cows (Highfill et al., 1987). Anderson et al. (1988b) indicated that NDF intake and digestibility increased when steers fed an ensiled corn stalk basal diet were supplemented with soybean hulls at 12.5% to 50% of the diet due to the high NDF and low lignin content of soybean hulls. Greater NDF digestion with the addition of soybean hull supplements to low-quality forage may be due to the increased rumination activity caused by additional NDF derived from soybean hulls, to the absence of detrimental effects caused by starch supplements, or to greater digestibility of NDF from soybean hulls than from the forage.

Volatile Fatty Acid Concentrations. Highfill et al. (1987) indicated that soybean hull supplements produced greater total ruminal VFA concentrations than corn. Martin and Hibberd (1990) also reported that total VFA concentrations were increased when soybean hulls were fed to cows suggesting that fermentation tended to be more extensive than with corn-cottonseed meal supplementation (Chase and Hibberd, 1987). In addition, Highfill et al. (1987) indicated that soybean hull supplementation increased the ruminal concentration of acetate but not propionate within 12 h postsupplementation. Consequently, a higher acetate:propionate ratio was observed.

Increased VFA production in the rumen usually is related to decreased ruminal pH. Although soybean hulls produced the lowest ruminal pH (pH=5.36) due to extensive fermentation when compared with corn fiber, oat hulls or cottonseed hulls (Hsu et al., 1987), high levels of supplemental soybean hulls do not decrease ruminal pH as much as corn. Martin and Hibberd (1990) reported that ruminal pH was maintained above 6.2, even when 3 kg of soybean hulls were fed with low-quality native grass hay. Anderson et al. (1988b) indicated that ruminal pH was maintained above 6 when 25% and 50% soybean hulls were included in a corn stalk diet; in contrast, pH was lower with the 25% corn (pH<6) and 50% corn (pH=5.65) at 6 and 8 h postsupplementation. Consequently, soybean hull supplementation may ameliorate the drop in ruminal pH observed with corn supplementation.

Ruminal Ammonia. Ruminal ammonia concentration usually is higher with soybean hull than with corn supplements. When compared with an equal amount of corn, soybean hull supplements increased ruminal ammonia concentrations for the first 12 hours postsupplementation (Highfill et al., 1987). In addition, Martin and Hibberd (1990) indicated that when heifers consuming low-quality forage were supplemented with 3 kg of soybean hulls, ruminal ammonia concentration 2 h postsupplementation approached 7 mg/dl. Microbial growth may benefit from such increased ruminal ammonia concentrations.

Passage Rate. Martin and Hibberd (1990) indicated that cows consuming low-quality native grass hay (4.1% CP) with 1 kg of soybean hulls had the highest particle passage rate compared with the control, 2 and 3 kg levels of soybean hulls. They also pointed out that liquid passage rate increased ($P=.11$) with amount of soybean hulls fed, probably due to increased saliva flow to the rumen. In contrast, Anderson et al. (1988b) detected no differences in ruminal passage rate due to source or level of corn or soybean hull supplemented cattle fed a corn stalk-based diet. Particle size of soybean hulls may affect ruminal passage rate. Ground soybean hulls have a higher ruminal passage rate (4.5%/h) than whole soybean hulls (2.8%/h); smaller particles, via reduced ruminal retention, may have lower DM and NDF digestibilities (Anderson et al., 1988b).

# CHAPTER III

## CORN VERSUS SOYBEAN HULL SUPPLEMENTS FOR BEEF COWS FED LOW-QUALITY NATIVE GRASS HAY

### Abstract

Five mature, crossbred cows (543 kg) fitted with ruminal, duodenal and ileal cannulae were fed low quality native grass hay (4.6% CP, 81.1% NDF) with corn or soybean hull-based supplements (14.4 to 23.2% CP) to determine the effect of starch vs digestible fiber supplementation on forage intake and utilization. Treatments included a control (Vitamin A and minerals only) plus either corn or soybean hull supplements fed at either 1.5 or 3.0 kg/d in a 5 X 5 Latin square design. Soybean hulls tended ($P=.13$) to increase hay and total OM intake compared to corn supplements. Total tract OM digestibility increased ($P=.001$) when either supplement was fed. Digestibility of hay OM tended to be higher ($P=.14$) with soybean hulls than with corn. Intake of digestible OM was increased ($P<.0001$) with supplementation but was not affected ($P=.42$) by source of supplement. Ruminal true OM disappearance was greater ($P=.11$) with soybean hull than corn supplements although microbial OM yield was not affected by source of supplement. Ruminal NDF disappearance ($P<.0001$) and digestibility ($P=.005$) were higher for soybean hulls than corn presumably due to highly digestible NDF from the soybean hulls. Most (86%) of the starch in the corn supplements disappeared in the rumen. Total tract starch digestibility was not affected by source ($P=.36$) or level ($P=.19$) of supplement. Neither microbial N flow ($P>.45$) nor efficiency of microbial synthesis ($P>.38$) were affected by source or level of supplement. Soybean hulls produced the lowest ruminal pH at 2 h postfeeding whereas with corn supplement, pH was lowest 4 to 6 h postfeeding. Ruminal ammonia concentrations were higher ($P<.05$) with soybean hull than corn supplements at 2, 4 and 6 h postsupplementation. Soybean hulls increased ruminal liquid (P=.001) and NDF (P=.02) fill compared to corn supplementation. In situ hay NDF disappearance was decreased (P<.03) with the corn supplement fed at 3.0 kg/d. This study illustrates that corn and soybean hull supplements have different effects on the site and extent of forage utilization. Differences in digestible OM intake and duodenal N flow were small, however, suggesting that either corn or soybean hulls can be effective components of range supplements.

(Key Words: Corn, Soybean Hulls, Grass Hay, Intake, Digestibility.)

## Introduction

During dormancy, native range cannot provide enough nutrients to cattle, especially during environmental or physiological stress. Under such circumstances, energy supplements are required to meet energy requirements of the cattle. Energy supplements frequently are based on cereal grains such as corn. Cereal grains decrease both forage digestibility and forage intake; hence, total energy intake may not be increased (Chase and Hibberd, 1987). Recently, supplements based on digestible fiber feeds such as soybean hulls have been investigated. Soybean hulls are a ruminally noncompetitive feed that have very little impact on intake and digestibility of forage (Martin and Hibberd, 1990). Direct comparisons of corn and soybean hulls, as supplemental feeds, are rare. In addition, the effects of starch vs digestible fiber feeds on ruminal fermentation and microbial protein synthesis are unknown. Therefore, the objective of this experiment was to compare the effect of a high starch supplement (corn) vs a digestible fiber supplement (soybean hulls) on ruminal fiber fermentation and microbial protein synthesis in beef cows fed low-quality native grass hay.

## Materials and Methods

Five mature, nonpregnant Limousin x Hereford/Angus cows (543 kg), each fitted with permanent ruminal cannulae, and double-L type duodenal and ileal cannulae (Streeter et al., 1991) were allocated randomly to five treatments in a 5 X 5 Latin square. Cows were housed separately in an environmentally controlled barn in individual pens (4.7 X 2.3 m) with concrete-slatted floors. Coarsely chopped (5-cm screen) low-quality native grass hay and fresh water were supplied free choice. Native grass hay, primarily composed of Andropogon gerardi, Schizachyrium scoparium, Panicum virgatum and Sorghastrum nutans, was harvested in July. The five treatments (Table I) were the control (minerals and vitamin A only), 1.5 kg corn/d, 3.0 kg corn/d, 1.5 kg soybean hulls/d and 3.0 kg soybean hulls/d. Supplemental protein intake for the corn and soybean hull supplements was equalized by adding soybean meal. Minerals and vitamin A were added to meet the requirements of a 550 kg lactating beef cow (NRC, 1984). Sodium sulfate was added to maintain a 12:1 supplemental nitrogen to sulfur ratio.

Twenty-one day experimental periods included 15 days of adaptation and 6 days of sampling. On d 1 through 12 of each period, hay refusals were refed. On d 13 through 21, fresh hay was fed daily. Supplements were fed between 0700 and 0800 each morning. Fresh hay amounting to 4.5 kg plus the previous day's consumption was given immediately after supplements had been consumed. Hay, offered and refused, was recorded daily throughout the experiment. From d 16 through 19, hay and supplements were sampled daily. Hay refusals were sampled (10% of weigh back) from d 17 through 20, composited within each cow in each period and subsampled. Hay, hay refusals and supplements were ground (1-mm screen) and stored at 4° C.

Duodenal (500 ml), ileal (250 ml) and fecal (450 g as-is) samples were collected eight times during d 16 through 19 to represent every three hours of a 24-h day. Duodenal and ileal pH were measured within 10 min after sampling with a combination electrode. Duodenal, ileal and fecal samples, composited within cows in each period, were subsampled and stored (-15° C) until being lyophilized and ground (1-mm screen).

All samples were analyzed for DM, ash (AOAC, 1975) and acid-insoluble ash (2 N HCl method, Thonney et al., 1985). Acid-insoluble ash was used as an indigestible marker to determine nutrient flows and digestibility (Chase and Hibberd, 1985). Supplement OM digestibility was estimated using the TDN value (91%) for corn (NRC, 1982) and a value of 75% for soybean hulls

# TABLE I

## SUPPLEMENT COMPOSITION, NUTRIENT INTAKE AND CHEMICAL COMPOSITION OF HAY AND SUPPLEMENTS (DM BASIS)

| | | | Corn | | Soybean hulls | | |
|---|---|---|---|---|---|---|---|
| Item | Hay[a] | Control | Low | High | Low | High | SE[b] |
| Feed composition, % | | | | | | | |
| Ground corn | | | 61 0 | 80 8 | | | |
| Soybean hulls[c] | | | | | 62.6 | 83 7 | |
| Soybean meal | | | 31.6 | 13 3 | 29.7 | 10 2 | |
| Dicalcium phosphate | | 32 1 | 2 3 | 1 5 | 2 3 | 1 6 | |
| Trace mineralized salt[d] | | 25 8 | 1 8 | 1 2 | 1 9 | 1 3 | |
| Molasses | | 41 3 | 3 0 | 3 0 | 3 0 | 3 0 | |
| Sodium sulfate | | | 3 | 1 | 5 | 3 | |
| Vitamin A (30,000 IU/g) | | 79 | 06 | 04 | 06 | 04 | |
| Intake, g/d | | | | | | | |
| Total DM | | 174 | 2,461 | 3,711 | 2,398 | 3,586 | 330 |
| Corn DM | | | 1,500 | 3,000 | | | |
| Soybean hull DM | | | | | 1,500 | 3,000 | |
| CP[e] | | 1 | 535 | 534 | 566 | 580 | 3 9 |
| NDF[e] | | 4 | 328 | 467 | 1,079 | 2,037 | 1 0 |
| Starch[e] | | 1 | 1,013 | 2,024 | 87 | 103 | 16 6 |
| TDN[f] | | 52 | 2,071 | 3,224 | 1,611 | 2,304 | |
| Chemical composition, % | | | | | | | |
| CP[e] | 4 6 | 5 | 21 8 | 14 4 | 23 2 | 15 8 | 03 |
| Ash[e] | 6 8 | 89 2 | 7 4 | 5 1 | 9 9 | 9 0 | 24 |
| AIA[e] | 4 19 | 1 12 | 07 | 04 | 38 | 53 | 1 485 |
| NDF[e] | 81 1 | 2 1 | 13 4 | 12 7 | 44 0 | 54 6 | 60 |
| Starch[e] | 1 4 | 8 | 41 2 | 54 6 | 3 6 | 2 8 | 84 |
| TDN[f] | | | 84 2 | 86 9 | 74.1 | 73.5 | |

[a] Major species include *Andropogon gerardi*, *Schizachyrium scoparium*, *Panicum virgatum* and *Sorghastrum nutans*

[b] Five observations/mean

[c] Ground soybean hulls contained 90 13% DM, 6 93% ash and 12 12% CP (DM basis)

[d] Trace mineralized salt contained 92% NaCl, 25% Mn, 2% Fe, 033% Cu, 03% S, 007% I, 005% Zn and 0025% Co

[e] Actual analysis

[f] Estimated from NRC (1984)

(Streeter and Horn, 1983; Hsu et al., 1987). Hay OM digestibility was calculated by difference. Neutral detergent fiber content of hay, hay refusal, duodenal, ileal and fecal samples was determined (Goering and Van Soest, 1970). Supplement NDF was determined with added amyloglucosidase (Robertson and Van Soest, 1977). Crude protein content of hay, hay refusal, supplement, duodenal, ileal and fecal samples was measured with a KjelTec 1030 Auto Analyzer[a]. Ammonia nitrogen content of digesta was determined by magnesium oxide distillation (AOAC, 1975). Starch content of hay, supplements and digesta samples was determined by the procedure of MacRae and Armstrong (1968). Purine content of duodenal digesta was determined by the procedure of Zinn and Owens (1982).

To determine particle passage rate, coarsely ground (5-cm screen) native grass hay was labelled with ytterbium by immersion (Teeter et al., 1984). Labelled hay (250 g) was fed at 0700 on d 16. Fecal grab samples (300 g as-is) were collected at 0, 24, 36, 48, 60, 72, 96 and 120 h postdosing, dried (55$^{o}$ C) and ground (2-mm screen). Ytterbium was extracted from fecal samples with EDTA and concentrations were determined by atomic absorption spectrophotometry using a nitrous oxide-acetylene flame (Hart and Polan, 1984). Particle passage rate was estimated from the slope of the regression of the natural logarithm of Yb concentration over time.

To evaluate ruminal liquid kinetics, 1 g Co (500 ml Co·EDTA, prepared according to Uden et al., 1980) was dosed into five different ruminal locations between 0650 and 0710 on d 20. Ruminal contents were sampled at 0, 2, 4, 6, 9, 12, 18 and 24 h postdosing. Ruminal pH of whole contents was determined immediately after sampling with a combination electrode. Ruminal fluid (100 ml), strained through four layers of cheesecloth, was acidified (2 ml of 20% $H_2SO_4$) to terminate fermentation and frozen (-15$^{o}$ C).

Acidified ruminal fluid was centrifuged at 20,000 x g for 20 min to remove suspended particles. Ammonia content of the supernatant fluid was analyzed with the phenol-hypochlorite procedure (Broderick and Kang, 1980). Cobalt concentration was determined by atomic

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[a] Tecator Company; Tecator AB, Box 70, S-263 01 Hoganas, Sweden.

absorption spectrometry (Chase and Hibberd, 1987). Liquid passage rate was estimated as the regression of the natural logarithm of cobalt concentration against time. Ruminal volume was determined by dividing the cobalt dose by the extrapolated cobalt concentration at time zero. Liquid retention time was calculated as the inverse of liquid dilution rate.

To estimate microbial composition, 400 ml strained ruminal fluid was collected at 0, 6, 12 and 18 h postsupplementation on d 20. Formaldehyde (100 ml, 37%, .9% NaCl) was added to stop microbial growth. Fluid was composited within each cow in each period and centrifuged at 1,000 x g for 5 min to remove feed particles and protozoa (Merchen and Satter, 1983). The supernatant fluid was centrifuged at 20,000 x g for 20 min. The precipitate was collected, washed with saline (.9% NaCl) and centrifuged at 20,000 x g for 20 min. The precipitate again was collected, washed with distilled water and centrifuged at 20,000 x g for 20 min. The resulting pellet was lyophilized. Purine content of bacteria was determined by the procedure of Zinn and Owens (1982). Microbial N in duodenal digesta was estimated from the bacterial N:purine N ratio. Dry matter, ash (AOAC, 1975) and nitrogen (KjelTec 1030 Auto Analyzer[a]) contents of bacteria also were determined.

Dacron bags (10 X 20 cm; 53±10 $\mu$m pore size) were filled with 4.8 to 5.0 g of ground (2-mm screen) native grass hay. Two bags were randomly tied to a 65-cm tygon tubing line (4 cm between bags) weighted with two nuts. Lines were placed randomly in the ventral sac of the rumen at times corresponding to 6, 12, 24, 48 and 96 h of incubation. All bags were removed at 1900 on d 19, washed individually with lukewarm tap water, and dried (55$^{o}$ C).

To evaluate the effect of ruminal environment on supplement degradation, dacron bags (5 X 10 cm; 53±10 $\mu$m pore size) were filled with 1.15 to 1.25 g blood meal or soybean meal. Bags were placed in cows receiving the high corn and high soybean hull supplements in each period. Bags were incubated for 6, 12, 18, 24 and 48 h starting at 0700 on d 16. Bags were removed, washed and dried (55$^{o}$ C).

Dry matter disappearence of hay, blood meal and soybean meal was calculated. Residual NDF content of incubated hay was determined with the batch method of Moore et al. (1987). Rate of potentially digestible DM or NDF disappearance and lag times were calculated using the procedure of Mertens and Loften (1980).

To evaluate differences in ruminal fill, ruminal contents were evacuated 6 h postsupplementation on d 21. Solid and liquid components were separated with a mop squeezer. The liquid portion then was passed through 2-mm screen. Total weights of liquid and solid contents were recorded. Duplicate subsamples (250 g) of solid and liquid contents were frozen (-15° C), lyophilized and ground (1-mm screen). Ash (AOAC, 1975) and NDF (Goering and Van Soest, 1970) contents were determined.

Intake, flow and digestibility data were subjected to least squares analysis of variance with period, animal, energy source (corn vs soybean hulls), feeding rate (1.5 vs 3.0 kg/d) and the energy source x feeding rate interaction included in the model. Orthogonal contrasts were designed to test: 1) Control, control vs all supplements, 2) Source, corn vs soybean hulls, 3) Level, 1.5 vs 3.0 kg/day, and 4) the Source x Level interaction. If the source x level interaction was significant ($P<.10$), differences between the least square treatment means were detected by t-test (Steel and Torrie, 1980). Ruminal data were analyzed as a split plot over time with the effects of period, treatment, and cow tested with period X treatment X cow; and hour and treatment X hour tested with the residual error. A repeated measures analysis was conducted to determine an adjusted P value for treatment X hour. Treatment effects were tested with the previously listed contrasts. Relationships among selected variables were evaluated with partial correlation coefficients adjusted for period and animal.

## Results and Discussion

The native grass hay used in this study contained 4.6% CP and 81.1% NDF (Table I). Thus, this hay was similar in nutrient composition to the diet selected by mature beef heifers grazing dormant native grass (Trautman, 1987). Supplemental protein intake was reasonably similar for animals fed the corn and soybean hull supplements. The major energy source in the corn supplements was starch compared to NDF for the soybean hull supplements.

Energy supplementation increased (P=.006) hay OM intake (Table II). In contrast, Chase and Hibberd (1987) showed that hay OM intake decreased with corn supplementation at levels of 2 or 3 kg/d. Their control, however, was a cottonseed meal supplement. Soybean hulls tended (P=.13) to increase hay OM intake compared to corn. The higher level of supplementation, 3.0 kg DM/d, tended to decrease (P=.09) hay OM intake as a percent of body weight.

Total tract OM digestibility was increased (P=.001) with energy supplementation because the supplemental feeds (corn and soybean hulls) provided large quantities of digestible OM (Table II). Consequently, digestible OM intake increased (P=.0001) with energy supplementation. Because total tract OM digestibility was not affected (P=.75) by source of energy, digestible OM intake (% BW) remained unchanged (P=.42) by source of energy. The 3.0 kg/d feeding rate did not alter (P=.58) total tract OM digestibility although total OM intake tended (P=.18) to increase. Consequently, digestible OM intake (% BW) was greater (P=.04) with the higher feeding rate. This response appeared to be higher for corn, however, than for soybean hulls (Source X Level, P=.11). In addition, hay OM digestibility tended (P=.14) to be higher with soybean hull than with corn supplements.

The TDN content reported for corn (91%) is higher than the TDN content of soybean hulls (64%; NRC, 1984). Differences in supplemental TDN content were not reflected in total tract OM disappearance suggesting that the energy content of these two feeds is not as different as TDN values would suggest when they are used as components of range supplements (Anderson et al., 1988a; Martin and Hibberd, 1990). Compared to expected digestibilities based on NRC (1984) values, corn-supplemented OM digestibilities were similar to those expected but values for soybean hull diets were 15% greater than expected.

Intake of digestible OM from hay (calculated by difference using TDN to estimate supplement OM digestibility) was highly dependent on supplemental energy source (Figure 1). Compared to the control, corn supplements increased digestible hay OM intake by an average of 18% while soybean hull supplements increased digestible hay OM intake by an average of 51%. Compared to corn, digestible OM intake derived from the hay was increased (P=.06) with soybean

## TABLE II

## HAY AND TOTAL OM INTAKE AND DIGESTIBILITY OF BEEF COWS FED LOW-QUALITY NATIVE GRASS HAY SUPPLEMENTED WITH CORN OR SOYBEAN HULLS

| | | Corn | | Soybean hulls | | | Probability[a] | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Item | Control | Low | High | Low | High | SE | Control | Source | Level | S x L |
| Intake | | | | | | | | | | |
| Hay OM, kg/d | 5.5 | 6.7 | 6.5 | 7.6 | 6.7 | .37 | .006 | .13 | .18 | .39 |
| Hay OM, % BW | .99 | 1.21 | 1.15 | 1.36 | 1.19 | .06 | .006 | .13 | .09 | .40 |
| Total OM, kg/d | 5.5 | 8.9 | 10.0 | 9.8 | 10.1 | .82 | .006 | .13 | .18 | .39 |
| Digestible OM, kg/d | 2.6 | 5.1 | 6.0 | 5.7 | 5.9 | .20 | .0001 | .37 | .02 | .09 |
| Digestible OM, % BW | .47 | .93 | 1.08 | 1.02 | 1.05 | .04 | .0001 | .42 | .04 | .11 |
| Digestibility, % of intake | | | | | | | | | | |
| Total OM | 46.7 | 58.1 | 61.2 | 58.8 | 58.8 | 2.67 | .001 | .75 | .58 | .58 |
| Expected OM | 46.7 | 55.5 | 60.5 | 50.6 | 51.9 | | | | | |
| Hay OM | 46.7 | 49.0 | 47.5 | 54.4 | 51.2 | 2.86 | .26 | .14 | .44 | .76 |

[a] Probability levels for: Control = Control vs all supplements; Source = Corn vs Soybean hulls; Level = 1.5 vs 3.0 kg/day; S x L = Source x Level interaction.

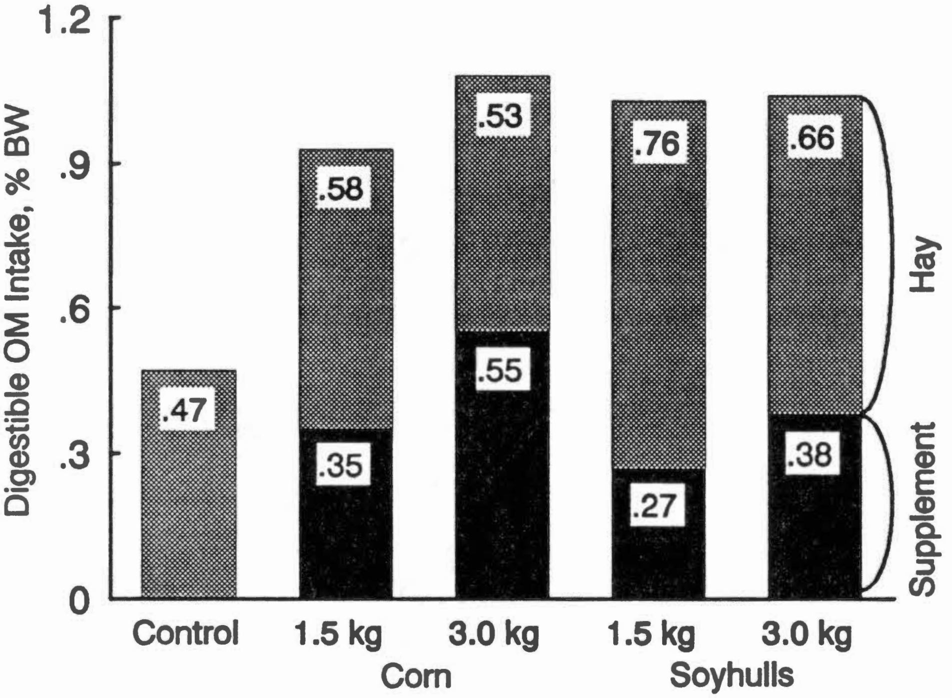

Figure 1. Effect of corn or soybean hull supplementation on digestible OM intake derived from hay and supplement in beef cows fed low-quality native grass hay

hull supplementation. This response can be attributed to increased hay OM intake (P=.13) coupled with higher (P=.14) hay OM digestibility with soybean hull supplementation (Table II). Thus, soybean hull supplementation affected forage utilization more positively than corn as suggested by Martin and Hibberd (1990).

Compared to the unsupplemented control, energy supplemention, averaged across source and level, increased OM flow and disappearance in most segments of the digestive tract (Table III). Increased ruminal OM disappearance (P=.0001) coupled with increased microbial OM flow (P=.0003) suggest that the primary effect of corn or soybean hull supplementation was to increase ruminal fermentability of the diet. Consequently, total tract OM digestibility (P=.001) and disappearance (P=.0001) were increased markedly by supplementation.

Microbial OM flow to the duodenum was not affected (P=.54) by supplement source (Table III). This observation suggests that both corn and soybean hull supplementation increased microbial growth similarly. Compared to corn, soybean hulls tended to increase (P=.11) the quantity of OM (corrected for microbial OM) that disappeared in the rumen. A larger (P=.11) proportion of digestion (% of total) occurred in the rumen with soybean hull than with corn supplements. Consequently, the rumen probably is a more important site for soybean hull digestion than for corn. Because of the high NDF content of soybean hulls, microbial action in the rumen would be necessary for digestion. In contrast, corn starch can be digested in any segment of the tract. Total tract OM disappearance (P=.37) and digestibility (P=.75) were not affected by supplement source illustrating that reduced ruminal disappearance with corn supplementation was compensated by increased disappearance in the lower gut.

Microbial OM flow to the duodenum tended to increase (P=.28) as supplementation rate increased (Table III). Ruminal OM disappearance, adjusted for microbial OM, also increased (P=.10) with the high supplementation rate and was correlated with microbial OM flow (r=.82, P=.0001). As expected, feeding a larger quantity of digestible carbohydrate from either corn or soybean hulls increased the quantity of OM fermented in the rumen.

## TABLE III

## SITE AND EXTENT OF OM DIGESTION IN BEEF COWS FED LOW-QUALITY NATIVE GRASS HAY SUPPLEMENTED WITH CORN OR SOYBEAN HULLS

| | | Corn | | Soybean hulls | | | Probability[a] | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Item | Control | Low | High | Low | High | SE | Control | Source | Level | S x L |
| Intake, kg/d | 5.48 | 8.94 | 9.98 | 9.80 | 10.07 | .372 | .006 | .13 | .18 | .39 |
| Flow, kg/d | | | | | | | | | | |
| To the duodenum | 3.21 | 4.52 | 4.90 | 4.63 | 4.73 | .308 | .001 | .94 | .45 | .66 |
| True | 2.67 | 3.52 | 3.89 | 3.74 | 3.71 | .270 | .005 | .95 | .55 | .48 |
| Microbial | .55 | .99 | 1.02 | .88 | 1.03 | .076 | .0003 | .54 | .28 | .47 |
| To the ileum | 3.28 | 3.88 | 4.94 | 4.24 | 4.56 | .298 | .005 | .98 | .04 | .23 |
| To the feces | 2.88 | 3.80 | 3.92 | 4.10 | 4.20 | .276 | .003 | .32 | .70 | .96 |
| Disappearance, kg/d | | | | | | | | | | |
| Ruminal | 2.27 | 4.42 | 5.08 | 5.17 | 5.34 | .281 | .0001 | .10 | .17 | .40 |
| True ruminal[b] | 2.81 | 5.41 | 6.09 | 6.06 | 6.36 | .271 | .0001 | .11 | .10 | .50 |
| Small intestine | -0.07 | .64 | -0.04 | .39 | .17 | .161 | .07 | .91 | .02 | .17 |
| Large intestine | .40 | .07 | 1.02 | .14 | .36 | .244 | .99 | .25 | .03 | .17 |
| Total tract | 2.61 | 5.14 | 6.05 | 5.70 | 5.87 | .202 | .0001 | .37 | .02 | .09 |
| Digestibility, % of intake | | | | | | | | | | |
| Ruminal | 41.0 | 49.3 | 51.3 | 53.4 | 53.6 | 2.52 | .002 | .23 | .67 | .73 |
| True ruminal[b] | 50.9 | 60.6 | 61.3 | 62.4 | 63.8 | 2.19 | .0007 | .33 | .64 | .88 |
| Small intestine | -1.7 | 6.8 | -0.7 | 3.6 | 1.0 | 1.68 | .04 | .67 | .01 | .16 |
| Large intestine | 7.4 | 2.0 | 10.7 | 1.8 | 4.1 | 2.44 | .33 | .19 | .04 | .22 |
| Total tract | 46.7 | 58.1 | 61.2 | 58.8 | 58.8 | 2.67 | .001 | .75 | .58 | .58 |
| Digestibility, % of total | | | | | | | | | | |
| Ruminal | 88.7 | 84.4 | 83.3 | 90.6 | 91.2 | 4.12 | .77 | .11 | .95 | .85 |
| Small intestine | -7.0 | 12.3 | -0.9 | 7.0 | 2.4 | 3.97 | .02 | .80 | .04 | .30 |
| Large intestine | 18.2 | 3.3 | 17.6 | 2.3 | 6.5 | 4.53 | .05 | .21 | .06 | .28 |

TABLE III (Continued)

| Item | Control | Corn |  | Soybean hulls |  | SE | Probability[a] |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  | Low | High | Low | High |  | Control | Source | Level | S x L |
| Digestibility, % entering segment |  |  |  |  |  |  |  |  |  |  |
| Small intestine | -2.1 | 14.3 | -2.0 | 6.4 | 1.1 | 3.64 | .11 | .53 | .01 | .15 |
| Large intestine | 11.8 | 1.5 | 20.9 | 4.5 | 9.0 | 5.61 | .66 | .44 | .05 | .21 |
| Digesta flow, l/d |  |  |  |  |  |  |  |  |  |  |
| To the duodenum, l/d | 75.2 | 74.4 | 81.3 | 78.5 | 97.6 | 7.08 | .35 | .17 | .09 | .41 |
| To the ileum, l/d | 36.8 | 40.7 | 54.8 | 52.7 | 53.6 | 3.7 | .007 | .17 | .07 | .10 |
| To the feces, kg/d | 14.8 | 21.4 | 20.9 | 24.3 | 23.9 | 1.24 | .0001 | .03 | .75 | .98 |
| pH |  |  |  |  |  |  |  |  |  |  |
| Duodenum | 2.23 | 2.25 | 2.34 | 2.32 | 2.25 | .05 | .29 | .82 | .80 | .13 |
| Ileum | 7.68 | 7.61 | 7.49 | 7.74 | 7.71 | .04 | .44 | .002 | .10 | .35 |

[a] Probability levels for: Control = Control vs all supplements; Source = Corn vs Soybean hulls; Level = 1.5 vs 3.0 kg/day; S x L = Source x Level interaction.

[b] Corrected for microbial OM contribution.

The high supplementation rate increased (P=.04) OM flow to the ileum (Table III). Reduced (P=.02) OM digestion in the small intestine (kg/d) with the higher supplementation rate may reflect an increased rate of digesta flow through the small intestine. Increased digesta flow (l/d) to the duodenum (P=.09) and ileum (P=.07) with the high supplementation rate supports this conclusion. With the higher supplementation rate, the large intestine compensated for reduced absorption from the small intestine.

Total fecal output (kg/d) was increased with soybean hull supplementation (Table III). Because total OM output was increased only slightly (P=.32) with soybean hull supplementation, most of the increased fecal output was in the form of water. This response was also noted in Martin and Hibberd (1990), who suggested that soybean hulls appeared to have a slight laxative effect.

Averaged across sources and levels, supplementation did not alter duodenal (P=.29) or ileal (P=.44) pH (Table III). Compared to soybean hulls, corn supplements decreased ileal pH (P=.002). Owens et al. (1986) suggested that ileal pH was correlated with ileal starch flow. Compared to soybean hulls, ileal starch flow should have been higher with corn supplementation. The higher supplementation rate tended (P=.10) to decrease ileal pH. This response is attributable mainly to the corn supplement.

Supplementation increased NDF flow to the duodenum (P=.02), ileum (P=.03) and feces (P=.007; Table IV). Most of this increase is due to an increased (P=.0001) NDF intake. Ruminal NDF disappearance (kg/d; P=.0001) and digestibility (%; P=.05) were increased with supplementation. Although total tract NDF disappearance (kg/d) was markedly increased (P=.0001) with supplementation, total tract NDF digestibility (%) was not (P=.16). Potential total tract NDF digestibilities may have been reduced by faster passage rate as intake increased with supplementation.

Total NDF intake was greater (P=.0002) with soybean hull than corn supplements (Table IV). This is because the soybean hull supplements contained a large quantity of NDF (Table I) and because hay intake was increased (P=.13). Ruminal NDF disappearance (P=.0001) and

# TABLE IV

## SITE AND EXTENT OF NDF DIGESTION IN BEEF COWS FED LOW-QUALITY NATIVE GRASS HAY SUPPLEMENTED WITH CORN OR SOYBEAN HULLS

| | | Corn | | Soybean hulls | | | Probability[a] | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Item | Control | Low | High | Low | High | SE | Control | Source | Level | S x L |
| Intake, kg/d | 4.77 | 6.16 | 6.10 | 7.73 | 7.91 | .319 | .0001 | .0002 | .86 | .73 |
| Flow, kg/d | | | | | | | | | | |
| To the duodenum | 2.21 | 2.71 | 2.75 | 2.93 | 2.89 | .197 | .02 | .39 | .99 | .83 |
| To the ileum | 2.48 | 2.77 | 3.42 | 3.02 | 3.39 | .243 | .03 | .65 | .06 | .58 |
| To the feces | 2.21 | 2.84 | 2.84 | 3.04 | 3.07 | .202 | .007 | .30 | .95 | .95 |
| Disappearance, kg/d | | | | | | | | | | |
| Ruminal | 2.56 | 3.45 | 3.35 | 4.80 | 5.02 | .244 | .0001 | .0001 | .82 | .53 |
| Small intestine | -0.27 | -0.06 | -0.66 | -0.09 | -0.51 | .129 | .68 | .64 | .002 | .47 |
| Large intestine | 27 | -0.06 | .58 | -0.02 | .33 | .215 | .80 | .64 | .04 | .49 |
| Total tract | 2.56 | 3.32 | 3.27 | 4.69 | 4.84 | .207 | .0001 | .0001 | .83 | .64 |
| Digestibility, % of intake | | | | | | | | | | |
| Ruminal | 53.4 | 55.4 | 54.9 | 62.8 | 63.8 | 2.41 | .05 | .005 | .91 | .76 |
| Small intestine | -5.9 | -1.7 | -11.2 | -1.9 | -7.0 | 1.98 | .85 | .33 | .003 | .29 |
| Large intestine | 5.1 | .1 | 10.1 | .5 | 4 8 | 3.04 | .71 | .44 | .04 | .37 |
| Total tract | 52.6 | 53.8 | 53.7 | 61.4 | 61.5 | 2.96 | .16 | .02 | .98 | .97 |
| Digestibility, % entering segment | | | | | | | | | | |
| Small intestine | -11.4 | -2.2 | -24.3 | -6.8 | -20.0 | 4.30 | .69 | .97 | .001 | .32 |
| Large intestine | 8 9 | -2.6 | 17.6 | .8 | 10.1 | 6.71 | .75 | .77 | .05 | .43 |

[a] Probability levels for: Control = Control vs all supplements; Source = Corn vs Soybean hulls; Level = 1.5 vs 3.0 kg/day; S x L = Source x Level interaction.

digestibility (P=.005) were higher with soybean hull than with corn supplementation. Corn supplementation has been suggested to reduce NDF digestion compared to cottonseed meal supplementation (Chase and Hibberd, 1987). Differences in NDF digestibility in this study, however, between the unsupplemented control and corn supplements were small. In addition, the quantity of total tract NDF disappearance appeared to increase with corn supplementation suggesting that added starch did not have a detrimental effect on NDF digestion when compared to unsupplemented hay. Although the increased NDF disappearance with soybean hulls can be attributed primarily to increased digestible NDF intake, small but positive associative effects on forage utilization may exist.

Starch intake was increased (P<.05) with corn supplementation, being highest (P<.05) for 3.0 kg/d corn (Table V). Ruminal starch disappearance was highly correlated (r=.99; P<.0001) with starch intake. A large quantity of starch (1,696 g) from 3.0 kg/d corn disappeared in the rumen. Total tract starch digestibility was not affected by source (P=.36) or level (P=.19) of supplement. Ruminal starch digestibility, however, was higher (P=.04) for the corn than the soybean hull supplements indicating that more of the dietary starch was fermented in the rumen with the corn than with soybean hull supplement. With the higher corn supplement, approximately 10% of digested starch disappeared in the large intestine. This illustrates that the lower gut can compensate for decreased ruminal and small intestinal starch digestion.

Compared to the unsupplemented control, N intake was more than tripled by supplementation (Table VI). Consequently, N flow and disappearance in most segments of the digestive tract were increased by supplementation. In addition, hay N intake tended (P=.12) to be higher with soybean hull than with corn supplements. Of particular note is the 110% increase in microbial N flow with supplementation. This illustrates the potential for increasing ruminal microbial yield with supplementation.

Total N intake with soybean hull supplementation was higher (P=.004) than with corn (Table VI). Neither microbial N flow (P>.45) nor efficiency of microbial synthesis (P>.38) were affected by source or level of supplement. Although true ruminal OM disappearance tended to

## TABLE V

## SITE AND EXTENT OF STARCH DIGESTION IN BEEF COWS FED LOW-QUALITY NATIVE GRASS HAY SUPPLEMENTED WITH CORN OR SOYBEAN HULLS

| | | Corn | | Soybean hulls | | | Probability[a] | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Item | Control | Low | High | Low | High | SE | Control | Source | Level | S x L |
| Intake, g/d | 83.0[e] | 1,117.7[c] | 2,121.7[b] | 202.4[d] | 205.6[d] | 16.57 | .0001 | .0001 | .0001 | .0001 |
| Flow, g/d | | | | | | | | | | |
| To the duodenum | 24.9[e] | 196.5[c] | 425.9[b] | 60.5[d] | 59.4[d] | 27.38 | .0002 | .0001 | .001 | .001 |
| To the ileum | 30.5[de] | 123.0[c] | 345.3[b] | 45.3[d] | 53.3[cde] | 29.57 | .005 | .0001 | .0007 | .001 |
| To the feces | 12.6[c] | 50.2[c] | 140.5[b] | 12.7[c] | 21.9[c] | 20.73 | .08 | .003 | .03 | .07 |
| Disappearance, g/d | | | | | | | | | | |
| Ruminal | 58.1[e] | 921.3[c] | 1,695.8[b] | 141.9[d] | 146.1[d] | 20.39 | .0001 | .0001 | .0001 | .0001 |
| Small intestine | -5.4 | 73.4 | 80.6 | 15.2 | 6.1 | 30.34 | .16 | .02 | .97 | .75 |
| Large intestine | 32.0 | 72.8 | 204.8 | 32.5 | 31.4 | 44.05 | .29 | .02 | .10 | .10 |
| Total tract | 70.4[e] | 1,067.5[c] | 1,981.2[b] | 189.7[d] | 183.6[d] | 25.95 | .0001 | .0001 | .0001 | .0001 |
| Digestibility, % of intake | | | | | | | | | | |
| Ruminal | 67.4 | 82.7 | 80.0 | 73.7 | 71.8 | 3.69 | .04 | .04 | .54 | .92 |
| Small intestine | -3.5 | 6.6 | 3.7 | 5.4 | 2.6 | 4.74 | .14 | .78 | .49 | .99 |
| Large intestine | 17.5 | 6.3 | 9.7 | 15.4 | 15.1 | 3.49 | .15 | .03 | .62 | .55 |
| Total tract | 85.1 | 95.6 | 93.4 | 94.6 | 89.5 | 2.59 | .02 | .36 | .19 | .59 |
| Digestibility, % of total | | | | | | | | | | |
| Ruminal | 80.4 | 86.5 | 85.9 | 77.4 | 80.2 | 5.11 | .72 | .17 | .84 | .75 |
| Small intestine | -5.2 | 6.9 | 4.0 | 6.1 | 2.8 | 5.24 | .10 | .83 | .50 | .96 |
| Large intestine | 20.3 | 6.6 | 10.1 | 16.4 | 17.0 | 3.18 | .09 | .02 | .54 | .66 |
| Digestibility, % entering segment | | | | | | | | | | |
| Small intestine | -4.1 | 39.0 | 16.7 | 14.0 | 7.7 | 26.28 | .58 | .19 | .99 | .34 |
| Large intestine | 59.4 | 56.8 | 53.9 | 75.8 | 56.6 | 14.30 | .93 | .39 | .38 | .52 |

[a] Probability levels for: Control = Control vs all supplements; Source = Corn vs Soybean hulls; Level = 1.5 vs 3.0 kg/day; S x L = Source x Level interaction.

[b,c,d,e] Means within the same row with different superscripts differ (P<.05).

## TABLE VI

## SITE AND EXTENT OF NITROGEN DIGESTION OF BEEF COWS FED NATIVE GRASS HAY SUPPLEMENTED WITH CORN OR SOYBEAN HULLS

| | | Corn | | Soybean hulls | | | Probability[a] | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Item | Control | Low | High | Low | High | SE | Control | Source | Level | S x L |
| N intake, g/d | | | | | | | | | | |
| Total | 46.5 | 141.3 | 139.4 | 153.6 | 149.7 | 3.19 | .0001 | .004 | .38 | .77 |
| Hay | 46.3 | 53.8 | 54.0 | 63.0 | 57.0 | 3.07 | .007 | .12 | .22 | .50 |
| Supplemental | .1 | 85.6 | 85.4 | 90.5 | 92.8 | .63 | .0001 | .0001 | .12 | .09 |
| N flow, g/d | | | | | | | | | | |
| To the duodenum | 68.0 | 134.9 | 140.7 | 143.7 | 150.5 | 7.48 | .0001 | .24 | .42 | .94 |
| Ammonia | 3.1 | 4.9 | 5.0 | 5.6 | 6.0 | .54 | .002 | .13 | .68 | .80 |
| Microbial | 38.5 | 81.7 | 78.7 | 76.6 | 87.8 | 5.33 | .0001 | .72 | .45 | .21 |
| Feed | 26.4 | 48.4 | 57.0 | 61.5 | 56.7 | 5.81 | .0007 | .29 | .75 | .27 |
| To the duodenum, % of intake | 147.2 | 95.0 | 99.7 | 92.9 | 99.5 | 5.73 | .0001 | .84 | .34 | .87 |
| Bypass N, % of intake | 57.3 | 34.2 | 40.6 | 39.5 | 37.4 | 4.58 | .003 | .83 | .65 | .37 |
| Microbial efficiency[b] | 14.6 | 16.1 | 13.1 | 12.7 | 13.9 | 1.46 | .70 | .38 | .53 | .17 |
| NAN | | | | | | | | | | |
| To the duodenum | 64.9 | 130.0 | 135.7 | 138.0 | 144.5 | 7.15 | .0001 | .26 | .41 | .96 |
| To the ileum | 35.8 | 61.2 | 71.0 | 74.4 | 76.1 | 4.61 | .0001 | .04 | .17 | .32 |
| To the feces | 37.8 | 58.1 | 57.4 | 65.2 | 72.0 | 4.91 | .0006 | .05 | .54 | .46 |
| NAN disappearance, g/d | | | | | | | | | | |
| Ruminal | -18.5 | 11.3 | 3.7 | 15.6 | 5.2 | 5.95 | .001 | .63 | .16 | .82 |
| Small intestine | 22 | 68.8 | 64.7 | 63.6 | 68.4 | 5.28 | .0001 | .86 | .94 | .34 |
| Large intestine | 4.1 | 3.2 | 13.5 | 9.2 | 4.1 | 6.74 | .65 | .78 | .65 | .20 |
| Total tract | 8.7 | 83.2 | 81.9 | 88.4 | 77.7 | 3.48 | .0001 | .90 | .11 | .20 |

TABLE VI (Continued)

| Item | Control | Corn Low | Corn High | Soybean hulls Low | Soybean hulls High | SE | Probability[a] Control | Probability[a] Source | Probability[a] Level | Probability[a] S x L |
|---|---|---|---|---|---|---|---|---|---|---|
| NAN digestibility, % of intake | | | | | | | | | | |
| Ruminal | -40.7 | 8.5 | 3.8 | 10.8 | 4.5 | 5.32 | .0001 | .78 | .32 | .88 |
| Small intestine | 60.3 | 48.3 | 45.6 | 41.3 | 44.9 | 3.55 | .002 | .22 | .88 | .31 |
| Large intestine | 5.5 | 2.8 | 9.8 | 5.9 | 3.1 | 5.65 | .99 | .71 | .67 | .32 |
| Total tract | 20.7 | 59.6 | 59.2 | 58.0 | 52.5 | 3.56 | .0001 | .27 | .42 | .49 |
| NAN digestibility, % entering segment | | | | | | | | | | |
| Small intestine | 41.7 | 52.8 | 47.0 | 46.1 | 46.2 | 2.45 | .04 | .10 | .19 | .18 |
| Large intestine | 8.9 | 5.3 | 17.0 | 12.3 | 6.6 | 9.24 | .89 | .83 | .71 | .28 |

[a] Probability levels for: Control = Control vs all supplements; Source = Corn vs Soybean hulls; Level = 1.5 vs 3.0 kg/day; S x L = Source x Level interaction.

[b] g microbial N/kg OM truly fermented.

increase (P=.13) with soybean hull supplementation, treatment differences were small. Both corn and soybean hull supplements stimulated microbial yield similarly.

Feed N flow to the duodenum was not affected by source (P=.29) or level (P=.75) of supplement (Table VI). The ruminal protein degradation of corn is about 45% (NRC, 1985). Similar bypass values for corn and soybean hull supplements suggests that the ruminal protein degradation of these two supplements was similar. Although soybean hulls tended to be slightly lower, total tract NAN digestibility (apparent) was not significantly affected (P=.27) by supplement source.

Treatment differences in ruminal pH were dependent on sampling time (treatment x sampling time interaction, P=.007, Figure 2). Ruminal pH was higher (P=.0001) for the control than for the mean of the other supplements at each sampling time. With soybean hull supplements, ruminal pH tended to be lowest at 2 h after feeding, whereas with corn supplements, the lowest pH was observed later (4 to 6 hour after feeding). Compared to soybean hulls, corn supplementation decreased ruminal pH at 4 (P=.0001), 6 (P=.01), 9 (P=.09) and 24 (P=.02) h postsupplementation. The higher supplement rate (3.0 vs 1.5 kg/day) reduced (P=.01) ruminal pH only at the 18-h sampling time.

Treatment differences in ruminal ammonia concentrations were dependent on sampling time (treatment X sampling time interaction, P=.0001, Figure 3). Supplementation increased (P<.04) ruminal ammonia concentrations at all sampling times except at 9 h. Compared to corn, soybean hulls produced greater ruminal ammonia concentrations at 2 (P=.0006), 4 (P=.0001) and 6 (P=.047) h postfeeding. In addition to decreased ruminal pH, a low ruminal ammonia concentration with the corn supplements may limit NDF digestion. Compared to 3.0 kg/day, feeding 1.5 kg/day resulted in higher ruminal ammonia at 2 (P=.05), 6 (P=.16), 9 (P=.006), 12 (P=.01) and 18 (P=.01) h postsupplementation. Because the 1.5 kg/day supplements provided more soybean meal than 3.0 kg/day, an increased ruminal ammonia concentration was expected.

Ruminal OM fill measured at 6 h postfeeding was increased (P=.002) with supplementation (Table VII). Ruminal NDF and liquid fill, however, were not affected (P>.33) by

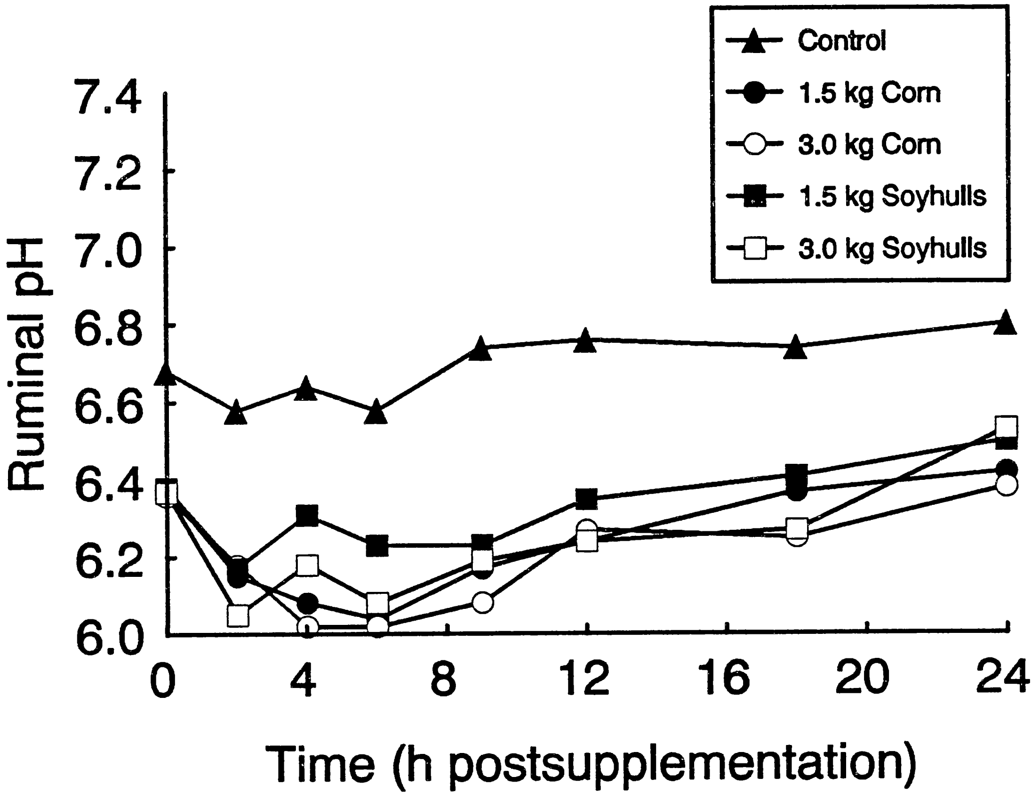

Figure 2. Changes in ruminal pH in beef cows fed low quality native grass hay supplemented with soybean hulls or corn

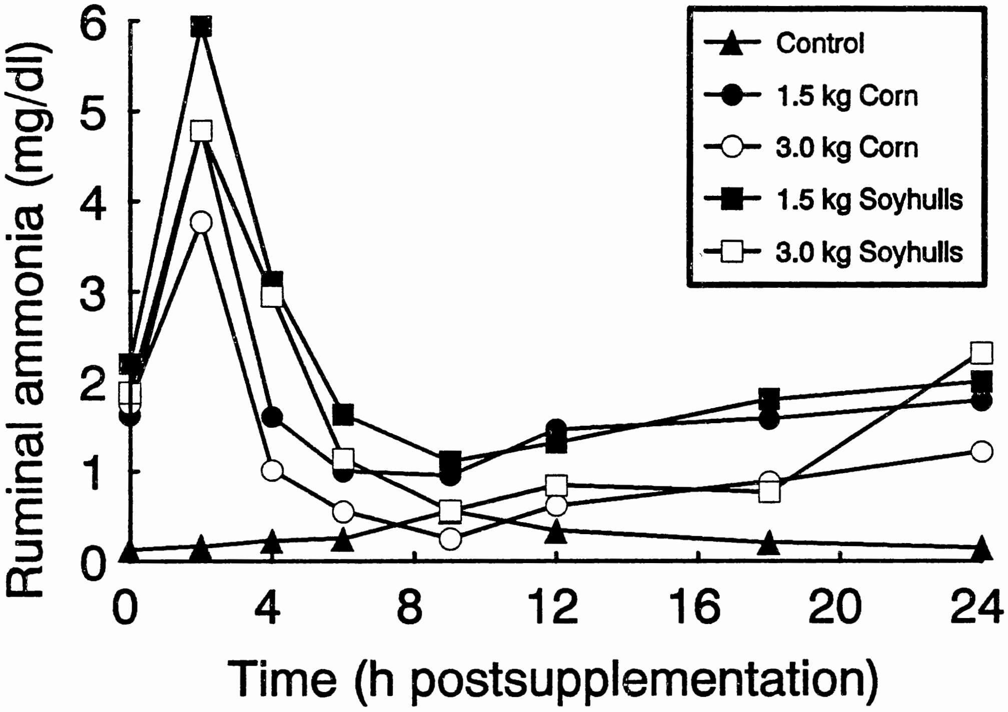

Figure 3. Changes in ruminal ammonia concentration in beef cows fed low quality native grass hay supplemented with soybean hulls or corn

## TABLE VII

## RUMINAL FILL OF BEEF COWS FED LOW-QUALITY NATIVE GRASS HAY SUPPLEMENTED WITH CORN OR SOYBEAN HULLS

| | | Corn | | Soybean hulls | | | Probability[a] | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Item | Control | Low | High | Low | High | SE | Control | Source | Level | S x L |
| Liquid fill | | | | | | | | | | |
| kg | 58.0 | 54.9 | 52.7 | 62.5 | 58.2 | 1.55 | .59 | .001 | .06 | .52 |
| % BW | 10.5 | 9.9 | 9.4 | 11.2 | 10.4 | .28 | .33 | .001 | .03 | .61 |
| OM fill | | | | | | | | | | |
| kg | 9.0 | 9.9 | 10.2 | 10.5 | 10.5 | .29 | .002 | .16 | .58 | .72 |
| % BW | 1.6 | 1.8 | 1.8 | 1.9 | 1.9 | .05 | .002 | .16 | .87 | .84 |
| NDF fill | | | | | | | | | | |
| kg | 7.5 | 7.3 | 7.4 | 8.0 | 8.0 | .24 | .55 | .02 | .90 | .90 |
| % BW | 1.4 | 1.3 | 1.3 | 1.4 | 1.4 | .04 | .81 | .01 | .81 | .99 |

[a] Probability levels for: Control = Control vs all supplements; Source = Corn vs Soybean hulls; Level = 1.5 vs 3.0 kg/day; S x L = Source x Level interaction.

supplementation. Compared to corn, soybean hulls increased liquid ($P=.001$) and NDF ($P=.02$) fill. Increased NDF fill with soybean hulls might be explained partly by greater NDF intake with soybean hulls. Increased liquid fill, however, also may be related to the high water absorbing ability of soybean hulls (Martin and Hibberd, 1990). Ruminal liquid fill was lower ($P=.06$) with the higher supplement feeding rate.

Particle passage rate (Yb-labelled hay) and liquid kinetic measurements (Co·EDTA) were increased ($P<.005$) by supplementation (Table VIII). Particle passage rate was not affected by source ($P=.89$) or level ($P=.43$) of supplement. Liquid dilution rate (%/h) and flow (l/h) were increased ($P<.06$) with soybean hull supplementation. Compared to corn, soybean hulls decreased ($P=.04$) liquid retention time and tended to increase ($P=.19$) ruminal liquid volume suggesting that they impact liquid dynamics in the rumen.

Rate and extent of in situ hay DM and NDF disappearance were increased ($P<.0006$ for 12 through 96 h) by supplementation (Table IX). Increased ruminal degradable protein and energy from supplementation might be expected to increase rate of hay disappearance. In situ hay disappearance for 1.5 kg/d corn, 1.5 kg/d soybean hulls and 3.0 kg/d soybean hulls was similar at all sampling times. The high corn supplement (3.0 kg/d) reduced in situ hay disappearance at 12, 48 and 96 h of incubation. Chase and Hibberd, (1987) observed that rate and extent of hay disappearance from dacron bags were decreased when a high level (3 kg/d) of corn was fed. However, rate of in situ hay disappearance was not significantly affected by sources ($P=.79$) or levels ($P=.58$) of supplements in this study.

Rate and extent of in situ DM degradation were greater ($P<.05$) for soybean meal than for blood meal (Table X). Rate and extent of in situ blood meal DM degradation were similar when incubated in cows fed either corn or soybean hull supplements. Compared to corn supplements, soybean hulls resulted in greater ($P<.05$) soybean meal DM degradation. Orskov (1982) and Loerch et al. (1983) suggested that the rate of degradation of protein feeds is affected by the proportion of concentrate in the diet. Our data illustrate that even low levels (3.0 kg/d) of corn supplementation can decrease the DM degradation of soybean meal.

## TABLE VIII

## RUMINAL DIGESTA KINETICS OF BEEF COWS FED LOW-QUALITY NATIVE GRASS HAY SUPPLEMENTED WITH CORN OR SOYBEAN HULLS

| | | Corn | | Soybean hulls | | | Probability[a] | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Item | Control | Low | High | Low | High | SE | Control | Source | Level | S x L |
| Particle passage rate, %/h | 2.1 | 4.2 | 3.3 | 3.6 | 3.8 | .42 | .005 | .89 | .43 | .23 |
| Ruminal volume, l | 59.4 | 56.7 | 59.7 | 62.0 | 63.2 | 3.17 | .79 | .19 | .53 | .78 |
| Liquid dilution rate, %/h | 6.0 | 8.8 | 8.5 | 9.7 | 9.3 | .38 | .0001 | .06 | .33 | .82 |
| Liquid flow rate, l/h | 3.5 | 5.1 | 5.0 | 6.0 | 5.9 | .27 | .0001 | .007 | .58 | .91 |
| Liquid retention time, h | 17.0 | 11.6 | 12.2 | 10.3 | 10.9 | .54 | .0001 | .04 | .29 | .99 |

[a] Probability levels for: Control = Control vs all supplements; Source = Corn vs Soybean hulls; Level = 1.5 vs 3.0 kg/day; S x L = Source x Level interaction.

## TABLE IX

## RATE AND EXTENT OF IN SITU HAY DISAPPEARANCE IN BEEF COWS FED LOW-QUALITY NATIVE GRASS HAY SUPPLEMENTED WITH CORN OR SOYBEAN HULLS

| | | Corn | | Soybean hulls | | | Probability[a] | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Incubation time (h) | Control | Low | High | Low | High | SE | Control | Source | Level | S x L |
| DM disappearance, % | | | | | | | | | | |
| 6 | 11.5 | 11.5 | 11.2 | 12.6 | 12.3 | .40 | .39 | .008 | .41 | .89 |
| 12 | $13.6^{d}$ | $18.3^{b}$ | $14.8^{cd}$ | $17.7^{b}$ | $17.5^{b}$ | .60 | .0001 | .09 | .004 | .01 |
| 24 | 19.9 | 28.5 | 25.2 | 30.1 | 28.2 | 1.06 | .0001 | .04 | .02 | .50 |
| 48 | $33.6^{d}$ | $51.1^{b}$ | $43.5^{c}$ | $46.1^{b}$ | $49.8^{b}$ | 2.12 | .0001 | .77 | .36 | .01 |
| 96 | 55 9 | 66.2 | 62.4 | 67.2 | 65.6 | .76 | .0001 | .01 | .001 | .16 |
| Rate, %/h | 2.5 | 3.4 | 3.2 | 3.2 | 3.3 | .16 | .0018 | .79 | .58 | .49 |
| Lag time, h | .93 | .66 | .75 | .67 | .68 | .036 | .0001 | .44 | .21 | .30 |
| NDF disappearance, % | | | | | | | | | | |
| 6 | 6.9 | 7.3 | 6.6 | 8.6 | 8.5 | .48 | .15 | .002 | .35 | .56 |
| 12 | $9.4^{d}$ | $13.8^{b}$ | $10.5^{cd}$ | $13.6^{b}$ | $13.8^{b}$ | .84 | .0006 | .07 | .07 | .04 |
| 24 | 15.8 | 24.9 | 20.6 | 26.3 | 24.8 | 1.12 | .0001 | .02 | .01 | .22 |
| 48 | $30.3^{d}$ | $49.0^{b}$ | $40.8^{c}$ | $49.4^{b}$ | $47.5^{b}$ | 1.18 | .0001 | .005 | 0001 | .01 |
| 96 | $54.0^{d}$ | $67.5^{b}$ | $60.6^{c}$ | $66.0^{b}$ | $64.9^{b}$ | 1.30 | .0001 | .29 | .004 | .03 |
| Rate, %/h | 3.5 | 4.3 | 4.3 | 4.1 | 4.0 | .25 | .048 | .30 | .77 | .95 |
| Lag time, h | .77 | .62 | .64 | .63 | .65 | .024 | .0003 | .68 | .42 | .87 |

[a] Probability levels for: Control = Control vs all supplements; Source = Corn vs Soybean hulls; Level = 1.5 vs 3.0 kg/day; S x L = Source x Level interaction.

[b,c,d,e] Means within the same row with different superscripts differ (P<.03).

## TABLE X

## IN SITU BLOOD MEAL OR SOYBEAN MEAL DISAPPEARANCE IN BEEF COWS FED LOW-QUALITY NATIVE GRASS HAY SUPPLEMENTED WITH CORN OR SOYBEAN HULLS

| | Blood meal | | Soybean meal | | |
|---|---|---|---|---|---|
| Hour | HC | HSBH | HC | HSBH | SE |
| | ------------------------% DM disappearance------------------------ | | | | |
| 6 | $13.0^c$ | $14.8^c$ | $52.2^b$ | $61.7^a$ | 1.67 |
| 12 | $10.9^c$ | $10.3^c$ | $72.0^b$ | $79.0^a$ | 1.86 |
| 18 | $10.3^c$ | $9.4^c$ | $80.0^b$ | $85.8^a$ | 1.69 |
| 24 | $8.6^c$ | $10.2^c$ | $85.7^b$ | $94.9^a$ | 1.68 |
| 48 | $7.7^c$ | $8.1^c$ | $96.9^b$ | $98.6^a$ | .84 |
| Rate, %/h | $.10^c$ | $.15^c$ | $.92^a$ | $.74^b$ | .181 |

$^{a,b,c}$Means within the same row with different superscripts differ (P<.05).

# Implications

Although the net effects of corn and soybean hull supplementation are somewhat similar, both increasing digestible OM intake and duodenal nitrogen flow, their modes of action differed. Corn appears to be an "additive" supplement whose nutrients were added to nutrients from hay. In contrast, soybean hulls appeared to exert a positive associative effect to enhance hay utilization and intake.

# CHAPTER IV

## CONCLUSIONS

Difficulties in sample collection and handling, problems with laboratory techniques and experimental errors complicated this experiment. For example, during the experiment, sampling times for collecting feces often did not match the planned time due to a lack of feces. This may have caused errors in determining Yb passage rate. In addition, a new Yb extraction method needs to be developed to eliminate the interference from organic matter.

Some data were lost when determining the nitrogen content of in situ blood meal and soybean meal residues with the KjelTec 1030 auto analyzer. This was due to a high level of nitrogen concentration in the samples causing measurements to be out of range for the machine. Thus, the conventional Kjeldehl method should be used in measuring supplements with a high protein content.

A titration pipet with a smaller scale should be used in order to accurately read ammonia nitrogen content of digesta following magnesium oxide distillation.

Ruminal evacuations were performed over a two hour period. Such an extended sampling time for ruminal evacuation might reduce OM and NDF fill for cows evacuated later because ruminal fermentation was not terminated during this period of time.

High Co concentrations in ruminal fluid caused analytical problems with atomic absorption. Although this problem was overcome by diluting the volume of ruminal fluid five fold, diluting errors may exist. Dosing less Co·EDTA would solve this problem.

## Application of Information

Compared to the unsupplemented control, both corn and soybean hull supplements effectively increased hay OM and digestible hay OM intake. When compared with the control, soybean hull supplements markedly increased digestible OM derived from the hay whereas the corn supplement increased digestible hay OM only slightly. Consequently, low-quality native grass was effectively utilized with soybean hull supplementation. Cow-calf producers may benefit from the use of soybean hull supplements, especially when the quality of forage in the native rangeland is low and the price of corn is high. In addition, when comparing the price of corn with soybean hulls ($86 vs $80/ton) and the similar nutritive values of these two supplements (Merrill and Klopfenstein, 1984), it appears judicious for cattlemen to use soybean hulls as a supplement for low-quality forage. Reducing the use of cereal (corn) grain in ruminants' diet also might help to alleviate the world food demand by human beings, especially in countries where cereal grains are considered a staple food.

Future research related to soybean hull supplementation may involve the following topics: (1) How do daily gains of cattle compare when supplemented with soybean hulls versus corn? (2) How can one maximize the utilization of low-quality forage with by-product supplements and obtain the most beneficial effects from soybean hulls? (3) What is or are the bottleneck(s) in rate and extent of cellulose digestion, passage and intake? (4) What are the mechanisms of low-quality forage digestion with corn (starch) and soybean hull supplementation? (5) Will the results of the cows used in this experiment be similar to those of grazing cattle on native rangeland? These puzzles await to be explored and solved in future studies.

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# APPENDIX

## TABLE XI

## EFFECTS OF CORN AND SOYBEAN HULL SUPPLEMENTATION ON COMPOSITION OF RUMINAL BACTERIA ISOLATED FROM BEEF COWS FED LOW-QUALITY NATIVE GRASS HAY

| | | Corn | | Soybean hulls | | |
|---|---|---|---|---|---|---|
| Item | Control | Low | High | Low | High | SE |
| Composition% | | | | | | |
| Ash | 22.0 | 15.8 | 14.3 | 16.9 | 17.3 | 3.69 |
| N | 5.5 | 7.0 | 6.7 | 7.2 | 7.1 | .76 |
| RNA | .45 | .72 | .78 | .84 | .81 | .18 |
| Bacterial N:RNAN | 12.3 | 9.8 | 12.2 | 8 8 | 8.8 | .57 |

## TABLE XII

## RUMINAL VFA CONCENTRATION IN BEEF COWS FED LOW-QUALITY NATIVE GRASS HAY SUPPLEMENTED WITH CORN OR SOYBEAN HULLS[a]

| | | Corn | | Soybean hulls | | | Probability[b] | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Item | Control | Low | High | Low | High | SE | Control | Source | Level | S x L |
| VFA, mmol/l | | | | | | | | | | |
| Acetate | 59.1 | 79.7 | 78.1 | 76.2 | 80.5 | 3.86 | .0007 | 89 | .72 | .46 |
| Propionate | 15.2 | 20.5 | 18.9 | 18.0 | 22.7 | 1.51 | .015 | .67 | .34 | .06 |
| Isobutyrate | .9 | 2.2 | 2.4 | 2.2 | 1.4 | .26 | .002 | .08 | .25 | .08 |
| Butyrate | 7.2 | 12.3 | 13 2 | 10.5 | 11.6 | .65 | .0001 | .02 | .15 | .85 |
| Isovalerate | .7 | 1.2 | 1.4 | 1.0 | 1.1 | .08 | .0002 | .007 | .15 | .50 |
| Valerate | .1 | .6 | .5 | .4 | .5 | .07 | .0003 | .06 | .94 | 16 |
| Total | 83.3 | 116.5 | 114.5 | 108.2 | 117.8 | 6.00 | .0006 | .68 | .55 | .35 |
| $C_2$:$C_3$ | 3.88 | 4.02 | 4.21 | 4.24 | 3.59 | .155 | .47 | .22 | .16 | .02 |
| VFA, mol/100 mol | | | | | | | | | | |
| Acetate | 71.0 | 68.5 | 68.3 | 70.4 | 68.4 | .47 | .002 | .06 | .03 | .09 |
| Propionate | 18.4 | 17.4 | 16.4 | 16.7 | 19.2 | .57 | .18 | .10 | .19 | .009 |
| Isobutyrate | 1.1 | 1.8 | 2.1 | 2.0 | 1.2 | .19 | .005 | .10 | .13 | .015 |
| Butyrate | 8 6 | 10 7 | 11.5 | 9.6 | 9.8 | .29 | .0001 | .0005 | .08 | .27 |
| Isovalerate | .8 | 1.0 | 1.2 | .9 | .9 | .07 | .03 | .01 | .26 | .19 |
| Valerate | .2 | .5 | 5 | .4 | .4 | .05 | .0001 | .03 | .97 | .20 |

[a] Volatile fatty acid concentrations were determined on ruminal samples collected 4 h postsupplementation. Subsamples (2 ml) were combined with 333 ml of 25% metaphosphoric acid containing 2-ethylbutyric acid (internal standard) and centrifuged (20,000 x g, 20 min). The supernatant fluid (1 ml) was injected into a Perkin Elmer AutoSystem gas chromatograph (Perkin Elmer, Norwalk, CT.) equipped with a spiral J & W fused silica Megabore column (30 m x .5333 mm; acidified (TPA) polyethylene glycol liquid phase; 1.0 um film thickness, J & W Scientific, Folsom, CA.). Helium served as the mobile phase with a flow rate of 40 ul/min. Column temperature was programmed to increase from 110° to 235° C in three stepwise increments. Inlet port and detector temperatures were both 250°C

[b] Probability levels for: Control = Control vs all supplements; Source = Corn vs Soybean hulls; Level = 1.5 vs 3 0 kg/day; S x L = Source x Level interaction.

## TABLE XIII

## RUMINAL pH IN BEEF COWS FED LOW-QUALITY NATIVE GRASS HAY SUPPLEMENTED WITH CORN OR SOYBEAN HULLS

| | | Corn | | Soybean hulls | | | Probability[a] | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Hour | Control | Low | High | Low | High | SE | Control | Source | Level | S x L |
| 0 | 6.68 | 6.38 | 6.36 | 6.38 | 6.37 | .047 | .0001 | .89 | .79 | .95 |
| 2 | 6.58 | 6.15 | 6.18 | 6.17 | 6.05 | .031 | .0001 | .26 | .40 | .14 |
| 4 | 6.64 | 6.08 | 6.02 | 6.31 | 6.18 | .058 | .0001 | .0001 | .06 | .53 |
| 6 | 6.58 | 6.04 | 6.02 | 6.23 | 6.08 | .055 | .0001 | .014 | .09 | .17 |
| 9 | 6.74 | 6.17 | 6.08 | 6.23 | 6.19 | .034 | .0001 | .09 | .22 | .67 |
| 12 | 6.76 | 6.24 | 6.27 | 6.35 | 6.24 | .039 | .0001 | .43 | .41 | .13 |
| 18 | 6.74 | 6.37 | 6.25 | 6.41 | 6.27 | .044 | .0001 | .53 | .01 | .83 |
| 24 | 6.80 | 6.42 | 6.38 | 6.50 | 6.53 | .044 | .0001 | .02 | .99 | .91 |

[a] Probability levels for: Control = Control vs all supplements; Source = Corn vs Soybean hulls; Level = 1.5 vs 3.0 kg/day; S x L = Source x Level interaction.

## TABLE XIV

## RUMINAL AMMONIA CONCENTRATION (mg/dl) IN BEEF COWS FED LOW-QUALITY NATIVE GRASS HAY SUPPLEMENTED WITH CORN OR SOYBEAN HULLS

| | | Corn | | Soybean hulls | | | Probability[a] | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Hour | Control | Low | High | Low | High | SE | Control | Source | Level | S x L |
| 0 | .13 | 1.63 | 1.77 | 2.20 | 1.88 | .458 | .0001 | .28 | .78 | .46 |
| 2 | .17 | 4.78 | 3.77 | 5.94 | 4.78 | .507 | .0001 | .0006 | .0006 | .81 |
| 4 | .23 | 1.61 | 1.01 | 3.11 | 2.95 | .495 | .0001 | .0001 | .22 | .47 |
| 6 | .25 | 1.00 | .55 | 1.64 | 1.14 | .319 | .017 | .05 | .12 | .93 |
| 9 | .55 | .96 | .25 | 1.11 | .56 | .186 | .63 | .46 | .04 | .81 |
| 12 | .34 | 1.47 | .62 | 1.32 | .84 | .227 | .04 | .92 | .03 | 55 |
| 18 | .21 | 1.59 | .88 | 1.81 | .77 | .287 | .003 | .87 | .005 | .58 |
| 24 | .15 | 1.79 | 1.22 | 2.00 | 2.32 | .327 | .0001 | .14 | .50 | .51 |

[a] Probability levels for: Control = Control vs all supplements; Source = Corn vs Soybean hulls; Level = 1.5 vs 3.0 kg/day; S x L = Source x Level interaction.

# VITA 2

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