EFFECT OF PROTEIN OR GRAIN SUPPLEMENTATION ON INTAKE, UTILIZATION, AND RATE OF PASSAGE OF MEDIUM QUALITY ROUGHAGE

By

MARIAN JOYCE GUTHRIE

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Mississippi State University

Mississippi State, Mississippi

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Thesis Approved:

Donald G Wagner
Thesis Adviser

David S Buchanan

Keith Lusby

Norman N. Durham
Dean of the Graduate College

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CHAPTER I

INTRODUCTION

Ruminants, due to their unique physiological characteristics, are able to efficiently utilize forages of high fiber content and low nutritive value. In a world where food supplies may not be adequate for the increasing population, utilization of roughages is becoming increasingly important. Considerable quantities of roughages having a low feeding value exist, and many which could be used in ruminant feeding are currently wasted or improperly utilized.

Studies to improve the utilization of low quality roughages have been conducted with varying degrees of success. It has been reported that alkalinization of crop residues will improve both intake and apparent digestibility of cereal straws. However, protein supplementation is more frequently used in attempts to improve the utilization of mature native range or hays.

Supplementation of low quality feedstuffs with nonprotein nitrogen sources (e.g., urea, biuret) has improved utilization in some instances. Moreover, it has been shown that protein supplements of plant origin (e.g., soybean meals, cottonseed meals, etc.) will improve intake and digestibility of low quality forages. However, in some cases, energy supplementation has depressed forage intake and utilization and fiber digestion. This effect may be caused by a fermentation pattern and ruminal environmental that is not beneficial for certain rumen bacteria, particularly cellulolytic strains.

Even though protein or nitrogen supplementation from plant protein sources has been shown to be beneficial in improving forage intake and fiber digestibility of low quality forages, more research studying different kinds of supplementation programs is needed. For example, the effects of different levels and/or sources of supplementary nitrogen or energy on roughage digestion deserves more investigation. Perhaps, even low levels of high protein supplements can improve the microbial environment; whereas, small amounts of starch in the supplement my either enhance or detrimentally alter the microbial population. However, the amount of starch which might be detrimental under *in vivo* conditions is not known. Possibly, an adequate nitrogen supply could alleviate any negative effects of the starch.

More recently, the study of rate of passage of digesta has received considerable attention. There is still much to be learned about the effects of supplementation on liquid and solid turnover rates and the interrelationship of forage intake and digesta rate of passage.

Therefore, two intake and digestion studies were conducted to: 1) compare the effects of two levels of high protein and a grain supplement on intake and fiber digestion of medium quality native prairie hay; 2) assess the effect of increasing levels of high protein supplement on intake and utilization of medium quality prairie hay; 3) evaluate the effect of supplementation on ruminal ammonia concentration and pH; and 4) determine rate of passage of digesta when feeding graded levels of protein supplement with medium quality prairie hay.

CHAPTER II

REVIEW OF LITERATURE

Introduction

With the ruminant animal, essentially two ecosystems exist. This includes the microbial ecosystem within the rumen and the animal's external environment (Russell and Hespell, 1981). The anatomical uniqueness of the ruminant digestive system permits the consumption of materials that otherwise would be of little or no value for animals with a simple stomach. This literature review briefly discusses the reticulo-rumen environment and investigates factors involved in voluntary intake and utilization of forages.

The Reticulo-Rumen Environment

Microbial Population

The rumen environment, due to anaerobiosis and dilution rate, only permits the growth of organisms for which the substrate and ruminal pH are optimal. Of the microorganisms present, bacteria are by far the most frequently occurring group. Abundance of several strains of cellulolytic bacteria gives to the ruminant animal the ability to survive on poor quality fibrous forages (Orskov, 1982).

Many of the ruminal cellulolytic bacteria are also amylolytic. The noncellulolytic species includes numerous starch-digesting strains, as well. Few, if any, of the major strains of rumen bacteria are obligatorily proteolytic, and the strains that are, appear to use bacteria as their nutrients. Other classifications of bacteria include hemicellulose digesters, sugar fermenters, acid utilizers, methanogenic and lipolytic bacteria (Hungate, 1966).

Less is known about the role of protozoa in the rumen. Protozoa may be classified into two general categories: Holotrichs, the digesters of soluble sugars and Entodinonorphs, the starch digesters (Hungate, 1966). Protozoa are larger but fewer in number than bacteria (Hungate, 1966; Orskov, 1982) and are considered to be highly proteolytic. The bacterial engulfment activity of protozoa should be noted (Hungate, 1966; Nugent and Mangan, 1981; Leng, 1982a). Nugent and Mangan (1981) confirmed that the proteolytic activity of protozoa is almost entirely associated with bacterial cells, and that cell-free ruminal fluid and protozoa have little proteolytic activity.

Recently, anaerobic phycomycetous fungi also have been recognized as a functional group of rumen microorganisms (Bauchop, 1979). They are almost certainly cellulolytic (Orskov, 1982) as large numbers have been found to colonize plant fragments in the rumen of animals on fibrous diets (Bauchop, 1979).

Microbial Growth Factors

The microbial population in the rumen dictates ruminal fermentation and the efficiency of nutrient utilization by ruminants. The short chain fatty acids formed during fermentation serve as an energy source and the microbial cells provide protein to the animal. In addition, methane, heat, and ammonia are evolved representing a loss of energy and nitrogen (N) for the animal (Russell and Hespell, 1981).

Ruminal Ammonia Concentration. Ruminal ammonia (NH_3) is a central intermediate in both the assimilation and degradation of dietary N. Ammonia is required by many species of bacteria; amino acids and peptides also are essential for some strains (Hungate, 1966). Wallace (1979) reported that an increase in NH_3 concentration in the rumen increased the size of the microbial flora and its hydrolytic activity.

Considerable variation exists in the literature as to the optimal NH_3 concentration for supporting maximum rate of rumen bacteria growth. Estimates range from a high of 23.5 mg NH_3-N/dl of rumen fluid in sheep fed whole barley plus urea (Mehrez et al., 1977) to a low of 1.4 mg/dl with pure *in vitro* cultures of ruminal bacteria (Schaefer et al., 1980). Satter and Slyter (1974) reported 2 mg/dl as the precise limiting *in vitro* concentration and that 5 mg/dl would support maximum bacterial growth allowing a slight NH_3 excess. An additional study *in vivo* supports the view that 2 to 5 mg/dl is sufficient to allow maximum growth of rumen microbes (Slyter et al., 1979).

Kropp et al. (1977) suggested that the NH_3 level in the rumen is a more precise index of N status for rumen bacteria than that which can be calculated from the feed composition. More recently, Slyter et al. (1979) suggested the point at which N is likely to become limiting for rumen bacteria and protozoa growth is better indicated by animal growth response than by N balance.

Numerous factors may contribute to these variations in reported literature values of NH_3 concentration. Location in the rumen (dorsal, midpoint, or ventral rumen), method and time of sampling, type of diet, and rumen fluid volume are the most obvious (Wohlt et al., 1976). In addition, peaks in NH_3 concentration reflect a diurnal pattern of feed intake (Orskov, 1982; de Faria and Huber, 1984) or oscillatory behavior even on an ad libitum feeding schedule (Mahadevan et al., 1982). Moreover, different analytical methods are used in NH_3 determinations. Despite these variables, ruminal NH_3 continues to be used extensively to estimate N status in the rumen.

Ruminal pH. The entire physiological makeup of the ruminant animal and its reticulo-rumen have evolved to work in the presence of high fiber levels in the diet. Fiber stimulates both mastication and rumination which increases salivary secretion, thus enhancing the buffering capacity of the ruminal liquor. On a high forage diet, the rumen generally has a pH close to neutral with only slight variations (Arelovich, 1983).

Unfortunately, cattle are often unable to achieve the high levels of performance needed in the beef industry while on roughage diets unless supplements are provided. So, protein or protein-energy supplements are often fed to cows or growing animals consuming low quality forages. Thus, rumen etiology may be affected by a number of factors, including a shift in pH from normal range (Arelovich, 1983).

The fermentability or digestibility of cereal grains is greater than for roughages, increasing volatile fatty acid (VFA) production per unit weight of feed weight consumed. Ideally, more saliva is needed to buffer the ruminal contents, yet less saliva is produced due to decreased rumination resulting in lower pH of the ruminal fluid (Orskov, 1982).

After a meal, the pH of the ruminal fluid may drop temporarily due to immediate changes in VFA production as a result of altered metabolism of the existing microorganisms. Long term changes in the ruminal microbial population would take place in response to a more permanent pH alteration (Esdale and Satter, 1972).

Cellulolytic bacteria have been shown to be very sensitivie to ruminal pH. A ruminal pH of less than 6.2 will seriously inhibit their growth. Amylolytic bacteria generally are less sensitive to pH changes, and their activity remains virtually unaltered between a pH of 5.6 and 7.0 (Orskov, 1982). Accordingly, supplementation with cereal grains may severely lower ruminal pH and inhibit the activity and growth of cellulolytic bacteria. This would in turn depress total fiber digestibility and dry matter intake as well as have other physiological implications.

Ruminal Turnover and Fractions of Ingesta. Ruminal turnover can be defined as the length of time that digesta remains in the rumen. Obviously, turnover time varies with the fraction of digesta considered, particle size, gravity of feed particles and level of feed intake (Church, 1979).

The ruminal contents can be visualized as solid and liquid phases. The liquid fraction contains water, soluble feed components, and nutrients solubilized by the microorganisms; whereas, the solid fraction contains undegraded and indigestible material (Evans, 1981). Bacteria in the rumen are associated with both the liquid and solid phases and with the epithelial wall of the rumen. The latter group contains most of the urease-producing bacteria (Cheng et al., 1979). Thus, it could be expected that the turnover rate of bacteria will be that of the fraction to which they are associated, influencing the rate and amount of microbial protein which moves to the small intestine.

Water intake and salivary secretions make the liquid volume entering the rumen much greater than the solid volume. This liquid may leave the rumen at a rate faster than that exhibited by the solid fraction.

Therefore, the rate of removal of soluble nutrients would be expected to be greater than the rate of removal of insoluble nutrients (Evans, 1981). This increased turnover rate appears to enhance bacterial protein production (Owens and Isaacson, 1977), yet decreases dry matter (DM) and acid detergent fiber (ADF) digestibilities (Hoover et al., 1982). However, the effect on total digestion depends on feed consumption and physical form (Bull et al., 1979).

Varga and Prigge (1982) investigated the influence of forage species and level of intake on ruminal turnover rates in sheep. Alfalfa (20.6% CP) and orchardgrass (13.5% CP) hays were compared at two intake levels. A two-fold increase in liquid turnover rate and a tendency for increased solids turnover rate occurred at the higher level of intake, averaged over forage species. Mudgal et al. (1982) also studied ruminal turnover rate in sheep fed two levels of alfalfa pellets (16% CP). The higher intake level increased fluid dilution rate by 54 percent and solid turnover rate by 25 percent.

The most complete digestion of fibrous forages would be achieved with the slowest turnover rate (Hungate, 1966), since the material would be exposed for a longer time to the degradative bacterial action. However, if fibrous materials stay in the rumen for a longer period of time, ruminal distension will probably affect voluntary consumption. (This will be discussed in greater detail at a later point in this review.) Therefore, determining the optimum turnover rate for different roughages and conditions is complex.

Ruminal Bacterial Growth

Physical-chemical characteristics of the rumen, including temperature, pH, oxidation-reduction potential, and osmotic pressure have been found to affect bacterial growth (Hespell, 1979). Ruminal bacteria, similar to other living organisms, have specific requirements for nutrients and environmental conditions to achieve their optimal growth rate. All nutrients required for cell growth must be present simultaneously and at an adequate concentration for uptake and utilization, since nutritional deficiencies along with decreased bacterial growth rates are the major sources of low cell yields (Hespell, 1979).

The fermentation products of dietary carbohydrates that accumulate in the rumen are acetate, propionate, butyrate, carbon dioxide (CO_2), and methane. Ratios of these products vary with diet and frequency of feeding and are caused by changes in microbial metabolism and species (Russell and Hespell, 1981). Bacteria as a whole have relatively low maintenance energy requirements even with high cell yields (Hespell, 1979).

Proteins degraded in the rumen yield NH_3, CO_2, and either short-straight, branched-chain or aromatic fatty acids (Russell and Hespell, 1981). However, the availability of plant protein is usually limited by the extent to which the fiber fraction is degradable, as pH values less than 6.2 depress cellulolytic activity. Thus, proteolysis may occur to a lesser extent, affecting ruminal NH_3 concentration and N uptake (Orskov, 1982). However, available ammonia (NH_3 and/or NH_4^+) appears to be incorporated rapidly into rumen bacteria in the form of amide groups and used for synthesis, first of glutamate, aspartate, alanine, and then other amino acids (Smith, 1979).

The rapid degradation of nonprotein nitrogen (NPN) sources results in rapid increases in ruminal NH_3 concentration. Absorption of NH_3 and reconversion to urea permits urea to be recylced in the blood, part of which can be returned to the rumen via saliva. Passage of urea from the blood through the rumen wall increases once the NH_3 concentration falls, suggesting potentially high efficiency of utilization of degradable N (Orskov, 1982).

The efficiency of the overall production is primarily dependent upon the rate and extent of degradation of carbohydrate and N sources and to a lesser degree, dietary sulfur (Stern and Hoover, 1979). A review by Stern and Hoover (1979) suggests that an average of 16.9 g of microbial protein are synthesized per 100 g of organic matter (OM) apparently digested in the rumen. Inadequate N consumption would result in a reduced protein supply to the animal with a corresponding decrease in overall performance.

Nutritional Value of Forages

Activity and growth of the ruminal microbial population appears to be greatly influenced by the quality of the forage consumed. The plant cell wall of forages is recognized as a complex entity of cellulose fibers found in a matrix of hemicellulose and pectin (Akin and Barton II, 1983). Ruminal degradation of these cellular components is variable; yet, lignin was believed to be virtually unaltered. However, in a review paper, Fahey and Jung (1983) reported large variations in lignin degradation. Consequently, the validity of using lignin as a marker should be carefully evaluated.

As plant maturity advances, forages deteriorate and become low in quality due to increased cellulose and lignin content and decreased protein (Umunna, 1982). Total energy content, water, minerals, and vitamins also decrease, altering irreversibly the nutritive value of forage. Then, as a result of the poor nutritional environment limiting microbial proliferation, a decline in voluntary intake and digestibility of forages by ruminants is observed (Umunna, 1982).

In addition, the occurrence of antiquality factors in plants may appreciably alter animal responses. Terpenoids, flavonoids, phenols, and alkaloids have been reported to be present in various plant species (Burns, 1978).

Voluntary Intake of Forages

Eating behavior of ruminants is governed by complex interactions between the proposed physiological mechanisms of regulation and factors associated with the nature of the feedstuffs, physiological and nutritional status of the animal, the environment and stress conditions, etc. Techniques have been developed to evaluate voluntary intake in grazing situations; however, intake is more precisely assessed under controlled conditions.

Influencing Factors

A definite association exists between voluntary intake level, particle size and rate of passage of digesta (Mertens, 1977). As forage intake increased, rate of passage also increased (Blaxter et al., 1955; Lambourne, 1957; Graham and Williams, 1962; Eng et al., 1964; Saenger et al., 1983). However, distension of the reticulo-rumen by bulk fill is generally recognized as the major factor limiting intakes when ruminants are fed roughages (Campling and Balch, 1961; Bines and Davey, 1970; Ellis, 1978; Saenger et al., 1983). Other factors functioning in intake regulation and rate of passage of digesta include animal species, body size, type of diet (Uden et al., 1982) and its physical form (Leng, 1982b; Uden et al., 1982), diet digestibility (Freer et al., 1962; Saenger et al., 1983) and feeding frequency (Coleman et al., 1984).

In a study by Grovum and Phillips (1978), the intake of chopped lucerne hay by sheep receiving abomasal infusions of bulk-laxative methyl cellulose was not limited by the capacity of the small and large intestines to transport the bulk. Intake was maintained (during infusion) even though wet fecal output was doubled and the intestines apparently became markedly distended. Thus, it appeared that intake would only be limited by ruminal distension.

Then, Grovum (1979) studied the effects of physical stimuli, applied in the rumen, abomasum and reticulum, as satiety signals. Physical distention of the rumen had no effect on intake; whereas, distension of either the abomasum or reticulum depressed intake. However, these effects were not additive. Tactile inputs to the reticulum also depressed intake with no effect when applied to the abomasum. So, the rumen appeared to be the least likely origin of satiety signals. However, Van Soest (1982) suggests that grazing and forage-fed ruminants do not reach the limits of satiety since rumen fill or time required for eating and ruminating limits voluntary consumption.

Metabolic Regulatory Mechansims

The gastrointestinal hormones, gastrin, secretin, and cholecystokinin may play a regulatory role in feed intake, but results of an experiment with sheep infused intravenously with these compounds were inconsistent (Grovum, 1981). In a review of metabolic regulatory factors, Van Soest (1982) confirmed cholecystokinin as a satiety regulating factor in sheep. In addition, bombesin and pancreatic polypeptide may also be satiety components (McLaughlin, 1982).

Nervous stimulation, hormonal factors, or humoral levels of metabolites have been suggested as signals which may stimulate the satiety control center in the hypothalmus for initiation and cessation of eating in various species. In ruminants, VFA limit intake, and heat increment after feeding has been considered as a potential intake regulator (Van Soest, 1982).

Low Quality Roughages

Utilization

A roughage is described as a bulky material with a high fiber content, usually of plant origin. Low quality roughages are of poor nutritive value due to increased lignification of cell walls, proportionately higher total fiber and very low protein and soluble carbohydrate contents. However, low quality roughages such as late vegetative stage grasses, cereal straws, cottonseed hulls, and other agricultural residues are commonly fed to cattle. Methods are needed to improve the utilization of and animal performance on such feeds (Arelovich, 1983).

Roughage utilization may be improved by chemical treatments. Anhydrous ammonia treatment of wheat straw improved dry matter (DM), organic matter (OM), crude protein (CP), and acid detergent fiber (ADF) digestibilities (Herrera-Saldana et al., 1983) and has been shown to improve DM, OM, and CP intake (Herrera-Saldana et al., 1982). Klopfenstein (1978) reviewed the use of sodium hydroxide, ammonium hydroxide, calcium hydroxide, and potassium hydroxide as chemical treatments. Though differences in response are noted, alkalinization may increase feed intake up to 37 percent, improve digestibility and double or triple feedlot gains with improved gain to feed ratios. However, feasibility depends on the roughage involved, level of treatment used and its mode of action. Cost effectiveness must be considered, as well.

Supplementation

A more extensively used approach to improve roughage utilization is supplementation of the low quality forages. Supplementation may be in the form of a NPN source such as biuret (Fick et al., 1973; Martin et al., 1981) or urea (Kropp et al., 1977; Kempton and Leng, 1979; Martin et al., 1981; Leng, 1982b; Umunna, 1982) or with plant protein origin concentrates (Campbell et al., 1969; Koes and Pfander, 1975; Church and Santos, 1981; Coleman and Wyatt, 1982; Hennessy et al., 1983).

Supplements containing a concentrated source of protein and/or energy are commonly fed to cattle grazing or being fed low quality roughages. Cereal grains or their by-products often represent the energy source; whereas, oil seed meals may contribute much of the protein and possibly energy in these kinds of supplements. Thus, starch and protein concentration can vary widely with the source and proportions of major feed materials used in feed manufacture.

Generally, N supplementation improves the utilization of low quality feedstuffs by increasing their total DM digestibility and intake. The addition of large amounts of readily available carbohydrates may, however, depress fiber digestion and intake. Thus, a nitrogen-energy interaction may exist when supplementing low quality feeds. Meeting the N needs of the ruminal bacteria is essential in order to achieve a higher rate of fermentation. The carbohydrate fraction of a feed appears to be more fermentable when there is adequate available N to meet bacterial growth potential (Orskov and Grubb, 1978).

Cellulose and OM digestibilities were enhanced by the addition of urea or biuret to low quality hay (3.6% CP) fed to sheep by Martin et al. (1981). Improved intakes also were observed in sheep fed native hay (4.6% CP) and supplemented with urea (Umunna, 1982). In addition, biuret fed to sheep increased intake of pangola grass hay (3.3 and 4.5% CP) and apparent digestibility of N, cellulose and OM (Fick et al., 1973).

Though a similar response may be obtained with protein concentrates of plant origin such as soybean meal (SBM) and cottonseed meal (CSM), protein meals are generally less degradable in rate and extent than urea or biuret. Church and Santos (1981) reported improved voluntary intake of wheat straw and digestibility of CP and ADF in heifers fed 128 g or more SBM per day. Hadjipanayiotou et al. (1975) observed increased intake of straw by lambs fed SBM supplement. Similar results have been observed with CSM supplementation of range hays (Gallup and Briggs, 1948; Coleman and Wyatt, 1982; Hennessy et al., 1983).

The effects of supplementation become more complex when a supplemental energy source from concentrates is added to the supplemental N source. Even with the studies conducted to date, it is still very difficult to predict with much accuracy the optimal levels of supplemental protein and possibly energy which should be fed with roughages of varying qualities in any given production situation.

An early study shows that when low protein diets (14 g CP/day) were fed to sheep, increments in starch consumption (0, 99, or 149 g/day) representing 0, 27, and 36 percent of the diet, respectively, led to a reduction in the number and type of microorganisms in the rumen. But, as the protein level increased (from 14 to 60 and 83 g CP/day), such an effect was not evident. For either the medium or high starch contents in the diet, the addition of protein has been shown to significantly increase digestibility of DM and protein, and increase rumen counts (Williams et al., 1953).

Kane et al. (1959) found that additions of cornstarch to alfalfa hay diets depressed nitrogen free extract (NFE), protein and DM digestibility in cattle; however, this effect was removed when an extended adaptation period was allowed. Koes and Pfander (1975) reported that feeding 250 g/day of cracked corn to sheep consuming orchardgrass hay (12.7% CP) increased intake of DM,digestible energy (DE) and digestible protein and improved DM, OM, and protein digestibility with no effect on crude fiber (CF) digestibility.

However, in sheep fed pangolagrass hay (3.3 and 4.5% CP) with an energy supplement (25% starch) at varying levels, no change in intake was observed and cellulose digestibility was depressed (Fick et al., 1973). Conversely, when an energy supplement (25% cornstarch) or a low level (80 g) of molasses was fed to sheep consuming hay (3.6 to 3.9% CP), OM digestibility and N retention increased; and with supplemental N, additional improvement in OM and cellulose digestibility occurred. However, the high molasses level (160 g) depressed voluntary intake of hay (Martin et al., 1981).

In summary, utilization of low quality roughages appears to be affected by the levels of supplemental energy and protein. The inhibition of cellulose digestion by dietary starch is generally attributed to a competition between celluloytic and amylolytic groups of bacteria for nutrients, especially N. Also, adequate N in the diet may alleviate the inhibitory effects and improve the utilization of such roughages.

CHAPTER III

THE EFFECT OF PROTEIN OR GRAIN SUPPLEMENTATION ON INTAKE, UTILIZATION, AND RATE OF PASSAGE OF MEDIUM QUALITY PRAIRIE HAY

Summary

Sixteen Hereford steers (479 kg) were used in four replications of a 4 x 4 Latin square to determine the effect of different protein and grain supplementation programs on intake and digestibility of medium quality prairie hay (4.2% crude protein [CP], dry matter [DM] basis). Prairie hay was fed *ad libitum*. The four treatments (DM basis) were: 1) control (C), minerals-vitamin mix; 2) low level of supplemental protein (LL), .36 kg of 32 percent CP; 3) high level of supplemental protein (HL), .67 kg of 34 percent CP; 4) Corn-grain based supplement with low protein (GR), 1.41 kg of 13 percent CP supplement/day. The HL provided twice the supplemental protein of the LL; and at an equal total dry matter intake, the LL and GR treatments would provide equal total dietary protein.

Supplementation increased ($P < .01$) daily prairie hay intake, total DM, total organic matter (OM), apparent CP, acid detergent fiber (ADF), cellulose and lignin digestibilities and ruminal ammonia (NH_3) compared with C. The HL increased ($P < .01$) hay intake, total DM, total OM, apparent CP and cellulose digestibilities and ruminal NH_3 and enhanced ($P < .05$) ADF digestibility compared with the LL. Roughage intake, ruminal NH_3 values and digestibility coefficients of total DM, total OM,

apparent CP, ADF, and lignin were similar ($P > .05$) between the LL and GR diets. However, the GR treatment depressed ($P < .01$) cellulose digestibility compared with the LL diet. Ruminal pH did not differ ($P > .10$) among the diets.

In a second experiment, soybean meal (48% CP, DM basis) was fed at 0, 121, 241, 362, and 603 g DM/day to fifteen English crossbred heifers (219 kg) utilized in three simultaneous 5 x 5 Latin squares. A mineral-vitamin supplement was provided daily with ad libitum prairie hay (5.2% CP, DM basis).

A quadratic increase ($P < .01$) in prairie hay intake, apparent CP digestibility and ruminal NH_3 values and ($P < .05$) in total OM digestibility occurred with increasing level of soybean mean (SBM) supplement. A linear improvement ($P < .01$) in total DM, ADF, and cellulose digestibilities was noted across levels of supplementation. Though ruminal fluid pH values were very similar, a slightlinear decline ($P < .01$) in pH was observed as level of SBM increased. In addition, as supplementation increased, a linear increase ($P < .01$) occurred in particulate rate of passage.

Introduction

A positive effect of nitrogen supplementation on low quality forage utilization has been widely recognized. Low quality roughages commonly fed include winter range pasture, marginal quality grass hays or cereal straws. Usually nitrogen (N) supplementation has been shown to increase voluntary intake and improve digestibility of the fiber fraction (Campbell et al., 1969; Fick et al., 1973; Hadjipanayiotou et al., 1975; Koes and Pfander, 1975; Church and Santos, 1981; Martin et al., 1981; Coleman and Wyatt, 1982; Umunna, 1982; Hennessy et al., 1983).

Protein supplementation is common during the winter months. The supplements generally contain from 20 percent (or lower) to 40 percent (or higher) all natural crude protein and are often fed to beef cattle (stockers, replacement heifers, and cows, dry or lactating) grazing or being fed low quality roughages such as range pasture.

While protein supplementation has been shown to be beneficial in improving forage intake and utilization of low quality roughages, there have been limited reports concerning the effects of different types of supplementation programs (e.g., different levels of high protein vs. low protein-grain supplementation). In addition, few research results are available on the effects of low or incremental levels of high protein supplementation on forage intake, utilization, and the rate of passage of low quality roughages.

An inherent consideration in grain supplementation programs is the effect which starch content may have on forage intake and utilization. Starch may alter the activity of the ruminal microbial population; however, limited data on quantity or level of starch required to depress fiber intake and utilization is available. Moreover, the effect of increasing protein on alleviating any negative effects is not well documented. A few limited trials have shown that N supplementaion or increasing protein level may alleviate some of the inhibitory effects of starch on high energy levels in the diet (el-Shazly et al., 1961; Campbell et al., 1969; Fick et al., 1973).

The objectives of this study were: 1) to investigate the effects of two levels of high protein and a grain supplement on forage intake, utilization and ruminal measures in steers consuming medium quality prairie hay, and 2) to assess the effect of graded levels of high protein supplementation on ruminal measures and the intake, digestibility, and rate of passage of medium quality prairie hay.

Materials and Methods

Experiment 1

Sixteen mature Hereford steers (479 kg) were randomly allocated to slatted-floor pens, blocked into four groups by weight, and utilized in four simultaneous replications of a 4 x 4 Latin square design.

All animals daily received the same basal diet of medium quality prairie hay (harvested in July) fed _ad libitum_. The supplemental treatments were: 1) control (C), vitamin A and minerals; 2) low level of supplemental protein (LL) using a SBM based supplement (32% CP); 3) high level of supplemental protein (HL) using a SBM based supplement (34% CP); and 4) corn grain (GR) based supplement containing low level (13% CP) of protein.

The mineral-vitamin mix was fed to control animals at the level of 97 g DM/day. The LL, HL, and GR treatments were fed at .36, .67, and 1.41 kg DM/day. The diets were formulated so that the HL would provide twice the supplemental protein of the LL; and at an equal total dry matter intake, the LL and GR treatments would provide equal total dietary protein. The four supplements were fed once daily. Chromic oxide, an indigestible marker, was administered in labeled cottonseed hulls (CSH) fed at 177 g DM twice daily. The composition of this carrier (as fed basis) was 93.8 percent CSH, 2.5 percent molasses, and 3.8 percent Cr_2O_3.

The ingredient composition of the supplements is shown in Table I and the nutrient composition of the hay and supplements in Table II. All supplements were prepared at the beginning of the experiment.

The length of each period in the Latin squares was ten days, with

TABLE I

INGREDIENT COMPOSITION OF THE SUPPLEMENTS USED IN EXPERIMENT 1 (DM BASIS)

Ingredient	Supplements[a]			
	C	LL	HL	GR
Soybean meal, %	___	77.7	89.1	14.6
Corn, %	___	___	___	79.7
$CaCO_3$, %	___	1.45	2.06	0.57
Dicalcium phosphate, %	42.3	9.48	3.01	1.67
KCl, %	17.9	0.97	___	0.71
TM salt, %	28.1	7.33	4.12	1.91
Na_2SO_4, %	11.2	2.93	1.64	0.76
Vitamin A, %	0.57	0.15	0.08	0.04

[a]C = Control; LL = .36 kg DM/day of 32 percent CP; HL = .67 kg DM/day of 34 percent CP; GR = 1.41 kg DM/day of 13 percent CP.

TABLE II

NUTRIENT COMPOSITION OF PRAIRIE HAY AND SUPPLEMENTS USED IN EXPERIMENT 1 (DM BASIS)

Item, %	Prairie Hay	LL[a]	HL[b]	GR[c]	Labeled CSH[d]
Dry matter	90.8	92.2	90.8	88.8	88.4
Organic matter	92.8	73.4	84.6	91.4	95.2
Crude protein	4.2	31.6	34.4	13.4	3.5
Acid detergent fiber	48.5	6.9	7.6	4.4	63.1
Lignin	8.0	1.0	1.2	0.9	12.3
Cellulose	35.7	5.7	6.2	3.4	49.0
Ash	7.3	26.6	15.4	8.6	4.8

[a].36 kg DM/day of supplement (soybean meal based).

[b].67 kg DM/day of supplement (soybean meal based).

[c]1.41 kg DM/day of supplement (corn based).

[d]CSH = Cottonseed hulls.

diet adaptation being days one through five. Prairie hay and supplements were sampled on days four through seven. Rejected prairie hay was sampled on days five through eight, and fecal samples were collected twice daily (a.m. and p.m.) on days six through nine. All samples were placed in individual plastic bags and refrigerated until processing.

Rumen fluid was sampled via stomach tube the last day of each period four to seven hours after the supplement was fed. Approximately 250 ml of ruminal fluid were collected per animal. The pH of the ruminal fluid was measured, and 1 ml of 20 percent H_2SO_4 was added per 50 ml of fluid. The ruminal fluid was then frozen for later NH_3-N analysis. Body weight (full, not shrunk) was recorded the same day.

Hay intakes were recorded daily, and a sample of the daily refusals for each animal was collected during the four-day sampling phase. At the end of each period, samples were composited by animal and then subsampled. At the same time, fecal samples were composited similarly on an approximate equal wet basis. Fecal subsamples were weighed and then dried at 60°C for 96 hours to ensure complete moisture evaporation. Samples were allowed to stabilize with air humidity for 24 hours and were weighed again to calculate air-dry matter concentration. All samples (feeds, refusals, and feces) were ground in a Wiley mill fitted with a 2 mm screen and stored for future analysis.

All samples were analyzed for crude protein ($N \times 6.25$) by the macro-kjeldahl method, DM and ash (A.O.A.C., 1975), and ADF, cellulose, and permanganate lignin (Goering and Van Soest, 1970). The CSH and fecal samples were analyzed for chromium (Fenton and Fenton, 1979). Ammonia-N was measured with 40 ml of rumen fluid distilled over magnesium oxide in a macro-kjeldahl flask (A.O.A.C., 1975).

Preplanned comparisons of the treatment means were conducted using the "logical" contrasts despite lack of orthogonality (Table III).

Experiment 2

Fifteen Angus-Hereford heifers (219 kg) were blocked into three groups based upon hay intake determined during a preliminary period. Three simultaneous 5 x 5 Latin squares were used. Prairie hay (harvested in July) was provided ad libitum. The soybean meal (treatment) levels (fed once daily) were 0, 121, 241, 362, and 603 g DM/day, plus 78 g of mineral mix DM/head/day. The mineral-mix composition was that of the C treatment in Experiment 1 (Table 1). Chromic oxide, an indigestible marker, was administered in labeled CSH fed at 177 g DM twice daily. Composition (as fed basis) of this carrier was 90 percent CSH, 5 percent molasses, and 5 percent Cr_2O_3. Nutrient composition of the hay and supplements is shown in Table IV.

In each of the five twelve-day periods, the first seven days were for adaptation to the diet. On days eight through eleven, approximately 250 g of wet feces were collected twice daily (a.m. and p.m.). All feeds were sampled two days prior to each fecal sampling day. Rejected prairie hay was weighed daily and samples were obtained one day prior to each fecal sampling day. On the last day of each period, approximately 250 ml of ruminal fluid were collected per animal, and body weight (full, not shrunk) was recorded. All samples were composited or processed and chemically analyzed as described in Experiment 1.

The statistical analysis included square, period, and animal within period as discrete effects and levels of SBM as continuous variables. Linear, quadratic, and cubic terms were used to determine the response curve.

TABLE III

CONTRASTS AMONG TREATMENT MEANS IN EXPERIMENT 1

Contrasts	Treatments[a] C	LL	HL	GR
Control vs. All	3	-1	-1	-1
LL vs. HL	0	1	-1	0
LL vs. GR	0	1	0	-1

[a]C = Control; LL = .36 kg DM/day of 32 percent CP; HL = .67 kg DM/day of 34 percent CP; GR = 1.41 kg DM/day of 13 percent CP.

TABLE IV

NUTRIENT COMPOSITION OF PRAIRIE HAY AND SUPPLEMENTS USED IN EXPERIMENT 2 (DM BASIS)

Item, %	Prairie Hay	SBM	Labeled CSH
Dry matter	91.7	88.6	89.7
Organic matter	93.3	92.4	92.2
Crude protein	5.2	47.5	5.3
Acid detergent fiber	47.9	8.5	59.1
Lignin	9.1	1.4	13.3
Cellulose	34.7	6.9	42.3
Ash	6.74	7.61	7.81

In addition, approximately 200 g (as fed basis) of ytterbium (Yb) labeled prairie hay was fed at the beginning of each fecal collection period to each heifer as a single pulse dose for the purpose of determining particulate rate of passage of hay. Each heifer received approximately 2 g of Yb. The prairie hay was labeled using ytterbium chloride ($YbCl_3$) in the immersion technique as described by Mader et al. (1984) and Teeter et al. (1984). After labeling, the prairie hay was then dried to its approximate original DM.

Fecal samples were collected at zero hours (blanks) and 34, 46, 70, and 94 hours post dosage. Samples were dried at 90^{o}C for 96 hours, ground in a Wiley mill fitted with a 2 mm screen, and stored for future analysis. Dry matter and ash of each sample were determined (A.O.A.C., 1975). Ash residues from fecal samples were prepared for Yb analysis by digesting with a 1:1 v/v mixture of 3 N nitric and 3 N hydrochloric acid for 12 or more hours. Then after appropriate dilutions, the Yb content of each sample was determined by atomic absorption spectroscopy using a nitrous-oxide acetylene flame.

Rate of passage values were determined from calculated slopes (Ln marker concentration vs. time). Standards containing 0, 5, and 10 ppm Yb were used to determine the standard curve. Then, natural log of Yb concentration (Y) was regressed on time (x). An example calculation is described in Table V. Since Yb concentrations were similar at 34 and 46 hours (Figure 1), it appeared that the 34 hour values were on the upslope of the fecal excretion curve; whereas, the 46 hour values would be on the opposite downslope (Figure 2). Thus, the 34 hour values were deleted from the statistical analysis, since the actual slope of the descending portion of the excretion curve equals passage rate (%/hour). Accordingly,

TABLE V

EXAMPLE CALCULATION OF PARTICULATE RATE OF PASSAGE

Time (x)	Yb Conc., ppm	ln Yb Conc. (Y)
46	39.14	3.67
70	19.67	2.98
96	8.95	2.19

[a]Regress natural log of Yb concentration (Y) on time (x).

[b]In this experiment, all values collected before 40 hours were deleted to establish the "downslope" of the curve (Figure 2).

[c]Slope is passage rate (%/hour).

[d]Sign is ignored; thus, passage rate is 3.08%/hour.

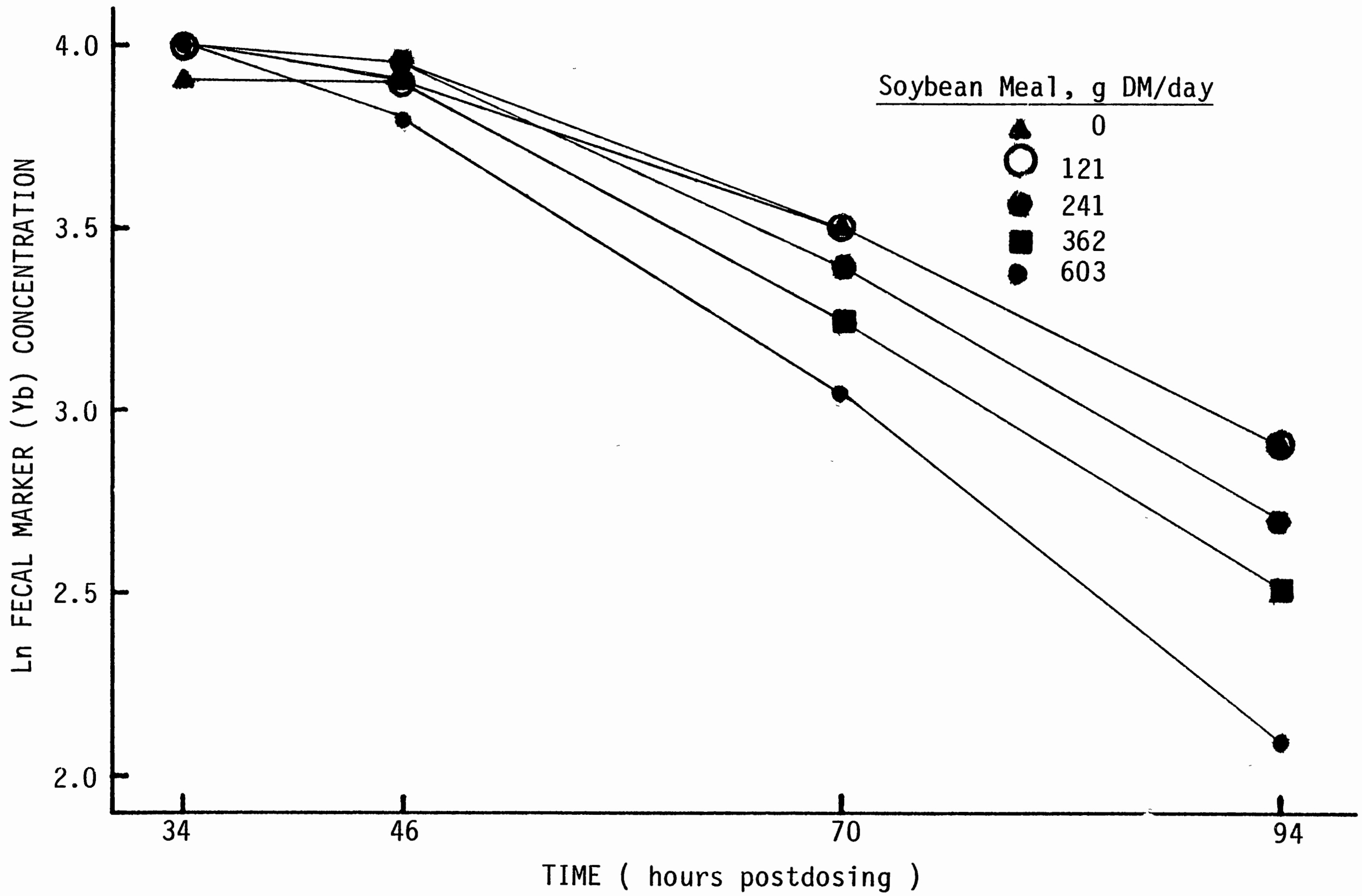

Figure 1. Ln of Yb Concentration Over Time (Postdosing) by Supplemental Treatments (Exp. 2)

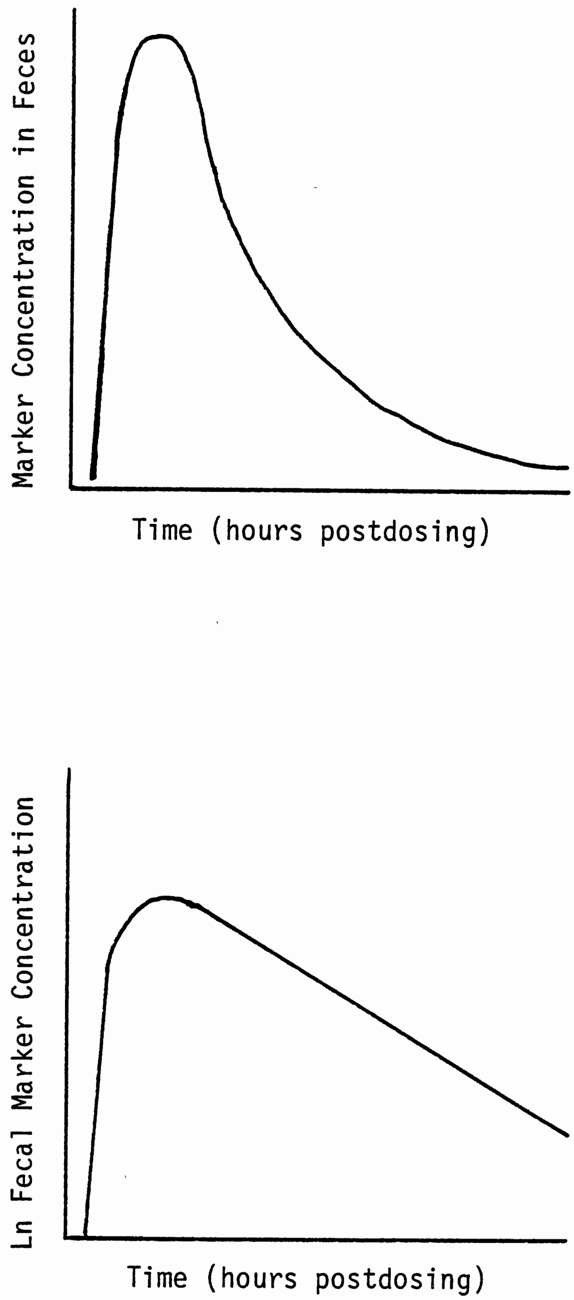

Figure 2. Examples of Theoretical Excretion Curves of a Pulse Dosed Marker

the use of complex models (e.g., Ellis et al., 1979) was unnecessary in this case since intake was determined directly and chromic oxide was used as the digestion marker.

Results and Discussion

Experiment 1

Supplementation improved all intake measurements considered in this experiment (Table VI). Daily intake of prairie hay, total DM and CP was higher ($P < .01$) on all three supplemental treatments compared to the C and higher ($P < .01$) on the HL treatment compared with the LL. An increase ($P < .01$) in total DM and CP intakes also was observed in the GR treatment compared to the LL diet, though hay intake was similar ($P > .10$) at 5.62 and 5.93 kg/day, respectively. The possible substitution effect occurring in the GR diet is of a much smaller magnitude than originally anticipated.

There was a substantial boost in digestible DM intake with all supplemental treatments compared to the control. Average total DM intakes of 6.65, 7.91, and 7.37 kg/day for the LL, HL, and GR supplemented steers was comparable to or in excess of the 6.4 to 7.0 kg/day suggested minimum DM requirement for maintenance as reported by NRC (1976) for beef cattle.

As supplement is increased, digestibility of the ration should improve because supplement is more digestible than hay, and the percentage of hay in the diet is being diluted. Comparison of observed vs. expected ration DM digestibilities on the various treatments (Figure 3) illustrates a very positive synergistic effect for enhancing ration digestibility (observed > expected) for the two protein supplement treatments. Importantly, the comparison further illustrates the absence of any negative effects

TABLE VI

MEASURES OF DAILY INTAKE (EXPERIMENT 1)

Daily Intake	Supplements[a]				
	C	LL	HL	GR	SE
Prairie hay DM, kg[bc]	4.11	5.93	6.91	5.62	0.16
Total DM, kg[bcd]	4.56	6.65	7.91	7.37	0.16
Digestible DM, kg	2.26	3.61	4.62	4.13	____
Total DM as % of BW[e]	0.98	1.39	1.63	1.53	____
Protein DM, g/day[bcd]	176.00	365.00	516.00	426.00	6.66
CP as a % of total DM intake	3.86	5.49	6.52	5.78	____

[a]C = Control; LL = .36 kg DM/day of 32 percent CP; HL = .67 kg DM/day of 34 percent CP; GR = 1.41 kg DM/day of 13 percent CP.

[b]C vs. All, P < .01.

[c]LL vs. HL, P < .01.

[d]LL vs. GR, P < .01.

[e]Based on full, not shrunk, body weight (BW) average of 464 to 486 kg/treatment.

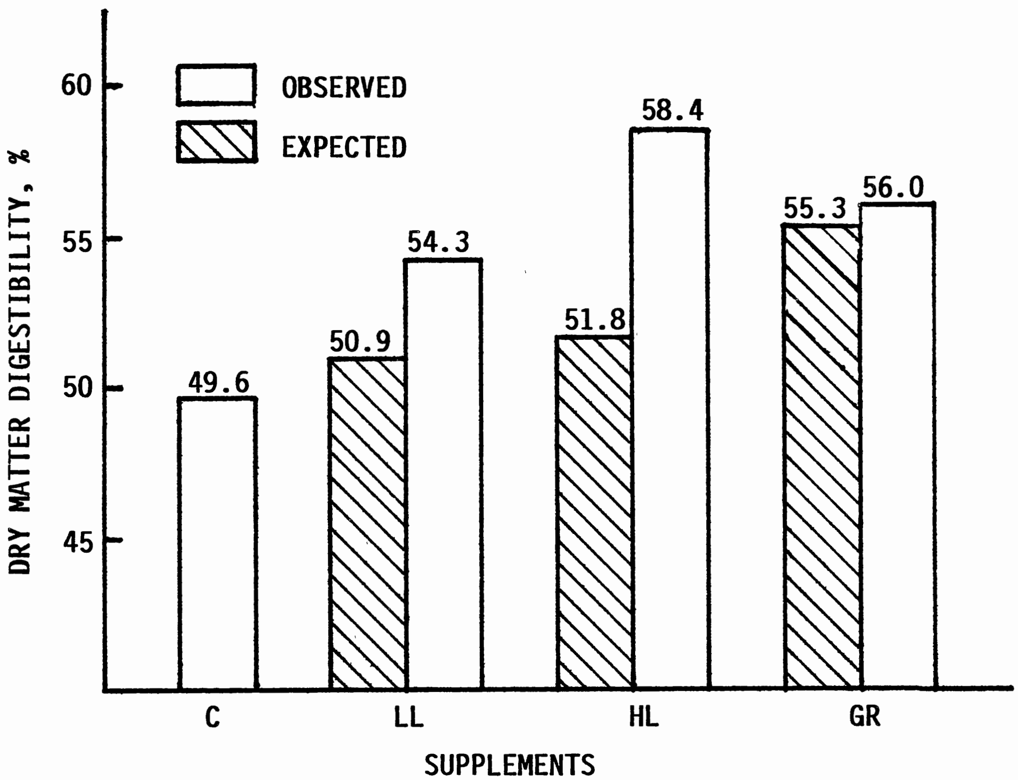

Figure 3. Comparison of Observed Versus Expected Diet Dry Matter (DM) Digestibilities (Exp. 1). Expected digestibilities are based upon values obtained for the hay on the control treatment and 80% DM digestibility for the supplement

of the level of grain supplement fed in this study on DM digestibility of the forage used.

Digestibility (Table VII) of the total diet DM (49.6%) and total OM (51.8%) was lower ($P < .01$) and the apparent CP digestibility (16.4%) much lower ($P < .01$) on the C diet compared with the three supplemental protein treatments. The digestibility of the total diet DM, OM, apparent CP, and cellulose was improved ($P < .01$) and acid detergent fiber (ADF) digestibility was higher ($P < .05$) on the HL compared with the LL. Additionally, total DM, OM, and apparent CP digestibilities were similar ($P > .10$) between the LL and GR diets, as were the ADF digestibilities (53.2 and 51.2%, respectively). The GR treatment depressed ($P < .01$) cellulose digestibility (60.4%) compared with the LL diet (64.0%).

Lignin digestibility was enhanced ($P < .01$) by supplementation compared with the C diet (14.9%). A tendency for improved ($P < .10$) lignin digestibility in both the HL (26.4%) and the GR (26.3) diets when compared with the LL treatment (21.1%) was noted. It appears that digestibility of the lignin component of these diets was enhanced by the supplemental treatments. However, this apparent effect may be an artifact of the analytical methods used for lignin determinations; since, the choice of analytical method and the resultant extent of recovery may drastically alter data interpretation (Fahey and Jung, 1983).

The ruminal NH_3 concentration (Table VIII) was very low ($P < .01$) on the C diet (.71 mg/dl) compared with the three supplemental treatments and was lower ($P < .01$) on the LL (1.07 mg/dl) than the HL (2.01 mg/dl). These ruminal NH_3 values generally would be considered deficient compared with current literature estimates. Ruminal fluid pH values were almost identical across treatments (Table VIII).

TABLE VII

DIGESTIBILITY COEFFICIENTS IN EXPERIMENT 1
(DM BASIS)

Digestibility, %	Supplements[a]				
	C	LL	HL	GR	SE
Total DM[bc]	49.6	54.3	58.4	56.0	1.02
Total OM[bc]	51.8	56.3	60.5	58.0	0.98
Crude protein[bc]	16.4	43.7	53.4	43.6	2.09
Acid detergent fiber[be]	49.7	53.2	57.1	51.2	1.08
Cellulose[bcd]	60.9	64.0	67.7	60.4	0.93
Lignin[bfg]	14.9	21.1	26.4	26.3	1.94

[a]C = Control; LL = .36 kg DM/day of 32 percent CP; HL = .67 kg DM/day of 34 percent CP; GR = 1.41 kg DM/day of 13 percent CP.

[b]C vs. All, $P < .01$.

[c]LL vs. HL, $P < .01$.

[d]LL vs. GR, $P < .01$.

[e]LL vs. HL, $P < .05$.

[f]LL vs. HL, $P < .10$.

[g]LL vs. GR, $P < .10$.

TABLE VIII

RUMINAL MEASURES AT FOUR TO SEVEN HOURS AFTER FEEDING OF SUPPLEMENTS (EXPERIMENT 1)

Item	Supplements[a]				
	C	LL	HL	GR	SE
Ruminal NH_3, mg/dl[bc]	.71	1.07	2.01	0.85	0.16
Ruminal fluid pH	7.14	7.16	7.24	7.15	0.03

[a]C = Control; LL = .36 kg DM/day of 32 percent CP; HL = .67 kg DM/day of 34 percent CP; GR = 1.41 kg DM/day of 13 percent CP.

[b]C vs. All, $P < .01$.

[c]LL vs. HL, $P < .01$.

Any of the three supplementation programs substantially increased the digestible DM intakes to 3.61, 4.62, and 4.13 kg/day (LL, HL, and GR, respectively) compared with C, 2.26 kg/day. In a study by Crabtree and Williams (1971), lambs fed cereal straw (3.9% CP) plus a concentrate supplement (19.1% CP) increased straw intake approximately 50 percent. Digestible energy intake also increased when the concentrate was fed at up to 25 percent of total diet; at higher levels of concentrate, the consumption of straw began to decline. In the present study, supplementation represented 6, 8, and 19 percent of total DM intake on the LL, HL, and GR treatments, respectively. These percentages are well below the 25 percent cited by Crabtree and Williams (1971); and in agreement with their observations, forage intake was enhanced in this study.

An increase in roughage consumption by the supplemented animals may be attributed to the additional protein furnished. There was a 44, 68, and 37 percent boost in forage consumption on the LL, HL, and GR treatments, respectively, over the C. Lyons et al. (1970) reported a 25 percent increase in voluntary consumption of barley straw (2.8% CP) for cattle fed supplements containing 13.6, 19.1, or 29.2 percent CP over a control (8.9% CP) supplement. Moreover, Hennessy et al. (1983) reported a boost in consumption of low quality (3.9% CP) grass hay ranging from 30 to 44 percent for cattle fed a protein supplement (41% CP) at 600 and 1200 g/day, respectively.

The observed increases in feed intake with N supplementation may be due to an increased rate of ruminal digestion of cellulose (Johnson et al., 1981). In this experiment, supplementation (average of LL, HL, and GR) enhanced the digestion of ADF and cellulose; whereas, the GR diet depressed cellulose digestion (60.4%), compared with the LL (64.0%). The low ruminal NH_3 values (.85 mg/dl) on the GR treatment indicate a poor N status in the rumen; therefore, decreased microbial activity may account for the reduced digestibility. Fick et al. (1973) also reported depressed cellulose digestion at higher levels of energy supplementation (4.6% CP) in sheep fed low quality (3.3 and 4.5% CP) pangolagrass hay and supplemented with low levels of N from feed grade biuret. This depression was attributed to the presence of readily available carbohydrates in the supplements provided (Fick et al., 1973). Possibly, a shift in the microbial population from cellulolytic strains occurred. Similarly, Campbell et al. (1969) observed a linear decline in the digestibility of crude fiber (CF) with the increasing level (0,50,and 100 g/day) of corn supplement (10.5% CP) in sheep consuming kikuyu grass (5.1% CP). The sheep were in negative N balance throughout the trial (Campbell et al., 1969). However, Koes and Pfander (1975) found similar fiber digestibility coefficients in sheep fed orchard grass hay (12.7% CP) and supplemented with 0 or 250 g of corn/day. This may be due to the additional N provided in the higher CP hay.

The starch present in the GR supplement may have resulted in the depressed cellulose digestion. It appears that the effect of starch on voluntary intake and fiber digestibility would depend on the level of fiber and starch in the diet as well as N availability to ruminal bacteria. Willims et al. (1953) observed that for low protein diets (14 g CP/day), increases in starch intake, representing 27 and 36 percent of the diet, reduced ruminal counts and types of microorganisms present. However, when protein intake was increased to 60 and 83 g CP/day, no such effect was evident. el-Shazly et al. (1961) suggested that the inhibition of cellulose digestion by starch is due to a competition between cellulolytic and amylolytic bacteria for nutrients, with N being the major nutrient involved. Thus, if N is readily available, the inhibitory starch effect can be decreased or removed depending on the starch concentraction in the diet.

The higher ruminal NH_3 concentration on the LL, HL, and GR diets compared with the C treatment illustrates the positive effect of protein supplementation, though all values in this study were considered to be low (Table VIII). Results of an in vivo study by Slyter et al. (1979) support the previous view of Satter and Slyter (1974) that values ranging from 2 to 5 mg of NH_3-N/dl are sufficient to allow maximal growth of ruminal microbes. This suggests that N was probably limiting on all treatments.

Experiment 2

As level of SBM supplementation increased, a corresponding boost occurred in intake (Table IX) and digestibility coefficients (Table X). A positive quadratic response ($P < .01$) in prairie hay and total DM intake and ($P < .05$) total CP intake was observed as level of supplementation increased. (All quadratic responses reported herein increase at a decreasing rate.) A substantial rise in digestible DM intake also occurred across the treatment levels. Average total DM intake ranged from 5.2 to 7.9 kg/day as SBM supplement increased from 0 to 603 g DM/day and was well in excess of the suggested minimum DM requirement for maintenance of 4.4 kg/day (NRC, 1976). Diet quality should be considered in determining the adequacy of these intake levels. Accordingly, total protein intake approached or exceeded the suggested daily maintenance protein requirement of 350 g (NRC, 1976) at all treatment levels (ranging from 334 to 653 g CP/day) except the control hay diet (258 g CP/day).

TABLE IX

MEASURES OF DAILY INTAKE (EXPERIMENT 2)

Daily Intake	Soybean Meal, g DM/Day					
	0	121	241	362	603	SE
Prairie hay DM, kg[a]	4.71	5.07	5.93	6.15	6.81	0.08
Total DM, kg[a]	5.15	5.63	6.61	6.95	7.85	0.08
Digestible DM, kg	1.99	2.33	3.10	3.29	3.92	____
Total DM as a % of BW[c]	2.05	2.25	2.62	2.75	3.09	____
Protein DM, g/day[b]	258.00	334.00	436.00	504.00	653.00	5.05
CP as a % of Total DM intake	5.01	5.94	6.61	7.26	8.33	____

[a]Significant linear ($P < .01$) and quadratic ($P < .01$) terms.

[b]Significant linear ($P < .01$) and quadratic ($P < .05$) terms.

[c]Based on full, not shrunk, body weight (BW) average of 250 to 254 kg/treatment.

TABLE X

DIGESTIBILITY COEFFICIENTS IN EXPERIMENT 2
(DM BASIS)

Digestibility, %	Soybean Meal, g DM/Day					
	0	121	241	362	603	SE
Total DM[a]	38.7	41.4	46.9	47.3	50.0	1.29
Total OM[b]	41.1	43.8	49.4	50.0	52.8	1.27
Crude protein[c]	17.5	29.5	38.5	41.7	48.3	1.37
Acid detergent fiber[a]	33.5	35.7	40.9	40.8	43.9	1.56
Cellulose[a]	45.6	47.3	53.5	54.5	58.2	1.53
Lignin	5.2	8.8	13.0	8.8	10.2	2.02

[a]Significant linear ($P < .01$) term.

[b]Significant linear ($P < .01$) and quadratic ($P < .05$) terms.

[c]Significant linear ($P < .01$) and quadratic ($P < .01$) terms.

Digestibility of total diet OM increased ($P < .05$) quadratically as did apparent CP digestibility ($P < .01$) as level of SBM supplementation increased. A linear improvement ($P < .01$) in total DM digestibility was observed across the treatment levels. The quadratic term for diet DM digestion approached significance ($P < .10$). Observed values were higher than expected for ration DM digestibility at all SBM supplement (treatment) levels (Figure 4), indicating the positive synergistic effect of increasing protein level on the digestibility of prairie hay. The magnitude of response above expected or calculated values was similar for the three highest SBM levels.

A linear improvement ($P < .01$) occurred in ADF and cellulose digestibilities across the treatment levels. Lignin disappearance values were variable, yet low as expected. In a review paper, Fahey and Jung (1983) reported large variations in lignin digestibility across trials. Thus, it appears that some changes in lignin may occur as it passes through the digestive tract in ruminants. However, apparent changes may be due to the analytical method selected rather than actual degradation in the rumen.

A quadratic improvement in ruminal NH_3 concentration (Table XI) occurred as level of SBM supplement increased; however, all values were very low except at the highest level of supplementation. Ruminal fluid pH exhibited a linear decline ($P < .01$) as supplement level increased, though all values were similar (Table XI). In addition, rate of passage of the particulate phase expressed as percent/hour (Table XI) increased linearly ($P < .01$) across the treatment levels.

A substantial boost in roughage consumption by the supplemented animals occurred. There was a 9 to 45 percent increase in forage

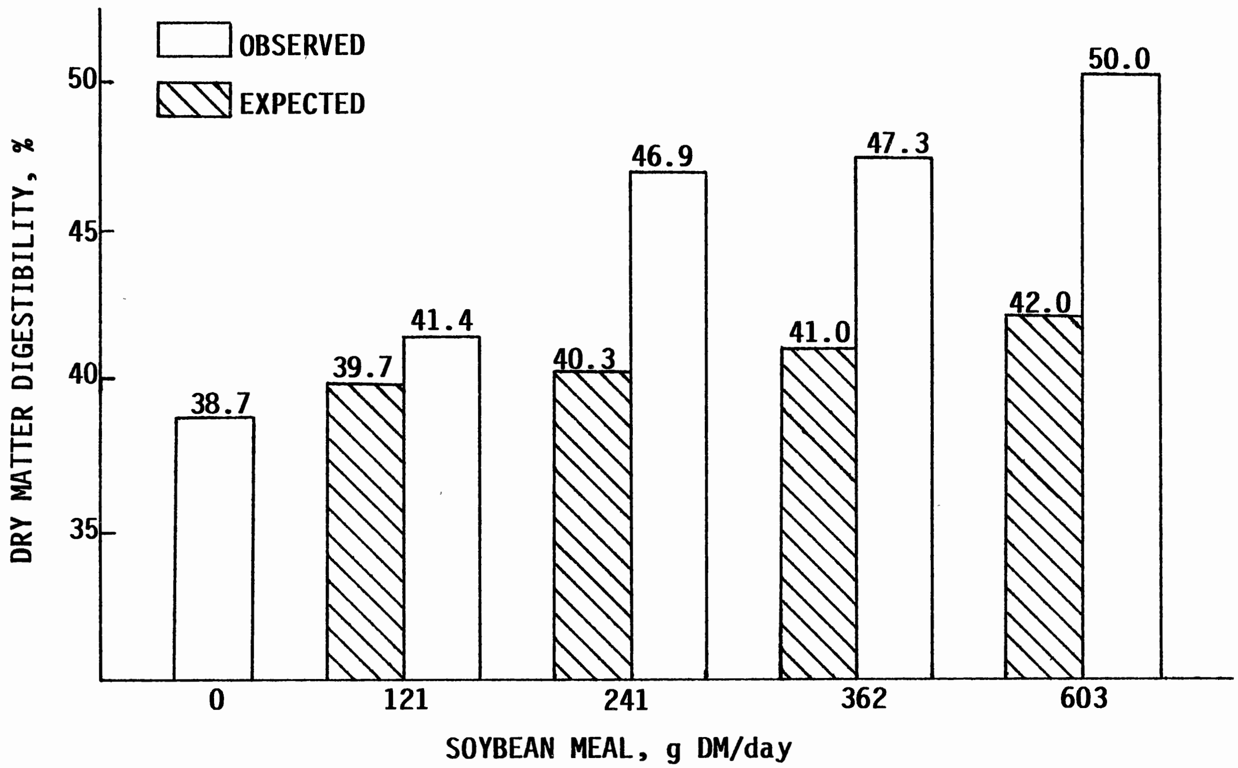

Figure 4. Comparison of Observed Versus Expected Diet Dry Matter (DM) Digestibilities (Exp. 2). Expected digestibilities are based upon values obtained for hay on the control treatment and 80% DM digestibility for the SBM supplement

TABLE XI

RUMINAL AMMONIA, pH, AND PARTICULATE RATE OF PASSAGE VALUES (EXPERIMENT 2)

Item	Soybean Meal, g DM/Day					
	0	121	241	362	603	SE
Ruminal NH_3, gm/dl[ab]	0.46	0.52	0.69	1.02	2.46	0.19
Ruminal fluid pH[ac]	6.96	6.97	6.83	6.90	6.81	0.03
Particulate passage rate, %/hour[c]	2.08	2.17	2.63	2.86	3.47	0.09

[a]Four to seven hours after feeding of supplements.

[b]Significant linear ($P < .01$) and quadratic ($P < .01$) terms.

[c]Significant linear ($P < .01$) term.

consumption over the control as level of SBM supplement ranged from 121 to 603 g DM/day, respectively. Church and Santos (1981) similarly reported an 18 to 32 percent increase in wheat straw (3.8% CP) consumption over the control in cattle fed SBM (52% CP) at levels from 128 to 512 g/day. Likewise, Hadjipanayiotou et al. (1975) reported a 43 percent boost in straw (3.1% CP) intake by lambs supplemented with 150 g of SBM.

Increasing levels of protein supplementation in our experiment greatly enhanced the digestibilities (Table X) of total DM, OM, apparent CP, ADF, and cellulose. Church and Santos (1981) observed peak DM and ADF digestibility (56 and 50%, respectively) at the 128 g SBM/day treatment with digestibilities decreasing to 52 and 43 percent, respectively, at the highest supplemental treatment level (512 g SBM/day). Lignin was used as the marker and assumed to be indigestible (Church and Santos, 1981). Thus, if any lignin degradation occurred, the digestion coefficients reported may be lower than true values. The authors also expressed concern about a possible cumulative effect on digestibility and consumption due to the extended feeding of the low quality wheat straw (3.8% CP). Church and Santos (1981) studied the treatments with a limited number of heifers, starting at the 0-g treatment level and proceeding successively with the higher level. Coleman and Wyatt (1982) found no difference in digestibility of DM, CP, ADF, or cellulose when comparing control vs. 204 g cottonseed meal (44% CP) fed to steers consuming native range hay (8% CP). In this case, with a higher quality hay, protein probably was not limiting. Supplementation increased apparent CP digestibility 14 percent over the control diet (Coleman and Wyatt, 1982). Additionally, Church and Santos (1981) reported improved apparent CP digestibility up to the 512 g SBM/day treatment level. This is as expected since apparent CP digestibility generally improves as N intake increases because of the dilution of metabolic fecal N.

Digestible DM intakes were 2.33, 3.10, 3.29, and 3.92 kg/day at the SBM levels of 121, 241, 362, and 603 g DM/day, respectively, compared to 1.99 kg/day on the control diet. This implies that digestible energy (DE) intake rose accordingly. Similarly, Church and Santos (1981) reported greater DE intakes with each successive SBM treatment level.

At the highest level of supplementation (603 g SBM DM/day) ruminal NH_3 values (2.46 mg/dl) were within the 2 to 5 mg NH_3-N/dl recommendations of Slyter et al. (1979). At all other levels of supplementation, ruminal NH_3 values were very low, ranging from only .46 to 1.02 mg NH_3/dl as SBM supplement increased from 0 to 362 g SBM DM/day. This may be largely due to the high percentage of hay in the diet; supplements in this experiment represented only 2 to 8 percent of the total DM intake. Thus, the small amount of supplement provided may have been rapidly degraded; and, at 4 to 7 hours after feeding, ruminal NH_3 values may be lower, particularly on this type of diet. The low ruminal NH_3 levels suggest that N was still limiting on all but the highest SBM treatment level.

The particulate rate of passage values in this experiment ranged from 2.08 to 3.47 percent/hour (Table XI; Figure 5). This represents a 4 to 67 percent increase in rate of passage of digesta as SBM supplement ranged from 121 to 603 g DM/day, respectively. These values are lower than those reported by Varga and Prigge (1982). In lambs fed alfalfa hay (21% CP) at two levels, solid turnover was 5.5 and 6.6 percent/hour. Similarly, in lambs fed orchardgrass hay (14% CP), solid turnover was 5.2 and 6.6 percent/hour. Both the alfalfa and orchardgrass hays used by Varga and Prigge (1982) were of much higher quality

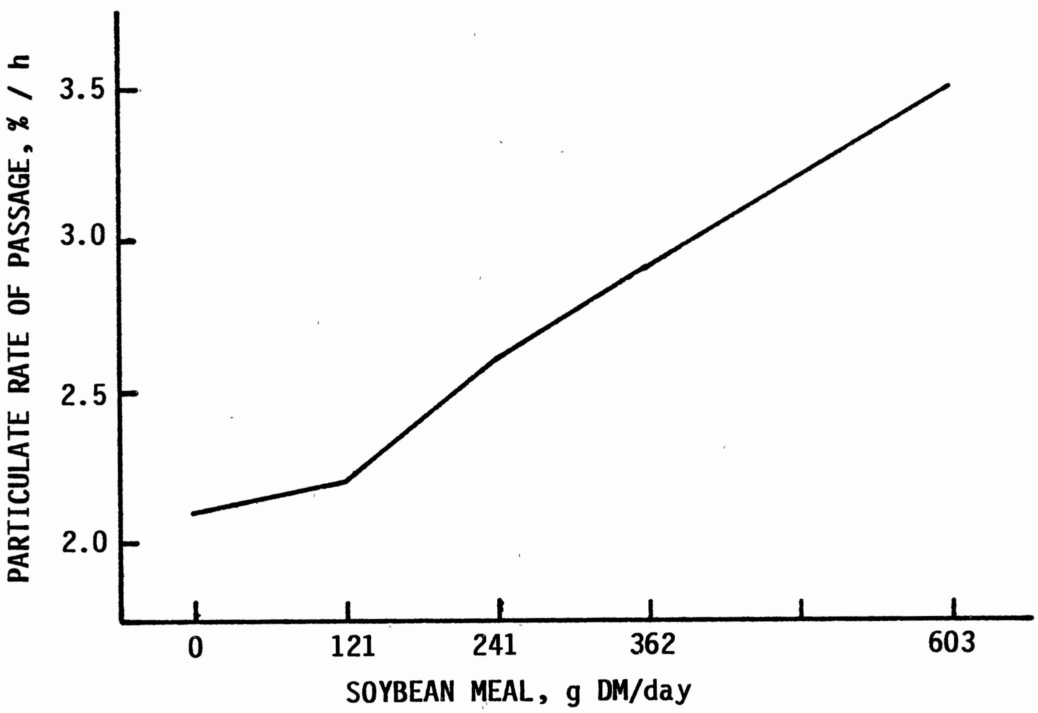

Figure 5. Particulate Rate of Passage (%/hr) as Increasing Levels of SBM Supplement are Fed With Medium Quality Prairie Hay (Exp. 2)

than the prairie hay used in our experiment. McCollum (1983) observed particulate passage rates ranging from 2.63 to 4.64 percent/hour in steers grazing blue grama range (7 to 18% CP). These passage rates (McCollum, 1983) were only moderately higher than in our study, possibly due to the higher forage quality. While literature estimates of rate of passage in low-quality, high-forage diets is especially limited, the values reported in McCollum's studies and our experiment may be more typical for range forages than those reported by Varga and Prigge (1982) for alfalfa and orchardgrass hays.

Presently, it appears that total feed intake influences passage rate, but results are inconclusive. As roughage intake increases, particulate rate of passage also increases or vice versa. Therefore, intake of forage diets may be a function of particulate rate of passage rather than a determinant of the passage rate (McCollum, 1983). Both appear highly interrelated and significantly increased by supplementation. Additional influencing factors likely include type, quantity, and quality of both supplement and roughage being fed. Accordingly, the effect of supplementation on intake and rate of passage as well as diet digestibility appears very important.

Conclusions

Though N supplementation in the form of high protein meals have been shown to improve consumption and utlization of low quality roughages, very limited research data is available concerning response patterns to graded levels of high protein meals across a range of protein supplement intakes. Variation also exists in the literature as to the effect of high-energy, low-protein supplementation on intake and digestibility coefficients. Additionally, rate of passage values for low-quality, high-forage diets are nonexistent.

In Experiment 1, two levels of protein supplement (.36 kg of 32% CP or .67 kg of 34% CP) or a 13 percent CP corn based supplement (1.41 kg/day) were fed with low to medium quality prairie hay (4.2% CP) fed free choice to measure intake and digestibility. The highest level of protein supplement (HL) was to provide twice the supplemental protein of the lower level (LL); and at an equal DM intake, the LL and the grain (GR) supplement would provide for the same total dietary protein intake. Forage intake (Table VI) and digestibilities of DM, OM, apparent CP, and ADF (TAble VII) were improved by all supplements. The HL further enhanced intake and digestibility coefficients compared with the LL. In addition, the GR diet improved total DM intake, provided a similar DM and ADF digestibility response, and only slightly depressed cellulose digestibility compared with the LL. Of particular interest is: 1) the strongly positive synergistic effect noted for the two protein supplement treatments when comparing observed vs. expected or calculated DM digestibility values (Figure 3), and 2) the absence of any negative effects of the grain supplement on DM (Figure 3) and ADF digestibility at the levels fed and with the forage used in this study. Accordingly, while the level of grain fed in this experiment was not noted to be determintal to forage intake or ADF and DM digestibility (as observed values were equal to or greater than expected or calculated DM digestibility values), it did increase digestible DM intake and therefore energy status. However, under the circumstances of this study, the highly positive synergistic effect on DM digestibility (observed > expected) noted with the protein supplements was not observed with the grain supplement. Perhaps, additional protein may have increased digestibility responses (observed > expected) still further. Thus, it appears that under conditions similar to this study, low levels of an energy supplement (e.g., corn-grain based) may be used to improve forage intake, digestibility, and energy consumption in some feeding situations, particularly if small amounts of high protein meals also are included in the diet.

In Experiment 2, when supplemental SBM was fed over a range from 121 to 603 g DM/day, prairie hay (5.2% CP) intake (Table IX) and digestibilities of DM, OM, apparent CP, ADF, and cellulose (Table X) were improved. Again, a positive synergistic effect was noted in digestibility of forage DM at all treatment levels (Figure 4) with the magnitude of response above expected digestibility being similar at the three highest SBM supplement levels. However, the digestibility coefficients reported in Experiment 2 (Table X) appeared lower (e.g., digestibilities of DM, ADF, and cellulose were 50.0, 43.9, and 58.2%, respectively, on the 603 g SBM DM/day treatment level; compared with 58.4, 57.1, and 67.7 percent, respectively, on the highest protein treatment level in Experiment 1). This reduction may be due to a level of intake effect since the heifers were consuming 2.1 to 3.1 percent of body weight as forage DM (Table IX), compared with 1.0 to 1.6 percent (Table VI) in Experiment 1. Moreover, increased transit time (Table XI) may have reduced digestibilities since time of exposure of feed particles to the digestive environment was reduced. Additionally, low ruminal NH_3 values (from .5 to 2.5 mg NH_3/dl; Table XI) may have resulted in decreased microbial activity. Possibly, even higher levels of supplemental SBM should have been tested.

What appeared to be relatively low ruminal NH_3 values were noted in both of these studies. The marginal or relatively low values may have been due to the high percentage (80 to 100%) of low to medium quality hay in the diets, too low of a level of protein in the diets (Experiment 1) or time at which samples were taken after feeding (4 to 7 hours) the small amount of supplement (Experiment 2). However, since forage intake and DM and fiber utilization did not appear hindered (except possibly in Experiment 2), these ruminal NH_3 levels may be adequate for forage type situations (e.g., range) similar to those described. Yet, there is a need to study responses to protein supplement levels which provide higher ruminal NH_3 levels than those noted in these studies.

Particulate rate of passage values ranged from 2.08 to 3.47 percent/hour (Table XI) as SBM supplement increased from 0 to 603 g DM/day. Moreover, as SBM supplement increased from 2 to 8 percent of the total DM intake (121 to 603 g DM/day, respectively), a 9 to 45 percent boost in forage consumption and a 4 to 67 percent increase in rate of passage occurred, respectively, compared with the control diet. Yet, it is unclear as to whether intake is the determinant or a function of particulate rate of passage.

Future research should investigate the effects of high protein meals and supplements over a broader range of intakes and forage qualities. Where do the positive effects of such supplementation plateau? When such research is conducted, an economic analysis would be appropriate. Another consideration involves further research into the pros and cons of high energy supplementation. What are the minimum and maximum levels of grain or starch that may be advantageously fed with or without added supplemental protein meals over a wide range of forage qualities? Moreover, at what level does supplemental energy intake increase forage intake, decrease forage intake (substitution effect) and/or decrease forage utilization? To what degree can any altered forage intake and/or utilization be modified by additional protein supplement? How is total energy status, animal performance and range carrying capacity altered? In addition, are the ruminal NH_3 values reported herein really too low for optimal animal performance or are low values, as observed in these experiments, really adquate for these types of forages? If inadequate, how may the N status of the animal be effectively improved in range-type feeding situations? Furthermore, are the particulate rate of passage values determined in this experiment typical of low-quality, high roughage diets supplemented with high protein meals, and exactly how do rate of passage and forage intake influence each other?

Each of these questions deserve consideration in future research efforts. Factors such as frequency of supplement feeding, level of protein and/or energy intake, physiological status of the animal and forage quality, quantity, and palatability provide additional investigative routes to study for advancement into the understanding of the role that protein supplementation plays toward utilization of the low quality roughages available around the world.

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VITA

Marian Joyce Guthrie

Candidate for the Degree of

Master of Science

Thesis: EFFECT OF PROTEIN OR GRAIN SUPPLEMENTATION ON INTAKE, UTILIZATION, AND RATE OF PASSAGE OF MEDIUM QUALITY ROUGHAGE

Major Field: Animal Science

Biographical:

Personal Data: Born in Forest, Mississippi, June 12, 1960, the daughter of Pace and Hazel Guthrie.

Education: Graduated from Scott Central High School, Forest, Mississippi, May, 1978; transfered from East Central Junior College, Decatur, Mississippi, December, 1979; received Bachelor of Science Degree in Animal Science from Mississippi State University, December, 1981; completed requirements for the Master of Science Degree in Animal Science at Oklahoma State University, July, 1984.

Professional Experience: Reared and worked on a purebred Angus and Brangus cow-calf operation in east central Mississippi; worked at Mississippi State University Boar Test Station and Sheep and Horse Unit, 1981; Graduate assistant in the Animal Science Department, Oklahoma State University, 1982-84; interim supervisor of Nutrition Laboratory in Animal Science Department, Oklahoma State University, 1983-1984.

Professional Organizations: Phi Theta Kappa, Phi Kappa Phi, Alpha Zeta, Gamma Beta Phi, American Society of Animal Science.