SUPPLEMENTAL PROTEIN TO ENHANCE NUTRIENT UTILIZATION OF

STEERS FED HIGH FIBER HAY

by

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ABSTRACT

Metabolism and performance studies were conducted to evaluate effects of incremental levels of rumen undegradable protein (RUP) on nutrient utilization of growing steers fed high fiber hay. Metabolism study: Holstein steers (n = 6, 217 ± 13.8 kg) were used in a replicated 3 x 3 Latin Square designed experiment. Incremental levels of RUP (32.5, 40.13, and 42.48% of CP) were fed as supplements at 1.72 $kg \cdot hd^{-1} \cdot d^{-1}$ (AF) to a bermudagrass (*Cynodon dactylon* L.) hay diet (10.2% CP, 76.4% NDF). Supplements were iso-nitrogenous (25.9% CP) and fed as pressed molasses blocks. The RUP was controlled by feeding different ratios of SBM, corn gluten feed, poultry protein meal and soy hulls. Corn was added to the diets to increase energy levels. Steers were fed treatments for 14 days. Steers were placed in metabolism crates for total fecal and urine collection from d 10 to d 14. Jugular blood was sampled before and after feeding on day 10 and 14, respectively. Hay and total DMI increased (3.95 to 4.27 kg/d and 5.56 to 5.92 kg/d) with RUP ($P < 0.05$). Fiber digestion was larger ($P < 0.05$) when steers were fed the high RUP diets due to inclusion of soy hulls; however DMD, OMD and DE were not affected ($P > 0.10$). Urinary N output was lower ($P < 0.05$; 23.82 ± 1.45 g/d) in steers fed the high RUP diets but treatments did not affect N retention ($P > 0.10$; 49.46 ± 2.13 g/d). Blood urea nitrogen (BUN) increased after feeding ($P < 0.05$; 14.15 vs. 16.3 mg/ dl) and tended to be negatively related to RUP. Performance study: British and Brahman x British steers (n = 48; 252.15 ± 22.5 kg initial BW; age 9 mo.) were ranked by BW, randomly allocated to one of 8 pens and fed supplement in two forms (pressed blocks or meal) and two levels of RUP (27 vs. 44% of CP for blocks and 30 vs. 46% of CP for the meal) in a 63-d 2 x 2 factorial feedlot trial. Bermudagrass hay (13.1% CP, 74.59% NDF) was offered free choice and supplements were fed at 1.72 $kg \cdot hd^{-1} \cdot d^{-1}$. Blood samples were collected on d 21 and d 63. Total DMI was not affected by treatments. Steer ADG (0.67 ± 0.05 kg) did not respond to RUP or form of supplement. Diet evaluation indicated that ME allowable gain was lower than the MP allowable gain. Blood urea nitrogen was lowered with RUP (14.1 vs. 12.1 mg/ dl; $P < 0.01$) and at d 21 than at d 63 of the experiment. An interaction between RUP levels and form was observed for blood glucose and insulin ($P < 0.01$). Despite some indications that RUP improved nutrient utilization,

animal performance was not affected, mainly because of low range of RUP consumed among treatments and because of levels of protein consumed related to energy.

INDEX WORDS: Protein Supplementation, Fiber, Growing Steers.

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DEDICATION

To Gillian, my parents and sister

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CHAPTER 1

INTRODUCTION

Most of the cattle in the world are raised and finished on forage-based diets. Pasture is considered to be a valuable crop, because of the great extension of grasslands and the unique capability of transforming grass into animal protein. In the U.S.A it is common to background calves on pasture followed by feedlot finishing to increase weight and reduce the time and amount of grain required.

Supplying the nutritional requirements of grazing beef cattle with suitable forage is the objective of any successful production system. Minimizing the use of feed supplements is essential to economic success. However, grass nutritional composition varies with plant species, stage of maturity, water stress or excess, shading, and nitrogen fertilization. Warm season perennial grass quality is more adversely affected than cool season perennials by heat and maturity. Animal requirements also vary with level of production, body weight and gain, breed, environmental conditions, physiological state, previous plane of nutrition, anabolic agents and level of activity (Beef Cattle NRC, 2000). Growing beef cattle grazing warm season grasses often have a deficit of nutrients resulting from decreased forage quality, making it difficult to achieve an economical and desirable level of production.

Therefore, in specific situations the use of protein and (or) energy supplementation is vital. Protein supplementation provided to cattle consuming low-

quality forage can improve animal performance through increased forage intake and digestion (Hannah et al., 1991). Energy is also frequently necessary at time of limited forage availability (i.e., the need to stretch existing forage supplies) and (or) the low nutrient content of forage relative to requirements for the desired level of performance (Horn and McCollum, 1987). Supplementation is an important decision that impacts profitability of growing beef calves grazing warm season grasses. Both animal performance and economic aspects must be evaluated and the improvement of pasture utilization has to be the main objective of a supplementation program.

Beef cattle performance on a supplemented forage diet will depend on a series of factors and how they interact to change the rumen environment and microbial population. These factors include protein and carbohydrate source and concentration in the supplement, amino acid supply, and the grass nutritional composition.

The objective of this thesis was to examine the different aspects of protein and energy supplementation, emphasizing their effects on utilization of forage diets fed to growing beef cattle.

CHAPTER 2

LITERATURE REVIEW

Protein Supplementation

Metabolizable Protein

The Beef Cattle NRC (2000) defines metabolizable protein (MP) as the true protein absorbed by the intestine estimated by the sum of the rumen microbial protein and rumen undegradable protein (RUP).

Wilkerson et al. (1993) estimated MP requirement for maintenance and growth, based on average daily gain of beef steers within the weight range of 203 to 288 Kg consuming a high roughage diet to be 3.8 g/d * $BW^{.75}$ (BW expressed as kg) and 305 g/kg of live weight gain. It was assumed that the microbial crude protein (MCP) was synthesized at a rate of 13% of the mass of TDN. The approach used considers that metabolizable protein for gain remains constant and that efficiency of MP use changes with rate of gain and body size. As a matter of example, the MP efficiency use declines from 59% at 0.11 kg/d to 52% at 0.89 kg/d of gain and from 60% at 203 kg to 53% at 288 kg of body weight.

The Beef Cattle NRC (2000) supports the MP maintenance requirement proposed by Wilkerson et al. (1993), however relationships between energy retained and protein content of the gain are used to calculate the MP requirement for gain as illustrated in equation 1. Energy is retained as either protein or fat, therefore composition of gain at

different weights can be estimated. Equation 2 describes the proportion of protein at a particular retained energy (RE), demonstrating an inverse relationship between protein content of the tissue and energy retained. Hence, MP requirements will vary with the amount of energy retained, as dictated by the energy required for a desired production level.

$$\text{Protein retained} = SWG*(268 - (29.4*(RE/SWG))) \quad \text{Eq. 1}$$

Where:

SWG is shrunk weight gain and RE is retained energy, equivalent to net energy for gain (NE_g).

$$\text{Proportion of protein} = 0.248 - 0.0264 * RE \quad \text{Eq. 2}$$

The Beef Cattle NRC (2000) estimates the feed MP supply as the sum of digestible undegraded dietary protein and truly digestible MCP that reaches the abomasum. The MP from rumen bacteria is calculated by assuming that microbial protein production is 13% of TDN. The MCP is considered to be 80% true protein and 80% digestible, hence MP_{bact} = MCP * 0.64. The MP_{feed} is considered to be 80% digestible and is calculated as RUP * 0.80. Therefore, MP_{total} is equal to MP_{bact} + MP_{feed}.

Although dietary requirement for amino acids are not listed in the Beef Cattle NRC (2000), their requirements are intimately related to energy intake in a similar manner as described previously for protein. In essence, the consumption of additional energy increases the animal's amino acid requirements. On the other hand, when

adequate nutrition and especially energy are available to the animal, protein deposition is linearly related to the metabolic supply of the most limiting amino acid (Titgemeyer and Löest, 2001).

Requirements for tissue growth are established by the Beef Cattle NRC (2000) as a function of the percentage of each amino acid in net protein accretion. Average values for nine of the ten essential amino acids expressed as a function of tissue protein deposited (g/ kg empty body protein) are listed as follows: leucine, 6.7; lysine, 6.4; valine, 4.0; threonine, 3.9; phenylalanine, 3.5; arginine, 3.3; isoleucine, 2.8; histidine, 2.5, and methionine, 2.0 (Beef Cattle NRC, 2000). Tryptophan values were not given because of limitations in assay procedures. Wilkerson et al. (1993) used the coefficient of variation (CV) for grams of amino acid flowing to the small intestine, when the MP requirement was met, to evaluate the need for a specific amino acid. They assumed that at the point of meeting the MP requirement there should be less variation in the small intestinal flow of the most limiting essential amino acid. A low CV for an essential amino acid from several test protein sources would indicate a higher correlation with gain by its availability most limiting growth. The authors suggested that methionine was usually first limiting using this technique. Titgemeyer and Löest (2001) indicated that methionine, lysine, histidine, and at least one of the branch chain amino acids (leucine, valine or isoleucine) are limiting for forage fed ruminants.

It is well recognized that ruminal microbial growth rate is influenced by type of substrate provided. Russel et al. (1992) demonstrated microorganisms that ferment cellulose and hemicellulose grow more slowly and specifically utilize ammonia for microbial protein synthesis; whereas, microorganisms that ferment starch, pectin and

sugars grow more rapidly and utilize either ammonia or amino acid as N source. Moreover, fiber-digesting bacteria may require branched-chain volatile fatty acids (isobutyrate, isovalerate and 2-methyl butyrate) that are supplied by degradation of branch chain amino acids valine, leucine and isoleucine, respectively (Hoover, 1986).

Ruminal Protein Degradability

According to the definition of MP, the ruminant requires two types of proteins: a rumen degradable protein (RDP) source for microbial protein synthesis and a RUP source to be digested directly at the small intestine. In order to maximize the efficiency of protein utilization by the animal, degradable protein requirements for microbial growth logically should be met before a response to escape protein can be realized (Klopfenstein, 1996). Nocek and Russel (1988) indicated that RDP intake can increase efficiency and synthesis of microbial growth, thereby stimulating OM digestion that in turn increases rate of passage, DM intake and consequently energy intake.

Ruminal Degradable Protein Requirement

Karges (1992) increased supplemental amounts of corn steep liquor, a completely degradable protein source, to gestating beef cows fed mature prairie hay diet with the objective to determine RDP requirement. In that study, 6.3% of RDP (% of OM) was required for beef cows to maximize total organic matter digestion (TDOM) at 51.3% of the diet. Expressing the RDP requirement as a percentage of TDOM results in an estimate of 12.3% (6.3% divided by 51.3%). Köster (1996), infused sodium caseinate into the rumen of fistulated beef cows at levels of 0, 180, 360, 540, and 720 g/d and observed that 4 g total RDP intake/kg $BW^{.75}$ was required to maximize total digestible organic matter intake. This value is equal to a RDP requirement of 11.1% of TDOM. A much lower

value was found by Hollinsworth-Jenkins et al. (1996) with cows grazing winter native Sand Hills range forage (5.6% CP and 66.9% NDF, from esophageal masticate samples) fed supplements containing 29, 50, 65, 75, 100, 125 and 139% of the total RDP requirement established by Beef Cattle NRC (2000). The RDP of supplements was altered, changing the concentration of steep liquor and soy hulls of the diets. The maximum gain (0.18 kg/d) and forage OM intake was achieved with RDP at 4% of OM intake, corresponding to a RDP requirement of 7.1% of TDOM. The lower RDP requirement found in this study may be related to the contribution of RUP from soy hulls to increase gain. The Beef Cattle NRC (1996) considers that the requirement for RDP to be 13% of TDN that corresponds to maximal bacterial crude protein (BCP) synthesis. However, the accuracy of using TDN as a basis to predict the RDP requirement for ruminal microbial growth can be questioned because it includes digestible lipids and ash. It is well recognized that digestible carbohydrates are the primary source of energy for ruminal bacterial growth (Russel et al., 1992).

The value of 0.130 g/kg of TDN for BCP synthesis should be used with caution as a constant. At both high and low diet digestibilities, efficiency may be lower but for different reasons. High-grain finishing diets contribute to lower rumen pH and consequently slower microbial turnover, leading to a lower microbial efficiency (Beef Cattle NRC, 2000). This is emphasized in the work of Russel et al. (1992) that suggested type of carbohydrate increases microbial maintenance requirement due to decreased rate of passage and rumen pH. When bacteria grow slowly, a larger proportion of the energy is used to maintain the cell, considerably affecting efficiency of cell growth and requirements for degradable protein. Klopfenstein (1996) suggested that many factors

affect microbial protein synthesis and the requirement for rumen degradable protein. These factors include rate of passage, type of energy being digested, rumen versus lower tract digestion and the lack of an accurate measurement method. These variables could be partially accounted by the work of Mathis et al. (2000) who found that RDP requirements varied for steers fed three different forages: bermudagrass (*Cynodon dactylon* L.) (8.2% CP, 71% NDF), bromegrass (*Bromus inermis* L.) (5.9% CP, 65% NDF), or forage sorghum (*Sorghum bicolor* (L) Moench) (4.3% CP, 60% NDF). The RDP requirement was found to be 8.2, 9.8 and 12.8% of TDOM respectively for the steers consuming these different forages. These researchers used the same group of animals and the same amount and type of supplement, emphasizing that forage type plays an important role on the requirements for microbial protein production. The authors suggested that in this case, differences among forages may be associated with their CP content and the potential for some of the digestible RUP to contribute to N recycling into the rumen. This potential seems to be greater for bermudagrass than for the other forages studied.

Rumen Degradable and Undegradable Protein

Requirements for supplemental undegradable protein vary according to forage quality and desired production level. Low TDN diets can reduce intake, passage rate and microbial efficiency (Beef Cattle NRC, 2000). Hence, young growing cattle grazing low quality forages may respond to supplemental RUP. Klopfenstein et al. (1985) suggested that in many cases (especially growing calves fed high forage-low protein rations) microbial protein is not sufficient to meet the animal's needs. The authors developed a system known as the slope ratio technique to compare feed proteins by measuring rate of gain from increasing levels of protein in the diet. From these comparisons it was

observed that blood meal meets the animal's protein requirement (maximum gain) with about 40 % as much supplemental protein compared with soybean meal. Karges et al. (1992) investigated the effects of RDP and RUP supplementation for steers grazing summer native range during two years (CP of esophageal extrusa samples: 14.1 to 7.1 %). These authors fed a negative control (no supplement) and an energy control (corn starch and molasses) treatment, and increased levels of degradable (0.15, 0.27 and 0.37 kg/d) or undegradable protein (0.07, 0.14, and 0.21 kg/d). The supplements were iso-energetic and the CP for the degradable and escape protein treatments were 60.8% and 53.3%, respectively. The authors found that enhanced performance was mainly attributed to an increase of RUP since the RDP treatment indicated a quadratic effect as performance (approximately 1.05 kg/d) was maximized at the lowest level of supplementation; whereas, the RUP treatments linearly increased average daily gain (approximately 1.12 kg/d) with increased RUP. Furthermore, responses to RDP and (or) NPN supplementation for cattle grazing warm season grasses were less consistent than those supplemented with natural protein sources, primarily due to RUP content of the RUP sources.

On the other hand, there are a substantial number of studies that indicate that RDP is more conducive to stimulating animal performance as compared to RUP. It is well recognized that microbial protein will adequately support performance of cattle with protein requirements less than 12% CP.

The provision of RUP is only successful when the protein requirement of the ruminant is high and microbial protein yield is less than protein required by the animal. This conclusion is supported by the work of Santos et al. (1998), who reviewed 15

metabolism trials in which soybean meal (SBM) was compared with several sources of RUP. The overall results demonstrate that elevated levels of RUP significantly changed the absorbed amino acid profile, but inconsistently improved lactational performance. Despite the fact that the experiments were conducted with lactating dairy cattle, these inferences can be applied to RUP utilization by growing beef cattle.

The importance of RDP driving microbial protein synthesis and its effect on animal performance and forage utilization has been demonstrated in a number of studies. Bandyk et al. (2001) infused casein ruminally as RDP or post-ruminally as a RUP source in beef steers consuming low quality hay (Tall grass prairie hay, 3.4% CP; 74.6% NDF), and showed that RDP stimulated forage intake twice as much as RUP. Bodine et al. (2000) supplemented prairie hay (6.1% CP; 74.6% NDF) fed to beef steers with two levels of corn (0 or 0.75% BW) and various amount of SBM to evaluate effects of RDP and readily available carbohydrate utilization of low quality forage. Soybean meal was added to the diet to achieve 0, 33%, 66% and 100% of the Beef Cattle NRC (2000) requirement for RDP to the high corn diet. Added RDP resulted in quadratic increases on intake of OM from hay with or without corn supplement. The highest increment was at the 0.75% BW of corn and 66% of the calculated RDP requirement. Digestibility was also improved for the 66% RDP diet with corn, but no differences were observed on digestibility due to levels of RDP without corn in the diet. The lack of digestibility response but higher hay intake with increased RDP with no supplemental corn may be related to increased rate of passage and decreased time for digestion with SBM supplementation. Positive effects on forage OM digestibility were also observed by Bodine and Purvis (2003) who indicated these effects alleviated negative interactions

believed to result from feeding high levels of supplemental grain with low-quality grass hay. Mathis et al. (1999) suggested that improved intake and digestion with increasing levels of supplemental SBM (up to 0.50% BW) primarily resulted from the provision of supplemental RDP, although the supplement provided both RDP and RUP. Olson et al. (1999) evaluated the effects of ruminal administration of supplemental degradable protein (casein) on utilization of low-quality (4.9% CP and 72.3% NDF) prairie grass hay, dominated by big bluestem (*Andropogon gerardii* Vitman), indiangrass (*Sorghastrum nutans* (L.) Nash) little bluestem (*Schizachyrium scoparium* (Michx.) Nash) sideoats grama (*Bouteloua curtipendula* (Michx.) Torr.), and switchgrass (*Panicum virgatum* L.) by beef steers. They observed that the highest level of supplemental RDP (0.12% BW) had a positive effect on forage and total organic matter intake. Digestibilities of DM, OM and NDF were maximized at the highest RDP level; total VFA increased significantly with RDP and rumen pH did not drop below 6.2. However, since the greatest intake and digestibilities were achieved by the highest RDP supplement, a maximum RDP requirement could not be established.

Non-Protein-Nitrogen Supplementation

The Southeast is a major poultry production region of the United States. Consequently, broiler litter, a by-product of poultry production is readily available and fed to cattle. During dry years many beef producers rely on broiler litter as a major source of nutrients for grazing cattle. Additionally, recycling litter through ruminants serves as method of reducing waste disposal, as well as more directly recycling of nutrients in a totally balanced nutrient management system. Broiler litter is relatively high in fiber (around 35% NDF) and non-protein nitrogen (NPN). Another NPN source, urea, is often

added to molasses mixtures and fed to grazing cattle using lick-tanks to regulate intake. Hence, it is important to highlight the potential beneficial factors and limitations of NPN for ruminants grazing low-quality forages.

One of the main factors that must be described and analyzed prior to the utilization of NPN for ruminants is its potential to maximize microbial protein synthesis. Urea fermentation potential (UFP) of feeds is used to quantify the amount of urea that can be utilized depending on the ration fed. A positive UFP value becomes an integral part of the MP system when urea is in the ration, and can be defined as grams urea/kg of feed DM consumed that can be transformed into microbial protein (Burroughs et al., 1974). Urea fermentation potential is described in equation 3 (adapted from Burroughs et al. 1974).

$$UFP = [(0.13 * TDN) – DP]/2.87 \quad \text{Eq. 3}$$

Where:

UFP is urea fermentation potential (g urea/kg of DMI) and DP is degradable protein.

The value of 13% of the TDN for microbial protein synthesis must be adjusted when the diet effective NDF (eNDF) is less than 20% (Beef Cattle NRC, 2000).

$$MCP = 0.13 * TDN * eNDF_{adj} \quad \text{Eq. 4}$$

$$eNDF_{adj} = 1.0 – ((20 – eNDF)* 0.025) \quad \text{Eq. 5}$$

The MP from urea fermentation potential is calculated as MP (g/kg) = 2.87 * 0.8 * 0.8 * UFP. If a positive value is determined, the MP from UFP is added to the original MP calculation (Sindt et al., 1994).

An intimate relationship exists between UFP and the energy of the diet. Total digestible nutrients is the most commonly used measurement to describe digestible energy and it is the energy measurement most commonly understood among beef cattle producers. However, it may not describe the exact energy available for gain from concentrates compared with roughages as feedstuffs. Also, as cited previously, rumen microorganisms are unable to utilize lipids and ash as energy sources. In general, it is recognized that TDN increases the need for ammonia by rumen bacteria, however an upper-limit of ammonia concentration in the rumen exists to maximize microbial growth. Satter and Slyter (1974) measured the minimal level of ammonia needed to provide maximum microbial protein production in an in vitro continuous culture fermenter. They concluded that increasing ammonia above 5 mg/dl did not result in further microbial protein production. Satter and Roffler (1974) and Russel and Strobel (1987) reaffirmed that once ammonia starts to accumulate above this value, no further rumen microbial production results from additional supplementation with NPN. Highlighting the importance of ration energy concentration, it was observed that ruminal ammonia N exceeds or reaches 5 mg/dl sooner with low-energy rations than with high-energy rations. A much higher rumen requirement for NH_3 (23.5 mg/dl) was determined by Mehrez et al. (1977) to maximize in vivo fermentation of barley DM. There are several variables that can account for the differences of in vitro studies and in vivo or practical situations. These include physical form of the ration (ground barley), use of nylon bags in vivo,

basal diet fed, dilution rate of fermenters, level of available carbohydrates and the protein content of the diet. Non-protein-nitrogen is better utilized in low-protein high-energy rations than in high-protein, low-energy rations (Satter and Roffler, 1974). Table 1 summarizes the effects of protein and energy content of the ration on mean ruminal ammonia concentration and non-protein nitrogen utilization.

Table 2.1 Influence of ration composition on mean ruminal ammonia concentration and non-protein nitrogen utilization[1]

% CP in the ration	% Total Digestible Nutrients (TDN) in ration DM							NPN utilization
	55	60	65	70	75	80	85	
	(mg/dl)							(%)
8	6	5	4	3	2	2	1	
9	6	5	4	3	2	2	1	> 90
10	6	5	4	3	2	2	1	
11	6	5	4	3	3	2	2	
12	7	6	5	4	4	3	3	
13	8	7	6	6	5	4	4	0 – 90
14	10	9	8	7	6	6	5	
15	12	11	10	9	8	8	7	
16	14	13	12	11	10	10	10	
17	17	16	15	14	13	13	12	0
18	20	19	18	17	16	16	15	
19	23	22	21	20	19	19	18	
20	27	26	25	24	23	23	22	

[1] Adapted from Satter and Roffler (1974).

More recent research has been directed at studying performance of grazing cattle supplemented with increasing levels of urea. Köster et al. (1997) studied increased proportion of urea (0, 25, 50, 75, and 100%) in supplemental RDP fed at 380 g/d. Forage OM, total N intake, and efficiency of microbial growth were similar with increasing urea levels. In contrast, because digestion decreased, digested OM intake decreased linearly. The decline in digestion may be due to the lack of bacterial growth factors from intact

protein sources of RDP, such as amino acids, peptides and branched chain VFA required by fiber digesting bacteria, as described previously. Köster et al. (2002) conducted similar experiments with linear increases of urea within the range of 0 to 60 % and 0 to 45% of total RDP portion of a 30% CP supplement for cows and steers grazing low quality tall grass prairie forage (2.42 to 5.7% CP, 73% NDF), respectively. Rumen degradable protein requirements were met in all studies. Overall, urea could replace between 20% and 40% of the RDP in a high-protein supplement without significantly altering cow and calf performance. The most notable result was that cattle refused to consume the ration with the highest urea supplement (60 % substitution).

Nitrogen Recycling

Ruminants have the capacity to survive on very low N diets by recycling the circulating N back to the GI tract. Urea is the major end product of N metabolism in ruminants and is either excreted in urine or recycled to the gastro intestinal tract by diffusion across the gut wall or as a component of saliva. Amount of N recycled through saliva depends on blood urea concentration and amount of saliva produced. Because saliva production increases with roughage level in the diet, salivary recycling increases with dietary roughage level (Owens and Zinn, 1993). Urea recycled to the rumen is hydrolyzed by urease from rumen bacteria adherent within the stratum corneum of the ruminal epithelium, yielding ammonia and CO_2 (Archibeque, 2001; Owens and Zinn, 1993). Ammonia then diffuses in the rumen and can contribute to the synthesis of rumen microbial protein.

Amount of rumen N recycling depends on its intake (Marini and Van Amburgh, 2003; Archibeque et al., 2001; Huntington, 1996), ruminal ammonia concentration

(Owens and Zinn, 1993), and degradability of dietary N and fermentability of carbohydrates in the rumen (Hoover, 1986). Marini and Van Amburgh (2003) demonstrated that animals fed low N diets (1.45% N) had less urea N excreted in the urine as percentage of the urea N produced (15 vs. 71%), a smaller urea N pool, but faster urea N turn over rate and higher amounts of urea N being incorporated into microbial protein synthesis (43% vs. 6%) than animals fed high N diets (3.40% N). The N recycling was also diminished in the study of Archibeque et al. (2001). These authors found that when the N intake exceeded maintenance requirement of steers, a greater proportion of N was excreted as urea in the urine. Huntington (1996), investigating effects of roughage concentrate ratio, concluded that at 20% or less dietary concentrate mature steers recycled 90% of liver urea production compared with 64% at 63% dietary concentrate and 51% at 90% concentrate. These effects mainly resulted from lower N intake for the low concentrate diet, since the diets were not iso-nitrogenous.

Enhanced N recycling was evident in a study conducted by Beaty et al. (1994) where steers consuming wheat straw diet (3.8 % CP, 81 % NDF) were supplemented either at seven or three times per week. Steers supplemented at three times per week were able to sustain elevated NH_3 levels even on days when they were not supplemented and consequently achieved similar N utilization as those fed seven times per week.

Level of Protein Supplementation

Cattle consuming low-quality forage should be supplemented with adequate digestible protein to increase ruminal microbial production and consequently stimulate forage intake to achieve greater levels of production. Hannah et al. (1991) worked with cattle grazing dormant big bluestem range forage supplemented at equal amounts but

different levels of crude protein (0, 12.8%, 27.1%). They reported better intake and digestibility for the steers supplemented at 27.1% level of crude protein. The authors suggested that protein supplements should contain at least 20% CP. Wheeler et al. (2002), conducted two experiments where supplementation levels of CP were varied for cows and steers grazing stockpiled bermudagrass forage. Treatments consisted of feeding 0.2, 0.4, and 0.6 g of supplemental protein per kg of BW in a cow performance trial, and 0.23, 0.46, and 0.69 g of supplemental protein per kg of BW in a steer trial. Both experiments indicated that the low level of supplementation was sufficient to acquire the maximal forage intake, digestibility and consequently performance, and agree with the work of Hannah et al. (1991). Similarly, Del Curto et al. (1990), evaluating graded concentrations of supplemental CP using SBM and sorghum grain, observed that the intermediate level of CP (25%) was best in regards to stimulating intake, digestibility, and ruminal characteristics of beef steers and cows grazing low quality warm season grasses. Ferrell et al. (1999) also observed that supplements with relatively high crude protein concentration fed to ruminants consuming low-quality forages enhanced forage use and livestock performance.

Energy Supplementation

Energy Requirements

Maintenance energy requirement is defined as the amount of feed energy intake that will result in no net loss or gain of energy from the tissues of the animal body (Beef Cattle NRC, 2000). Net energy is the most accurate measurement of energy requirements for ruminants. The primary advantages of this system are that animal requirements stated as net energy are independent of the diet, and the energy value of feeds for different

physiological functions are estimated separately (Beef Cattle NRC, 2000). Furthermore, the energy density of feedstuffs (concentrate vs. roughages) is best related to animal performance than previous other forms of measurement (TDN, DE and ME). In order to measure the net energy requirement for maintenance (NE_m) it is necessary to calculate the heat production (HP) of a fasting animal. In fed animals, HP is made up of basal metabolism, heat increment and heat produced by activity. At zero feed intake, heat increment is zero and the components of HP are basal metabolism and heat of activity which can be equal to net energy required for maintenance. Heat production is measured at various levels of feeding and the HP at zero feed-intake is estimated by extrapolation (Lofgreen and Garret, 1968). Data of Lofgreen and Garret (1968) using comparative slaughter method found energy requirement for beef cattle to be equal to 0.077 $W^{0.75}$ (where W equals to body weight, kg and NE_m is in Mcal).

The Beef Cattle NRC (2000) does not precisely estimate the extent to which grazing animals expend more energy than penned cattle. Grazing beef cattle behave differently than pen-fed animals, inherently related to their grazing activity and its influence on maintenance energy requirements. As grazing time increases and forage availability declines, work associated with grazing activity increases (Caton and Dhuyvetter, 1997). Ferrell (1993) illustrated that although the combined masses of nervous tissue, heart, kidney, digestive tract and liver account for less than 10% of body mass, these organs consume more than 50% of energy required for maintenance. The largest tissue that consumes maintenance energy is muscle, being responsible for 23% of the total energy expenditure. He indicated that if a 500 kg cow travels 5 km horizontally and ascends 500 m during a day, the ME requirement is about 23% greater than those of a

similar animal held in confinement. Hence, energy expenditure is associated with grazing time and forage availability. Any environmental factor that influences forage availability and quality, as well as stocking rate, supplementation and level of production will potentially affect activity and therefore energy expenditure of grazing animals. Adams (1985) studied grazing behavior and performance of beef steers fed corn supplement (0.3% BW) and observed greater distance traveled and more time spent grazing for supplemented steers than for controls, resulting in inferior performance because of their greater energy expenditure. Besides the effects of grazing activity, breed, sex, age, season, temperature, physiological state and compensatory gain (previous nutrition) also have the potential to influence maintenance requirement (Beef Cattle NRC, 2000).

Lofgreen and Garret (1968) simply defined net energy for gain (NE_g) as the energy deposited in the gain. Hence, gain composition is a function of NE_g requirement. Equation 6 was developed by Garret (1980) from a data set of 72 comparative slaughter experiments using approximately 3,500 cattle and is the base for predicting energy retained and daily gain in growing cattle. Factors such as weight, stage of growth, rate of gain, use of metabolic implants and ionophores will influence requirements for gain (Fox et al., 1995). Body weights for all frame sizes and sexes are converted to the 1984 medium-framed steer equivalent weight (EQSBW) by multiplying shrunk body weight (SBW) by the equivalent weight factor (Table 3-2, Beef Cattle NRC, 2000). Variables for equation 6 (Garret, 1980) can be calculated using equations 7 to 9 as indicated in the Beef Cattle NRC (2000).

$$RE = 0.0635 * EBW^{0.75} * EBG^{1.0971} \quad \text{Eq. 6}$$

$$EBW = 0.891 * EQSBW \quad \text{Eq. 7}$$

$$EBG = 0.956 * SWG \quad \text{Eq. 8}$$

$$SWG\ (kg/d) = 13.91 * RE^{0.9116} * EQSBW^{-0.6837} \quad \text{Eq. 9}$$

Where:

EBW is empty body weight, EBG is empty body gain and SWG is shrunk weight gain.

Effects on DM Intake

Intake of grazing cattle is a subject that is not accurately defined. When ruminants are consuming a low to medium quality forage, intake will usually be lower than the capacity of the animal to utilize nutrients. This is because of the inability of the gastro intestinal tract (GIT) to process digesta, and in particular to the capacity of reticulo-rumen to accommodate undigested feed residue and to pass them to the post-ruminal GIT. When voluntary feed intake is restricted by this mechanism, the extent of substitution of forage to grain can be expected to depend on the ability of dietary grain to change rumen fill and tolerance of rumen fill by the animal (Dixon and Stockdale, 1999).

Ferrell et al. (1999) indicated that forage intake is often depressed when high energy, low protein supplements are fed to grazing cattle. Rapid rumen fermentation due to starch ingestion leads to a greater production of lactate, reducing ruminal pH and shifting the ruminal microbial population (Russel et al. 1992) to greater numbers of amylolytic and lower cellulolytic bacteria. Changes in rumen microflora negatively affect fiber digestion, lowering passage rate and depressing forage intake.

A variety of studies indicate the depression of forage intake caused by starch supplementation (Jones et al, 1988; Zorrila-rios et al. 1991; Carey et al. 1993; Bodine and Purvis, 2003). Brown (1993) conducted series of trials where molasses was either fed free choice in licking tanks or at 0.65% BW for steers consuming ammoniated stargrass (*Cynodon nlemfluensis* Vanderyst) hay. Low hay intake was observed, regardless of the amount of supplement.

It appears that levels of supplementation, carbohydrate sources and forage quality all might be responsible for divergent effects on forage utilization and performance of grazing animals. In an extended review on energy supplementation, Horn and McCollum (1987) indicated that energetic supplements did not affect forage utilization if amounts of supplement fed were not greater than 30 g/kg metabolic BW. Pordomingo et al. (1991), alternating levels of supplemented whole shell corn to steers grazing blue grama (*Bouteloua gracilis* Wild, ex Kunth Lag. Ex Griffihs), buffalograss (*Buchloe dactyloides* (Nutt.) Engalm), and tobosa grass (*Hilaria mutica*), observed significant linear decreases in forage OM intake, except at the lowest level of supplementation (0.2% BW) that was similar to the control treatment. In addition, Royes et al. (2001) found little differences in forage intake compared to the controls when corn was supplemented at 1.4 kg/day (0.56% BW) and a significant decrease in intake when supplemented at 0.60% BW. Similarly, corn supplemented at the level of 0.345% BW in the study of Brokaw (2001) did not depress forage organic matter intake. Vanzant et al. (1990) also failed to demonstrate lower forage intake even at higher levels of starch (sorghum grain, as-fed, up to 0.66% BW) in the diet of steers consuming bluestem (*Andropogon sp.*) range forage.

Although the level of supplementation was higher than in the previous studies, it was still below the limit of 30 g grain/kg metabolic BW proposed by Horn and McCollum (1987).

As mentioned, the majority of the literature reports lower forage intake but higher total organic matter intake, higher digestibility and performance as starch or sugar-base supplements are substituted at high levels for forage. Greater performance and intake were achieved for cattle fed at higher levels of corn because of improvements in nutrient utilization (Pordomingo et al. 1991; Royes et al. 2001).

Digestibility

The overall effect of grain supplementation on forage utilization of cattle is highly related to digestibility. A lower total tract organic matter digestibility might reduce rate of passage, increase rumen fill and consequently lower forage consumption. However, reports of nutrient digestibility on grain-supplemented steers are sometimes variable.

According to Caton and Dhuyvetter (1997) it is important to consider several variables when accounting for factors that influence digestion of forage based diets. First, it is necessary to differentiate the effects of basal forage digestibility and that of total diet digestibility because production management objectives may favor one situation over another. And second, results of energy supplementation on dietary digestibility in ruminants consuming forage-based diets in grazing and pen-fed situations have been varied. Depressed TDOM is not usually attributed to grain supplementation, obviously because of the high digestibility of the supplement (Ferrell et al., 1999). This has been verified in various studies where TOMD were either not significantly affected, or higher than controls, when starch was added to the diet (Grigsby et al. 1993; Vanzant et al., 1990; Carey et al. 1993; Royes et al., 2001; Brokaw et al., 2001; Heldt et al., 1999).

However, as previously mentioned forage intake responses are highly related to NDF digestibility. The effect of starch on the rumen environment accounts for the negative associative effect of the supplement and the basal forage depressing NDF digestibility and intake (Royes et. al, 2001; Grigsby et al. 1993; Carey et al., 1993; Jones et al., 1988). Other researchers have found very minor or no effect of supplements on NDF digestibility (Heldt et al., 1999; Vanzant et al., 1990; Brokaw et al., 2001), when feeding lower levels of supplements. Similar effects of levels of starch supplemented on NDF digestibility were detected for forage intake, emphasizing the role of physical factors limiting consumption of nutrients.

Sugar cane molasses has often been used as a supplement for beef cattle consuming tropical forages. According to Kellems and Church (2002), molasses contains around 44.0% sucrose and 13.0% fructose, therefore it is considered to be highly digestible in the rumen. The majority of studies using molasses as a supplement have indicated that it lowers NDF digestibility (Brown, 1993; Moore, 1999; Royes et al., 2001; Kalmbacher et al., 1995) and depresses forage intake.

Forage nutrient characteristics may influence the effects of supplementation on dietary digestion. Jones et al. (1988) compared corn supplementation for steers grazing orchardgrass (*Dactylis glomerata* L.) or bermudagrass. In this case orchardgrass hay (82.4% NDF) was of relatively lower quality or more mature than bermudagrass (79.3% NDF). Addition of corn improved ruminal fiber digestibility for orchardgrass but did not influence NDF digestibility of bermudagrass. Goetsch et al (1991) indicated that corn reduces bermudagrass NDF digestion more when its NDF concentration of the forage was lower, and they emphasized that corn reduces ruminal pH and impairs microbial

attachment (more critical for digestion of high quality forages) to fibrous particles. Horn and McCollum (1987) also affirmed that negative associative effect becomes more pronounced with increasing forage digestibility. They observed that high quality forages are ruminated less and fermented more rapidly. As a result, ruminal pH is lower and may be more easily depressed to points that decrease rate of fiber digestion and (or) washout cellulolytic bacteria by energy supplements. In addition, as forage quality increases, smaller amounts of concentrate are required to increase energy density of the total diet to points where metabolic factors have greater influence on intake.

Rumen pH

Ruminal pH has received considerable attention as the mechanism explaining reduction in forage digestibility and intake with supplementation of forage based diets. As mentioned, depression in ruminal pH leads to a shift in ruminal microbial population that diminishes forage microbial fermentation and utilization by the host animal. Optimal activity of cellulose digesting rumen bacteria is required for degradation of fiber polysaccharides. The main bacteria involved in this process are *Ruminococcus albus, Ruminococcus flavefaciens, Fibrobacter succinogenes* and *Butyrovibryo fibrisolvens*. Russel (1996) described that *Ruminococci* and *F. succinogenes* could not tolerate a pH below 5.9 and *B. fibrisolvens* were a little more resistant, tolerating pH of 5.7. However, this latter organism is not as efficient on digesting cellulose as the other species.

The literature has not always indicated a coordinated trend in depression of ruminal pH and consequent depression of digestibility and intake of forage. Jones et al. (1988) and Pordomingo et al. (1991) found no influence on rumen pH with corn supplemented up to 0.6% BW in the diet but depression of forage intake was noticed.

Even at a higher amount of supplemental corn (up to 0.8% BW), Zorrila-rios et al. (1991) did not find an influence of corn supplementation on pH depression, but forage intake was negatively affected. Conversely, Grigsby et al. (1993) noticed reductions in ruminal pH as corn was increased in the diet (0.66% BW). Similarly, Royes et al. (2001) measured a rumen pH below 6.2 at 8 and 12 hours after feeding an energy supplement, and depression in forage intake was consequently observed.

Moreover, (Vanzant et al., 1990; Brokaw et al., 2001; Heldt et al., 1999) observed minor changes in ruminal pH, or no significant differences for pH or forage intake when sorghum grain, corn, or starch was supplemented up to 0.66%, 0.34% and 0.30% BW, respectively. The minimal difference in pH and forage intake at higher levels of sorghum grain supplementation compared with corn or starch may be explained by the fact that sorghum starch is less digestible in the rumen than corn, which minimizes its negative associative effects on forage digestibility. Spicer et al. (1986) studied ruminal and post ruminal utilization of corn, barley and sorghum grain, and found less sorghum starch being digested in the rumen than in corn or barley diets. None of the previous experiments, except for the work of Brokaw et al. (2001) had a rumen pH below 6.2. Furthermore, the majority of the basal forages fed in these experiments had NDF and protein concentrations of 72% or above and 9% or below, respectively. Only Brokaw et al. (2001) deviated from the others and used irrigated and fertilized pasture averaging 18% CP in their experiment. These diets are expected to contain more fermentable carbohydrates, and the ruminal pH may be low even when no supplements are fed.

Effects of energy supplementation on forage utilization are sometimes negative; however, this response cannot always be attributed to lowered rumen pH when readily

fermentable carbohydrates are supplemented to grazing beef cattle. Other factors, such as substrate preference, in which rumen microorganisms more rapidly digest readily fermentable carbohydrates than structural carbohydrates, or a shifting in microbial population towards greater numbers of starch digesting bacteria could also cause lower digestibility of the fiber fraction and influence forage intake. Cecava et al. (1991) indicated depressed NDF digestibility (43.5 vs. 52.9 % of intake) of low a forage diet (2.17 Mcal ME/kg of diet DM) compared with a high forage diet (2.90 Mcal ME/kg of diet DM), because of a higher preference of ruminal bacteria to ferment non-structural carbohydrates associated with the low fiber diet rather than a pH effect. This theory was supported by increased digestibility of NDF (7.3 vs. 3.8 %) and ADF (6.5 vs. 2.9 %) at the hindgut.

In most of the cases, the effect of ruminal pH shifting ruminal environment occurs when higher energy feedstuffs substitute for large amounts of forage. This is sustained by Ferrell (1993) who indicated that negative associative effects of concentrate and roughage feedstuffs were most likely to occur at high levels of intake and may occur, in part, as a result of low ruminal pH and decreased rate of passage.

Suitable Energy Supplements for High Fiber Diet

The ruminant digestive system provides both opportunities to enhance and problems that can detract from productive efficiency and utilization of mixed forage and grain diets. The major impact of these feed mixtures on forage utilization is through negative interactions among forage and non-forage feedstuffs. Negative associative effects often occur when ME intake (Mcal/d) is less than expected, while positive effects occur when ME intake of the mix diet is greater than that expected. Therefore, when

grains constitute a substantial proportion of the diets, a negative effect is more likely to occur. Positive effects of the supplements can be observed if the forage is limiting in nutrient content for either rumen microbial activity or animal productivity (Dixon and Stockdale, 1999). In most instances, backgrounding cattle that have maximal forage utilization and optimal performance are most economically efficient (Ball et al., 2002). Therefore it is crucial to reduce the negative associative effects often observed when energy supplementation of basal forage diets is practiced. This section will discuss the associative effects of distinct feedstuffs in a more extensive fashion with the objective of providing alternatives to minimize such factors.

The use of concentrate feeds that contain more digestible fiber in supplements for grazing cattle may be more appropriate to improve forage utilization. Replacement of starch with non-forage NDF appears to increase digestibility of forage fiber, mostly in diets with high concentrations of non-fiber carbohydrates, apparently because of reduced negative associative effects (Firkins, 1997). In addition, for the most part, high fiber concentrates are byproducts and typically more economical than feed grains. The use of feedstuffs that minimize the negative effects of supplements on forage utilization is an attractive option to minimize costs and achieve desirable performances.

Garces-Yépez et al. (1997) investigating energy supplementation, by feeding corn/soybean meal, wheat middlings or soybean hulls to beef cattle reported no differences on forage intake, digestibility and gain when supplements were offered at 0.5% BW. However, a level of 1.0% BW hay intake was depressed by supplementation. Total organic matter digestibility and total tract NDF digestibility was higher for steers fed soy hulls (SH) at 1.0% BW, indicating that the negative associative effect was

reduced. Performance was improved at the higher level of supplementation for the SH treatment and was confirmed by higher body condition score. Grigsby (1993) replaced corn for SH in a supplement fed to beef steers grazing bromegrass. Steers were fed a 60:40 roughage concentrate ratio and supplements were fed at 0.6 % BW. The supplement containing 33% corn and 66% SH enhanced rumen NDF digestion and duodenal microbial N flow, whereas higher levels of corn inhibited fiber degradation in rumen. In a similar fashion, Royes et al. (2001) used supplemental corn, SH or sugar cane molasses for steers fed ammoniated stargrass hay at 0, 15 or 30% of diet DM or 0, 0.55 or 1.10% BW. Forage intake was depressed when supplements were fed and apparent NDF and ADF digestion decreased as the level of supplementation with corn or molasses increased, whereas increased levels of SH in the diet increased both apparent NDF and ADF digestibilities. Average daily gain did not significantly change among corn and SH treatments. Highfill et al. (1987) compared several ingredients (95% corn, 5% SBM; 100% SH; 100% corn gluten feed, CGF; 87.5% citrus pulp, 12.5% SBM; 50% SH, 50% wheat) in supplements offered to open, non-lactating beef cows fed low quality tall fescue hay. Supplements were fed at 25% of the total diet. No significant differences were detected among treatments, but fiber digestibility was affected. The SH supplement provided a higher NDF digestibility than 95% corn, 5% soybean meal. Moreover, there was a trend for increased NDF digestibility in cattle fed SH compared with the CGF and SH-wheat supplements. The ADF digestibility of the SH ration was higher than CGF or corn-SBM. In another experiment, SH were compared to corn at 0, 12.5, 25 or 50% (DM basis) of a corn stalklage diet fed to steers in work by Anderson et al. (1988). Intake and digestibility of NDF decreased with corn supplementation at all levels, when compared to

SH. In this case, ruminal pH was lower for steers supplemented with corn rather than SH. At the 50% diet DM level, steers consuming corn showed a rapid drop of ruminal pH to below 5.65. The positive interaction between SH and forages fed to steers is attributed to its highly digestible fiber, and its lack of lignin (Beef Cattle NRC, 2000)

Carey et al. (1993) observed greater NDF and ADF digestibilities, for steers fed beet pulp, comparing iso-nitrogenous supplements (195 grams of additional CP/day) containing soybean meal, corn, barley, or beet pulp fed to steers consuming average quality grass hay (predominately smooth brome; 9.9% CP). Forage intake was depressed with all sources of energy supplements. Ground corn (GC) and whole corn (WC) were compared to ground wheat (W) and sorghum grain (SG) supplemented at 1.0% BW to steers fed bermudagrass (9.7% CP; 74.9% NDF) in experiments conducted by Galloway et al. (1993). In vitro rate of disappearance of potentially digestible OM for grain was 5.6, 5.4, 4.9, and 8.6%/h for GC, WC, SG, and W, respectively. True ruminal OM digestion was lowest for SG, highest for W, and intermediate for control, GC, and WC. Live weight gain (kg/d) was 0.47, 0.84, 0.80, 0.81, 0.51 for control, GC, WC, SG, and W, respectively. The overall result indicates that grains that degraded more slowly in the rumen seemed to be used more efficiently than more rapidly degraded grains with bermudagrass as the basal forage diet for growing steers. Oliveros et al. (1989) compared corn and corn bran as energy supplements for growing steers. Alfalfa and corncobs or smooth bromegrass hay was used as the roughage in two distinct trials where supplements were offered at 25 or 50% of the total diet DM. In both trials, corn bran served as a better source of energy to stimulate fiber digestion, although it presented

some negative associative effect when compared to the control diet. As expected, the negative effects were augmented when the supplements were offered at the highest level.

Synchronization of Proteins and Carbohydrates

Rate of Nutrient Degradation

Nocek and Russel (1988) described the overall influence of nutrient degradation rates in regards to nutrient utilization in ruminants: 1) If rate of protein degradation exceeds the rate of carbohydrate (CHO) fermentation, large quantities of N can be lost as ammonia; 2) if rate of CHO fermentation exceeds protein degradation rate, microbial protein production can decrease; 3) if feedstuffs are degraded very slowly, rumen fill will decrease intake; and 4) if the degradation rate is slow, some of the feed may escape ruminal fermentation and pass directly to the lower gut.

Hydrolysis of peptides occurs rapidly, resulting in appearance of free amino acids and ammonia within few minutes after feeding and in peak of ammonia production at 1 h post feeding (Broderick, 1989). Most rumen organisms utilize ammonia as their source of N. However, some organisms preferentially degrade peptides or amino acids. Moreover, cellulolytic bacteria require branch chain volatile fatty acids (BCVFA) to grow. The BCVFA are provided as an end product of branch chain amino acid fermentation. Ruminal microorganisms attain their highest growth rates on mixtures of ammonia, amino acids and peptides (Hoover and Stokes, 1991).

Ruminal degradation of carbohydrates varies according to their molecular structure, the microbial population and environmental conditions of the rumen. Hoover and Stokes (1991) indicated that rate of digestion is the major factor controlling the availability of energy to rumen microorganisms and is directly related to the supply of

fermentable carbohydrates such as starches, pectin and sugars. These molecules are most readily digested by microorganism, and their metabolism results in energy necessary to drive microbial growth. Contrarily, polysaccharides with increased lignification, acetylation, and (or) phenolic esterification are much more resistant to rumen digestion (Jung, 1989). Therefore, forage diets rich in cellulose, hemicellulose and lignin are less degradable in the rumen compared with grain diets fed to ruminants. Weimer (1996) affirmed that lower rates of cellulose digestion have largely been blamed on effects of the plant cell wall matrix. That is because some plants cell types are digested from the inner lumen toward the primary wall and middle lamella; thus digestion of those cell walls requires that bacterial cells enter the lumina, apparently by purely passive means. Sensitivity to low pH and competition for nutrients among bacteria play major roles on regulating the rate of cellulose digestion. Effects of pH on ruminal cellulolytic bacteria is extensively mentioned and discussed as a mean to rationalize the grain induced depression on cellulose utilization in the rumen. As described, starch, sugars and pectin, are rapidly fermented in the rumen, causing ruminal pH to decline, and further affecting the population of microbes responsible for the digestion of fiber. Ruminococci and *Fibrobacter succinogenes* are both typically sensitive to a rumen pH below 6.0, but for unique reasons. *Fibrobacter succinogenes* increases pH gradient across the membrane in order to maintain a higher pH inside the cell. As a consequence, the electrical potential declines and the bacteria cell loses the ability to take up carbohydrates. The intracellular pH of *Ruminococcus albus* and *Ruminococcus flavefaciens* declines as the outside pH decreases, but growth ceases due to a negative effect on enzyme activity (Russel, 1996). The ability of rumen cellulolytic bacteria to attach onto the substrate is also diminished in

low pH environments. Miron et al. (2001), reviewing adhesion mechanisms, described studies where attachment of *F. succinogenes* was increased from pH 4.5 to 6 and then remained stable between pH 6 and 7; *R. flavefaciens* attachment was not affected between pH 3.3 and 7.5; and the optimum pH for *R. albus* attachment was between 5.5 and 8.

Synchronization Studies

Mabjeesh et al (1997) studied synchronization of nutrients providing different levels of rumen degradable protein (RDP) and rumen degradable non-structural carbohydrate (RDNSC) to dairy cows. The low RDP diets demonstrated higher digestibility, intake and total CP and bacterial crude protein (BCP) flow. Therefore a higher efficiency of BCP synthesis was observed for the low RDP, low RDNSC diet. The results were somewhat unexpected. The author speculated that a short-term asynchrony of high RDP diets would lead to ammonia accumulation in the rumen, and increased absorption and conversion to urea in liver. A deficiency of amino acids and peptides in the rumen for the high RDP, high RDNSC may also explain the results. The low RDP, low RDNSC had greater amounts of amino acids than the high RDP, high RDNSC diet, therefore amino acids were not limiting BCP synthesis.

Henning et al. (1993) conducted an experiment with the objective of minimizing confounded effects of ingredients in synchronization of energy and N supply. Equal amounts of soluble carbohydrates and N (urea and sodium caseinate) sources were ruminally infused in sheep at continuous doses or in two pulse doses in four treatment combinations. These treatments represented either slow or rapid availability of carbohydrates and (or) protein in rumen. The authors concluded that providing a balanced supply of ruminally available OM and N in daily intake does not improve rumen

digestion and microbial protein synthesis. This coincides with work of Casper et al. (1999), who achieved similar results in an experiment conducted with mid-lactation dairy cows. However, the experimental diets in that study did not provide a wide range of variation for RUP, due to inconsistency on degradability of extruded SBM sources used.

Petit and Veira (1994) were interested in increasing the utilization of soluble N from timothy (*Phleum prarense* L.) grass silage. They attempted to synchronize soluble N with carbohydrate by supplementing molasses, a source of readily available sugars, and (or) canola (*Brassica napus* L.) meal, a degradable protein source. A decrease in ruminal ammonia concentration and similar effects on N retention or plasma urea concentration with molasses supplementation were observed. The decrease in ruminal ammonia concentration was probably not caused by higher efficiency on microbial synthesis but to lower digestibility of CP. On the other hand, intra-ruminal administration of 1 kg of sucrose as a continuous dose or as two-6 hr infusions increased microbial protein synthesis (Kim et al., 1999). Overall results of the two experiments did not show any significant improvement in nutrient utilization for the synchronized diets (Petit and Veira, 1994; Kim et al., 1999).

Mansfield et al. (1994) utilized a continuous culture experiment to describe the effects of non-fiber carbohydrates (NFC) and RDP on BCP synthesis. Corn and soybean hulls (SH) were used as representative carbohydrate sources. Four fermenter flasks were inoculated with ruminal fluid from four lactating cows fed mixed diets identical to those supplied to fermenter flask. The pH was maintained at 6.4 ± 0.05. Non-fiber carbohydrates did not affect specific flows of N, but lower RDP increased flow of dietary N and decreased proportions of bacterial N flow. The data indicate that SH supported

similar microbial protein synthesis compared with corn, and synchronization of RDP was important to stimulate microbial protein synthesis.

Nocek and Russel (1988) compared the efficiency of four theoretical diets with different sources of carbohydrates and degradable proteins on microbial protein synthesis.

Microbial yield was calculated as:

$$Y_g = \text{g microbes/ g of CHO} \qquad \text{Eq. 10}$$

$$1/Y = \text{maintenance/ k} + 1/Y_g \qquad \text{Eq. 11}$$

Where:

Y_g is the theoretical maximum microbial yield; 1/Y is the microbial yield; and k is growth rate. Y_g was assumed to be 0.4 g bacteria/g fermented carbohydrate, while passage rate of liquid, forages and concentrate was assumed to be 0.13 h^{-1}, 0.03 h^{-1} and 0.05 h^{-1}, respectively.

The rapidly available carbohydrate diet with either rapidly or slowly available protein resulted in the highest microbial yield. However, when the amount of dietary CP degraded in the rumen was measured, a dramatic difference in the pool of non-microbial amino acids was observed. Dietary CP was insufficient to meet requirements for microbial synthesis previously calculated for the readily available carbohydrate, slowly available protein diet, showing the relevant importance of synchronizing carbohydrate and protein sources. This coincides with the work of Herrera-Saldana et al. (1990) with diets based on milo, barley, brewers-dried grain and cottonseed meal (CSM). Barley and

CSM were more rapidly and extensively fermented in the rumen, stimulating microbial protein synthesis. It was also evident that starch digestibility influences nutrient utilization in the rumen to a greater extent than protein. The work of Shabi et al. (1998) reassures the importance of available energy in the rumen. Cracked corn, expanded corn (heat treated), SBM and lignosulfated SBM were used as sources of rumen degradable and undegradable carbohydrates and CP, respectively. Lower plasma urea N (PUN) concentration and higher CP flow to the abomasum indicated a better efficiency in utilizing N with high rumen degradable carbohydrate diets, regardless of the source of protein. The lowest ruminal NH_3 concentration measured by Shabi et al. (1998) or Herrera-Saldana et al. (1990) was 16 mg/ dl and 13 mg/ dl, above minimum concentration (5 mg/ dl) recommended for efficient microbial growth (Satter and Slyter, 1974), but inferior to requirements stipulated by Mehrez et al. (1977) of 23.5 mg/ dl. Therefore, either dietary protein and (or) N recycling are providing sufficient supply of ruminal ammonia for maximum microbial growth, minimizing the role of protein synchronization.

As mentioned previously, 23 to 92% of plasma urea can be recycled to the digestive tract, via saliva and (or) by diffusion through the rumen wall (Owens and Zinn, 1993). Hence, it is plausible that N recycled to the rumen is contributing for the rumen N pool, masking dietary N effects. In a continuous culture study Griswold et al. (2003), examined the effects of low and high degradable protein, with or without the addition of urea infused as artificial saliva to simulate the action of N recycled to the rumen. The level of urea infused was based on physiological levels found in ruminant saliva. The

study demonstrated that N infusion affected all of the N partitioning and microbial protein synthesis measurements.

Other factors might also be contributing for the outcome of nutrient synchronization studies in this dynamic environment. As mentioned by Henning et al. (1993), feedstuffs can confound effects among experiments, mainly because of their different rumen degradability rates. The action of rumen protozoa on carbohydrate metabolism may also play an important role. Mendoza et al. (1993) showed differences on starch metabolism of defaunated and faunated sheep. Amylase activity, starch digestion and rate of digestion were all increased with defaunation, probably due to the capacity of ruminal protozoa to engulf starch granules and (or) to the predatory effect of protozoa on ruminal bacteria, which reduces the bacterial population and probably bacterial amylase as well as synthesis of microbial protein.

Conclusions

This review of the current literature relating to supplementation of grazing beef cattle diets indicates the complexity of interacting factors inherent to the dynamic gastro intestinal physiology of ruminants, and from the variability of feedstuffs consumed. The importance of energy to sustain elevated levels of gains in grazing beef cattle is unquestionable. However, detrimental effects on forage utilization are often observed mainly if considerable levels of readily digestible feedstuffs are used. The use of a highly digestible NDF energy source is recommended to minimize negative effects on forage utilization in order to support the sustainability of the system.

Utilization of medium to low-quality forages by growing steers is most always improved with high levels of protein supplementation. The use of non-protein N is

desirable to decrease feed cost but a maximum level of approximately 40% of the total RDP requirement is recommended to avoid deficiencies of microbial growth factors. Nitrogen is mainly recycled to the rumen if total N intake is low. The importance of synchronization of nutrients for more efficient ruminal fermentation is desirable. However, N recycling, and (or) the action of ruminal protozoa, may be confounding factors affecting results of studies in the literature. A requirement for RDP or RUP supplementation has demonstrated to be highly variable and it seems to be dependent on the supply of CP from the basal forage and the type and amount of energy being digested. More research is needed to accurately define these requirements in order to maximize the use of protein supplementation.

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CHAPTER 3

SUPPLEMENTAL PROTEIN TO ENHANCE NUTRIENT UTILIZATION OF STEERS FED HIGH FIBER HAY[1]

[1]Paiva, N. N., M. A. Froetschel, and G. M. Hill. To be submitted to the Journal of Animal Science.

Abstract

Metabolism and performance studies were conducted to evaluate effects of incremental levels of rumen undegradable protein (RUP) on nutrient utilization of growing steers fed high fiber hay. Metabolism study: Holstein steers (n = 6, 217 ± 13.8 kg) were used in a replicated 3 x 3 Latin Square designed experiment. Incremental levels of RUP (32.5, 40.13, and 42.48% of CP) were fed as supplements at 1.72 $kg \cdot hd^{-1} \cdot d^{-1}$ (AF) to a bermudagrass (*Cynodon dactylon* L.) hay diet (10.2% CP, 76.4% NDF). Supplements were iso-nitrogenous (25.9% CP) and fed as pressed molasses blocks. The RUP was controlled by feeding different ratios of SBM, corn gluten feed, poultry protein meal and soy hulls. Corn was added to the diets to increase energy levels. Steers were fed treatments for 14 days. Steers were placed in metabolism crates for total fecal and urine collection from d 10 to d 14. Jugular blood was sampled before and after feeding on day 10 and 14, respectively. Hay and total DMI increased (3.95 to 4.27 kg/d and 5.56 to 5.92 kg/d) with RUP ($P < 0.05$). Fiber digestion was larger ($P < 0.05$) when steers were fed the high RUP diets due to inclusion of soy hulls; however DMD, OMD and DE were not affected ($P > 0.10$). Urinary N output was lower ($P < 0.05$; 23.82 ± 1.45 g/d) in steers fed the high RUP diets but treatments did not affect N retention ($P > 0.10$; 49.46 ± 2.13 g/d). Blood urea nitrogen (BUN) increased after feeding ($P < 0.05$; 14.15 vs. 16.3 mg/ dl) and tended to be negatively related to RUP. Performance study: British and Brahman x British steers (n = 48; 252.15 ± 22.5 kg initial BW; age 9 mo.) were ranked by BW, randomly allocated to one of 8 pens and fed supplement in two forms (pressed blocks or meal) and two levels of RUP (27 vs. 44% of CP for blocks and 30 vs. 46% of CP for the meal) in a 63-d 2 x 2 factorial feedlot trial. Bermudagrass hay (13.1% CP, 74.59% NDF)

was offered free choice and supplements were fed at 1.72 $kg \cdot hd^{-1} \cdot d^{-1}$. Blood samples were collected on d 21 and d 63. Total DMI was not affected by treatments. Steer ADG (0.67 ± 0.05 kg) did not respond to RUP or form of supplement. Diet evaluation indicated that ME allowable gain was lower than the MP allowable gain. BUN was lowered with RUP (14.1 vs. 12.1 mg/ dl; $P < 0.01$) and at d 21 than at the d 63 of the experiment. An interaction between RUP levels and form was observed for blood glucose and insulin ($P < 0.01$). Despite some indications that RUP improved nutrient utilization, animal performance was not affected, mainly because of low range of RUP consumed among treatments and that energy was restricting performance and the need for additional RUP.

Introduction

The ability to sustain improved pastures year-round makes the southeastern United States an attractive area for grazing beef cattle. Cow calf operations are the predominant production system with the weaned calves shipped to feedlots or backgrounded in selected pastures.

Backgrounded animals are grazed on high quality pastures from weaning to usually 320 to 360 kg (Ball et al., 2002). Historically, the number of backgrounded calves represents a small fraction of the total cattle raised in the Southeast. According to the USDA National Agriculture Statistical Service (2003) the total number of calves in the Southeast during the year of 2002 under 226 kg body weight was 1,166,000 head and the number of steers above 226 kg was 138,000 head. Assuming those calves that weigh above 226 kg are being backgrounded this represents only 10.6% of the calf crop. One of the main reasons for this relatively low percentage is that backgrounding beef cattle is high-risk, mainly due to lower live cattle prices that occur with increments of body weight. Relatively high ADG attained at relatively low-cost are necessary to offset this effect and generate profit during backgrounding. Ball et al. (2002) estimated that profitable stockering of young growing cattle requires 0.68 kg of ADG. Assuming a dry matter intake of approximately 2.5% of body weight, a 250 kg steer requires 7.31% of MP or 9.94% CP, 4.84 Mcal/d of NE_m and 1.92 Mcal/d of NE_g or 63% TDN to achieve such performance (Beef Cattle NRC, 1984; Beef Cattle NRC, 2000). The nutrient composition of vegetative Coastal bermudagrass (*Cynodon dactylon* (L.) Pers) is 12.6% CP, 1.44 Mcal/ kg NE_m, 0.86 Mcal/ kg NE_g, and 64% TDN, and the nutrient composition

of Coastal bermudagrass hay, which more resembles dormant pastures is 7.8% CP, 0.93 Mcal/kg of NE_m, 0.39 Mcal/kg NE_g (Beef Cattle NRC, 2000).

Maximal use of grazed forage is vital to optimize economic returns and sustain production of backgrounded beef cattle. Adequate climate conditions to produce higher quality forages are necessary to provide nutrients to furnish the requirement for growing cattle consistently. Warm season perennial grasses cultivated in the southeastern U.S. fail to consistently supply such needs, especially in times of drought. Forage nutrient supply of the grasses declines during mid-summer to autumn as pastures mature and become dormant, diluting energy and protein content with fiber. At this point the upcoming cool season annual forage is not yet ready for grazing. This was demonstrated in a 3-year study where cattle grazing Tifton 85 bermudagrass gained 0.88 kg/d, from April to July, but only 0.43 kg/d from July to October (Hill et al., 1993). Hence, supplementation of pasture is necessary to obtain satisfactory levels of production. Cost-effective supplementation still should maximize the use of pasture nutrients, resulting in higher production at lower feed costs. Ferrell et al. (1999) suggested that forage use and beef cattle performance when consuming low quality forage, can be enhanced by providing supplements with relatively high concentrations of CP. However, ruminant nutritionists have segregated dietary proteins into two categories known as ruminal degradable protein (RDP) and ruminal undegradable protein (RUP) and it is still a subject for debate whether to use RDP or RUP to support grazing performance of growing calves. Karges et al. (1992) indicated that responses to non protein nitrogen (NPN) supplementation are variable when compared to natural sources of RDP. They suggest that natural RDP sources contain some RUP that may be responsible for improved performance. On the

other hand, research conducted by Olson et al. (1999) using low quality hay (4.9% CP) indicates that providing supplemental RDP to growing steers increased organic matter (OM) intake and digestion. Clearly, there is a need for further investigation for the different aspects of RUP versus RDP supplementation of forage diets fed to backgrounding calves.

Our laboratory has successfully developed a molasses pressed block to serve as an economical supplement for grazing beef cattle (Kumar, 2000; Wicklife, 1999). Self-fed supplements act as a cost-reducing factor and may also contribute to enhance animal performance compared with feeding a dry meal supplement. The hardness of the block may regulate its intake and more effectively deliver nutrients to support rumen fermentation.

The objective of this research was to determine effects of increasing RUP supplementation of growing beef cattle fed high-fiber hay diets using two supplement delivery systems.

Materials and Methods

Metabolism Study

A metabolism study was conducted to identify the effects of supplemental levels of RUP on nutrient utilization of steers fed free choice chopped bermudagrass hay (10.2% CP, 76.4% NDF). Six Holstein steers (217 ± 13.8 kg BW) were used in a 3 x 3 Latin Square experiment. The experimental protocol was approved by the University of Georgia Institutional Animal Care and Use Committee, IACUC # A2003-10037-0. Steers were kept indoors at the University of Georgia large animal research unit in a continuously lighted, temperature-controlled (22 °C) environment with free access to

water at all times. During the first 10 days of each experimental period, steers were housed in individual pens (2.3 x 3.5 m) and then moved to metabolism crates for total fecal and urine collection for the next four days. Supplements were fed at 1.72 kg/d as pressed molasses feed blocks, manufactured by compressing 2.08 kg of the ingredient mixture into a 20 cm diameter polyvinyl chloride cylinder using a hydraulic press. Blocks were then dried in a forced air oven at 80 °C for approximately 72 hours. Ingredients were selected to attain required RUP levels as described by the Beef Cattle NRC (2000) using suitable ingredients to manufacture compressed feed blocks (Table 3.1). Previous work developed by our laboratory have indicated that approximately 35% molasses and 20% of a high-fiber concentrate are necessary to facilitate the binding of feedstuffs within feed blocks, producing a stable (low moisture) product (unpublished data). Therefore, according to these implied restrictions and to the objective of the experiment, iso-nitrogenous blends containing either soybean meal/ corn gluten feed (low RUP) and poultry protein meal/ soy hulls (high RUP) were formulated to obtain blocks that had three distinct levels of RUP. Corn was added to the supplement mixtures in an attempt to make them isocaloric. All supplements contained 10% broiler litter, which served mainly as a source of minerals, fiber and RDP. The mineral concentration of the broiler litter used in the diets is listed as follows (ppm): 20,200 Ca; 16,900 P; 6,200 Mg; 31,900 K; 6,600 Na; 10,200 S; 435 Cu; 1,805 Fe; 490.5 Mn; 2.4 Mo; and 495 Zn. The soybean meal/ corn gluten feed blend was linearly substituted (0, 50 and 100 %) for the poultry protein meal/ soy hulls blend to accomplish incremental levels of RUP. The RUP portion of the CP was estimated using Beef Cattle NRC (2000) tabular values, to be 26.5, 35.3 and 44.0% for low RUP (LRUP), medium RUP (MRUP) and high RUP (HRUP)

treatments. In situ ruminal degradability was determined for the supplements utilized in this experiment, using a standardized procedure described in the Dairy NRC (2001) of the non-linear regression model developed by Ørskov and McDonald (1979).

Sampling and Laboratory Analysis

Feed intake was measured daily and feed block and hay were sampled daily and composited by week for each period. Total fecal and urine were measured and sampled every day during the 4-d collection period while steers were in metabolism crates. Urine samples were frozen for further analyses, and composite feed and fecal samples were dried in a forced air oven (55 °C) to constant weight to estimate dry matter (DM). Concentrations of all nutrients were expressed on a DM basis (lab dry matter). Feed and fecal samples were ground and analyzed for CP (Leco FP 528 N analyzer, Leco Inc. St. Joseph, MI), NDF and ADF (Ankom 200, Fairport, NY), and gross energy (Parr Instrument company, Ltd. Moline, IL). Concentration of CP (Leco FP 528 N analyzer, Leco Inc. St. Joseph, MI) was also determined on the urine samples. Jugular blood was sampled immediately before and approximately five hours after feeding on the first and last day (d 10 and d 14) of the collection period, respectively, prepared as plasma and serum, and then frozen. Blood serum samples were analyzed for urea nitrogen (Sigma diagnostics Kit, procedure number 640, St. Louis, MO) and insulin (ImmuChemTM125I RIA kit., ICN Pharmaceutical., Inc., Costa Mesa, CA) and plasma samples were analyzed for glucose (Sigma diagnostics Kit, procedure number 315, St. Louis, MO).

Nitrogen Measurements

Total feed intake, fecal and urine output and respective CP measurements were used to determine total N intake, and fecal and urine N output. The N retained (g/d) was

calculated as the difference of total N intake and total N output (fecal and urine). The N digestibility was determined using the difference between total N intake and fecal N output divided by the N intake. Nitrogen retained (% of N digested) was estimated as grams of N retained divided by grams of N digested.

Digestibility

Nutrient digestibility was measured using the differences between total nutrient intake and fecal nutrient output, divided by the total nutrient intake for each collection period. Digestible energy (DE) was estimated (Mcal) using the difference between gross energy (GE) intake and fecal GE excreted.

Statistical Analyses

Data were analyzed for treatment effects using the General Linear Model procedure of SAS (SAS, 2002) for a replicated 3 x 3 Latin Square design. A nested interaction was used as an error term to test main effects of experimental observations that had replicated measurements during a collection period.

Performance Study

Forty-eight British and British x Brahman steers weighing 256.7 ± 10.20 kg at approximately 9 months of age were used in a 63 d, 2 x 2 factorial experiment to evaluate supplementation of RUP and form of supplement on a high forage diet. The experiment was conducted at the Animal and Dairy Science Research Farm, Coastal Plain Experimental Station, Tifton, GA. Steers were handled and managed under guidelines approved by the University of Georgia animal care and use committee. Treatments consisted of supplementing a low and a high level of RUP in a feed block or in a standard meal supplement at 1.72 $kg \cdot hd^{-1} \cdot d^{-1}$. Levels of RUP were estimated at 27.72% and

44.03% of CP for the low and high RUP of the feed blocks and 30.72% and 46.55% of CP for the low and high RUP of the meal supplements, respectively. Ingredient composition of the feed blocks and meal supplement are described in Table 3.10. The same ingredients used to formulate supplements in the metabolism trial were utilized in this study but only 5% of molasses was used in the meal supplements, compared to 35% of molasses in the feed blocks. Higher levels of corn were used in the meal supplements to replace the molasses and maintain the DE at the same level as the feed blocks. Larger feed blocks (23.36 cm height x 20 cm diameter) were manufactured for the performance study, and blocks weighed 9.07 kg each. Treatments were described as block low RUP (Block LRUP), block high RUP (Block HRUP), meal low RUP (Meal LRUP) and meal high RUP (Meal HRUP). Coastal bermudagrass hay (13.1% CP, 74.6% NDF) was offered free-choice. Steers were ranked by weight and randomly allocated to one of eight pens. Initial and final BW, were determined as the average body weight at the first and last two days of the experiment, respectively. Body weight was also recorded before feeding on days 23 and 43. Feed intake was measured every other day and orts were discarded. Jugular blood was sampled on day 21 and 63, and prepared as plasma and serum for urea N (Sigma diagnostics Kit, procedure number 640, St. Louis, MO), glucose (Sigma diagnostics Kit, procedure number 315, St. Louis, MO) and insulin (ImmuChemTM125I RIA kit., ICN Pharmaceutical., Inc., Costa Mesa, CA) analyses.

On the 30th and 33rd day of experiment, one steer from pen 5 and one steer from pen 6 were removed from the experiment because of foot injuries, not related to treatments.

Statistical analyses were determined using GLM procedure of SAS (2002) for a complete randomized design with a 2 x 2 factorial arrangement of treatments. Repeated measurements were analyzed using the split-plot procedure of SAS (2000) with a fixed error term.

Results and Discussion

Metabolism study

Diet Description

The experiment was designed to provide different levels of RUP for steers consuming bermudagrass hay, a low energy diet, targeting better utilization of nutrients by the animals and consequently better performance. In theory this type of diet fed to backgrounded steers would increase the need for RUP since microbial protein synthesis would be limited by lack of fermentable carbohydrate in the rumen. Table 3.2 describes the estimated and measured nutrient composition of bermudagrass hay, and the experimental supplements fed to growing steers. In general, diet CP values measured were close to the expected concentrations. However, the range of differences between RUP values across treatments measured (Table 3.3) using the in situ procedure proposed by Ørskov and McDonald (1979) was lower (32.5, 40.13, and 42.8%) than the expected values (26.46, 35.24, and 44.03%) for the low, medium and high RUP treatments, respectively. Neither Beef Cattle NRC (2000) nor the Dairy Cattle NRC (2001) describe values for pet food grade poultry protein meal (PPM). Diets were formulated based on recent literature values for pet food grade PPM (Bohnert et al., 1998) of 55% RUP as portion of the CP. The source of poultry protein meal and probably some variations from tabular values of RUP for other ingredients may be causing the measured RUP value to

deviate from previous estimates (Bohnert et al., 1998; Beef Cattle NRC, 2000). The neutral detergent fiber (NDF) proportion of experimental feed blocks increased linearly along with the concentration of RUP in the diets because of the presence of soy hulls in the high RUP diets. Soy hulls represent a relatively high RUP source (42% of CP; Beef Cattle NRC 2000) and it provides the fiber needed for the binding of feedstuffs within the block. At lower DM intake, the RDP was reported to be 34% of CP for soy hulls (Dairy Cattle NRC (2001).

Intake

Both DMI and intake as percent of body weight are reported in Table 3.4. A main treatment effect was observed for block DMI ($P < 0.05$), but no difference was detected for block intake as percent of body weight. Steers fed the LRUP block consumed 3% less than steers fed the MRUP or HRUP. The highest variation in block intake was observed during the first phase of experiment and it was probably related to steer behavior in the metabolism crates. This is sustained by a treatment effect ($P < 0.01$) observed for block dry matter intake when steers were in the crates during the total collection period (Table 3.5). Except for some initial reluctance to consume the blocks, steers maintained regular consumption of the supplement throughout the rest of the experiment. Supplementation with RUP linearly increased hay DMI ($P < 0.10$), as well as hay intake as a percent of BW ($P < 0.10$). The majority of the studies done with protein supplementation for growing cattle fed similar diets utilized in this experiment have suggested an increase (Bandyk et al., 2001; Olson et al., 1999; Köster et al., 1996; Newbold et al., 1987) or no effect (Bohnert et al., 2002; Mathis et al., 2000; Hollinsworth-Jenkins et al., 1996) on forage intake with the increment of RUP. The positive effect of RUP on intake observed

in this study is not fully elucidated. One possibility is that the rumen degradable portion of the high RUP diets may be more slowly degraded in rumen and consequently better synchronized with the rumen carbohydrate available from forage. Another reason may be related to the animals fed high RUP are more appropriately meeting their essential amino acid requirements. It is well recognized that diets that provide an appropriate balance of essential amino acid in non-ruminant animals will result in improved intake. Canseco et al. (2002) also found positive effects on intake of dairy cows fed high RUP diets with high concentrations of PPM. As a consequence of the significant effect of block and hay intake, positive linear effect for total DMI ($P < 0.05$) and total intake as percentage of BW ($P < 0.05$) was also observed for calves fed the high RUP treatment. Table 3.5 describes the DMI in kg or as percent of body weight for each treatment when steers were in metabolism crates. Calves fed MRUP treatments had a slightly higher block dry matter intake ($P < 0.01$) as compared to calves fed the other treatments.

Table 3.6 describes individual nutrient intake when different levels of RUP were fed to growing steers. Total organic matter ($P < 0.05$), RUP ($P < 0.05$), MP ($P < 0.05$), NDF ($P < 0.05$), NDFD ($P < 0.05$; Linear $P < 0.05$), ADF ($P < 0.05$), DE ($P < 0.10$; Linear, $P < 0.10$), and TDN (Linear, $P < 0.10$) increased with the addition of RUP in the diet. Even though there was a linear increase ($P < 0.05$) in RUP consumed it only increased 4.7% and this may have not been enough to improve performance. The increase in RUP corresponded to a linear increase in MP that was 4.0 to 10.2% greater with the MRUP and HRUP diet, respectively. Total protein intake was higher than requirements established by Beef Cattle NRC (2000). However, it was assumed that protein associated with the fiber portion of the forage source would be indigestible and not actually

contribute to the MP. The Dairy Cattle NRC (2001) indicated that bermudagrass hay has approximately 4.0% of DM of neutral detergent indigestible crude protein (NDICP).

Apparent Digestibility

Apparent digestion of nutrients is reported in Table 3.7. Total tract NDF digestibility (NDFD) was greater ($P < 0.05$) in calves fed the high RUP treatment than those fed the low RUP treatment. The same trend was followed by ADF digestibility (Linear, $P < 0.06$). If digestibility of all other nutrients remained constant, an increase in total tract DM and OM digestibility would be expected with these changes in fiber digestibility. However, total tract DM and OM digestibilities were not influenced ($P > 0.10$) by treatments despite increases in fiber digestibility. This can be partially explained by a trend in depression of CP ($P = 0.17$). Improved NDF digestibility is often observed as response to supplemental protein but this response is generally though to be a result of RDP as opposed to RUP. Under conditions of limited ruminally available N, the provision of degradable protein should maximize NDF digestibility because of greater microbial growth. This was well characterized in the study of Köster et al. (1996), where NDFD was increased when tallgrass prairie forage was supplemented with 360 g of RDP but tended to decline at higher levels of supplementation. The increased NDFD with the HRUP diet may be related to its higher NDF content due to soy hulls (67.2% NDF) and poultry protein meal (43.4% NDF) used to formulate the diet. Neutral detergent fiber concentration of these two ingredients in the HRUP diet was 153% of the total NDF concentration present in the LRUP diet. It appears that more digestible NDF was supplemented with the HRUP treatment and responsible for the increased fiber digestibility. There were no differences observed for DE since it is a function of the total

tract DM digestibility. The NE_m and NE_g were calculated using Beef Cattle NRC (2000) equations based on TDN that was predicted from actual DE measured.

Nitrogen Metabolism

Nitrogen measurements calculated from total collection data are expressed in Table 3.8. As expected, N intake (g/d) was not altered across treatments in accordance with the intention to offer iso-nitrogenous diets. The only parameter involved in measuring N balance that was influenced by treatment ($P < 0.05$) was urinary N. The calves fed MRUP treatment had greater urine N output (29.46 g/d) than the LRUP (27.24 g/d) or the HRUP (23.82 g/d) and there was a quadratic response for this parameter ($P < 0.05$). Fecal N output and total N output (urine and feces) were not different between treatments. Even though urinary N output was influenced by the level of RUP fed, N retention g/d (49.5 ± 2.13) and as a % of N digested (63.96 ± 1.99) were both not influenced by treatment. If a value of 0.19 g of tissue protein/ unit of gain is used (NRC, 1985) predicted ADG during this trial was greater than that expected. This is likely due to overestimates of N intake and (or) failure to totally recover the N excreted. A trend ($P = 0.17$) for decrease N digestion with increased RUP diets was detected, and likely explains that RUP did not affect N retention. Canseco et al. (2002), using the mobile dracon bag technique, reported a 14.5% lower intestinal digestibility for PPM than for SBM. Hence, it is possible that PPM lowered CP digestibility in calves fed the HRUP treatment. Our N metabolism results concurs with results of Bohnert et al. (2002) who found no difference on efficiency of N use in lambs consuming low quality forage with CP degradability. The lack of effect on N retention suggests that with high fiber forages (approximately 2.40 Mcal/ kg of DE) energy rather than MP supplementation was more limiting in nutrient

utilization. Merchen et al. (1987) did not observe any effect in an N balance trial where lambs received supplemental protein sources (urea, soybean meal or cotton seed meal) with different RUP concentrations for a forage basal diet containing low levels of energy (2.16 Mcal/ kg DE) and 8 to 9% of crude protein. Digestible energy was probably more limiting than protein, since only low levels of supplemental protein were necessary to meet the requirement.

Blood Metabolites

Blood urea nitrogen (BUN), glucose and insulin determination from blood collected immediately before feeding (BF) and 5 hours after feeding (AF), are reported in Table 3.9 for the LRUP, MRUP and HRUP treatments. Blood urea nitrogen concentration in steers fed the high RUP diet tended to be lower ($P = 0.17$) than in the steers fed the low and medium RUP diets. Harmeyer and Martens (1980) affirmed that nitrogen intake is the major determinant of urea synthesis and that urea concentration in plasma is generally more positively related to daily N intake than other parameters. The data of Bohnert et al. (2002) did not indicate any difference in plasma urea N of grazing steers regardless of the protein degradability supplemented. The results of this study indicated that the ratio of RDP and RUP is also related to BUN concentration. Blood urea nitrogen was lower before feeding than 5 hours after feeding ($P < 0.05$). A time and treatment effect was tested as well, but none of the parameters measured showed significant difference ($P > 0.10$). No differences were detected for glucose or insulin. The rise of BUN, glucose and insulin after feeding were compared and no differences ($P > 0.10$) could be observed.

Performance Study

Diet Description

This trial was conducted with the objective to test the performance of beef steers fed Coastal bermudagrass hay supplemented with different RUP levels using a standard meal or a feed block supplement. Table 3.11 expresses the predicted nutrient concentration and the actual values measured in the laboratory. It should be noted that the estimated CP and TDN concentration of the supplements were not equal among treatments when expressed on a DM basis. However, estimated DM percentage of the diets was inversely proportional to protein and energy values. The same amount of supplement was fed (AF basis) for all treatments to supply equal amounts of CP and similar TDN on a DM basis. However, predicted differences in dry matter concentrations between blocks and meal were decreased when actually determined. In-situ rumen protein degradability for the diets used in this trial are not reported, but a similar tendency of the metabolism study diets for diminishing differences across treatments compared to predicted values should be expected since the ingredients were the same.

Intake

The DMI (kg and % of BW) is reported in Table 3.12. Hay DMI as well as intake as percent of BW were not influenced by level of RUP or the physical form (block or meal) of supplement fed. This observation is consistent with reports in the literature. Consumption of supplement as percent of BW was influenced by level of protein ($P < 0.01$) with an interaction between physical form and protein ($P < 0.05$). Consumption of the block LRUP (kg) was lower than the others ($P < 0.01$). During the first phase of the experiment, feed blocks were offered as a large block (10.32 kg) to 6 steers in a pen. The

blocks were fed in this manner to be consistent with the hypothesis that the slower ingestion of feed block could more effectively deliver nutrients to support rumen fermentation. However, a large variation in DMI among individual animals of the same group was observed (data not shown), and was believed to cause differences in supplement intake by individual animals within a pen. In an extended review about supplement delivery method Bowman and Sowell (1997) listed a number of experiments where block consumption by individual animals was highly variable by individuals within a group of ruminants and that the mean intake as a proportion of the target intake was significantly more variable for block than for meal fed animals. In order to minimize such variation and to distribute the block supplement to the steers in the pen, the blocks were broken into smaller pieces prior to feeding them to the steers. Although the comparison of delivery method was sacrificed the cattle received more uniform amounts of supplement. Table 3.13 describes the total nutrient intake of steers fed the supplement treatments along free access to hay. Total diet nutrient intake was calculated from measured values (CP, NDF, and ADF) and estimated values from Beef Cattle NRC (2000) for MP, RUP and TDN.

Performance

Animal performance data is reported in Table 3.14. Average daily gain and gain to feed ratio were not influenced by treatment ($P > 0.10$). The literature reports a relatively high variation in response (performance and forage utilization) of grazing beef cattle fed different levels of supplemental degradable protein (Mathis et al., 2000; Bandyk et al., 2001; Olson et al., 1999; Hollingsworth-Jenkins et al., 1996; Köster et al., 1996; Hafley et al., 1993; Karges et al., 1992; Merchen et al., 1987). Variability found in

studies is related to the animal requirement for metabolizable protein, and the concentration and rumen degradability of the protein and energy supplied by the forage. The diets offered in this experiment were evaluated using the Beef Cattle NRC (2000) Model, Level 1. The evaluation parameters are reported in Table 3.15. It is evident that all four diets supplied enough MP and RDP necessary for the predicted level of energy consumed by steers. Also, ME predicted less allowable gain than MP. Therefore, it is it is presumed that energy was limiting performance and preventing gain from the MP. Nicholson et al. (1992) noted difficulty in eliciting response in performance of yearling cattle to manipulation of protein in the diet; presumably because the requirement for MP was low. Additionally the Beef Cattle NRC (2000) Model Level 1 did not accurately predict the actual gain achieved by the steers. This was probably related to small differences between the estimated and the actual energy consumed.

Blood Metabolites

Blood parameters are expressed in Table 3.16. The main effects of protein, form and period and their interactions were statistically tested. Low RUP diets showed higher BUN than high RUP diets ($P < 0.01$). Nicholson et al. (1992) working with cattle consuming legume silage supplemented with urea, soybean meal or fish meal also found higher BUN values when the higher degradable protein sources (urea and soybean meal) were fed. The study of Nicholson et al. (1992) and Sultan et al. (1992) demonstrated that rumen fluid ammonia N was greater for high rumen degradable supplements and that the change was in parallel with BUN. Thus it is plausible to expect a higher ruminal ammonia N for calves fed the low RUP diets. Blood urea N was lower at d 21 than at d 63 ($P < 0.01$). A form by protein interaction was detected for glucose and insulin ($P <$

0.01). The calves fed block HRUP and meal LRUP had 24.16 and 58.9% higher glucose and insulin than calves fed block LRUP and meal HRUP, respectively. Insulin also demonstrated a period by protein interaction ($P < 0.10$). No main effect was detected for either glucose or insulin.

Conclusions

Despite indications of better forage intake and better N utilization by steers fed the HRUP treatment, there were no conclusive signals that forage utilization and growing beef cattle performance were different between the levels of RUP supplemented in this experiment. It can be asserted that higher levels of energy supplementation of the basal forage were needed to take advantage of the additional MP by increasing the RUP percentage in the diet to maximize growth of backgrounded beef cattle.

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Table 3.1 Ingredient composition of compressed feed blocks[1]

	Treatment[1]		
Item	**LRUP**	**MRUP**	**HRUP**
	% DM		
Cane molasses	35.0	35.0	35.0
Corn	0	3.0	6.0
Broiler litter	10.0	10.0	10.0
Poultry protein meal	0	13.0	26.0
Soybean meal	32.1	16.1	0
Corn gluten feed	22.9	11.4	0
Soy hulls	0	11.5	23.0

[1] LRUP (Low RUP) = 100 % soybean meal/ corn gluten feed blend. MRUP (Medium RUP) = replace 50 % soybean meal/ corn gluten feed blend with poultry protein meal/ soy hulls blend. HRUP (High RUP) = 100 % poultry protein meal/ soy hulls blend.

Table 3.2 Nutrient composition of bermudagrass hay and compressed feed blocks[1]

	Hay	Feed blocks		
		Treatment		
Nutrient		**LRUP**	**MRUP**	**HRUP**
Estimated values	---------- % ----------			
DM[2]	91.17	90.75	90.75	90.75
CP	9.62	25.94	25.94	25.94
RUP (% CP)[3]	23.00	26.46	35.24	44.03
RUP (g/d)[4]	84.41	106.89	142.36	177.88
TDN	52.54	78.73	77.23	75.71
NDF	75.97	15.06	23.19	31.32
Calcium	0.43	0.73	2.14	3.55
Phosphorus	0.20	0.62	1.15	1.69
Laboratory values	---------- % ----------			
DM	91.83	91.22	94.58	94.07
CP	10.15	25.43	24.77	24.25
RUP[5]	-	32.5	40.13	42.48
RUP (g/d)	-	133.06	165.00	169.97
NDF	76.38	17.54	24.45	30.12
ADF	35.26	8.32	13.08	16.95
Ash	5.26	11.09	12.14	11.71
OM	94.74	88.91	87.86	88.29
GE (Mcal/kg)	4.25	3.92	3.84	3.98

[1] Abbreviations: LRUP = Low rumen degradable protein, MRUP = Medium rumen degradable protein, HRUP = High rumen degradable protein, TDN = total digestible nutrients, NDF = neutral detergent fiber, ADF = acid detergent fiber, GE = gross energy, RUP = rumen undegradable protein.
[2] Block DM was estimated after drying feed blocks for 72 hours in 80 °C oven.
[3] Beef Cattle NRC (2000) tabular values for individual feedstuffs were used to calculate diets RUP. Neither Beef Cattle NRC (2000) nor Dairy NRC (2001) has RUP value for poultry protein meal. The values shown in the table were taken from Bohnert et al., 1998.
[4] RUP intake (g/d) was based on estimated DMI of 2.5% body weight.
[5] Calculated by the in-situ procedure described by Orskov and McDonald (1979)

Table 3.3 Degradability of crude protein[1]

Treatment	CP	Fraction			Kd[2]	Kp[3]	RUP	RDP
		A	B	C				
Laboratory values						2 X Maintenance		
LRUP	25.43	49.80	49.27	0.91	2.25	5.84	36.50	63.50
MRUP	24.77	50.69	38.15	11.14	1.85	5.84	40.13	59.87
HRUP	24.25	55.81	25.72	18.45	0.41	5.84	42.48	57.52

[1] Abbreviations: LRUP = Low RUP, MRUP = Medium RUP, HRUP = High RUP
[2] Kd = degradation constant calculated using the method proposed by Ørskov and McDonald (1979).
[3] Kp = passage rate: Kp concentrate = 2.904 + 1.375 * DMI (%BW) – 0.020 * % concentrate, Dairy NRC (2001).

Table 3.4 Dry matter intake of steers fed bermudagrass hay and different levels of supplemental rumen degradable protein over the entire experimental period[1]

	Treatments			
Intake[2]	**LRUP**	**MRUP**	**HRUP**	**SEM**
Block,				
kg	1.61[a]	1.66[b]	1.65[b]	0.01
% BW	0.73	0.76	0.73	0.01
Hay,				
kg[a]	3.95[c]	3.96[c,d]	4.27[d]	0.12
% BW[b]	1.78[c]	1.79[c,d]	1.90[d]	0.04
Total,				
kg[b]	5.56[a]	5.61[a,b]	5.92[b]	0.11
% BW[b]	2.51[a]	2.55[a,b]	2.63[b]	0.03

[1]Abbreviations: LRUP = Low RUP, MRUP = Medium RUP, HRUP = High RUP
[2]Dry matter basis
[a] Linear ($P < 0.10$)
[b] Linear ($P < 0.05$)
[a, b] Within a row, means lacking a common superscript letter differ ($P < 0.05$).
[c, d] Within a row, means lacking a common superscript letter differ ($P < 0.10$).

Table 3.5 Dry matter intake of steers fed bermudagrass hay and levels of supplemental rumen degradable protein during total collection period[1]

	Treatment[2]			
DMI	**LRUP**	**MRUP**	**HRUP**	**SEM**
	---------- kg/d ----------			
Block	1.56[a]	1.64[b]	1.61[c]	0.001
Hay	4.01	3.90	3.96	0.11
Total	5.58	5.55	5.57	0.11

[1] Steers were kept in metabolism crates during 4 days in each period.
[2]Abbreviations: LRUP = Low RUP, MRUP = Medium RUP, HRUP = High RUP
[a, b] Within a row, means lacking a common superscript letter differ ($P < 0.01$).

Table 3.6 Nutrient intake of steers fed bermudagrass hay and different levels of supplemental rumen degradable protein

	Treatment			
Nutrient[1]	**LRUP**	**MRUP**	**HRUP**	**SEM**
	---------- kg ----------			
OM	5.18[c]	5.23[c,d]	5.51[d]	0.11
CP	0.807	0.811	0.830	0.009
RUP	0.241[c]	0.257[d]	0.269[e]	0.002
MP[2]	0.442[c]	0.460[c,d]	0.487[d]	0.010
Digestible CP	0.486	0.483	0.461	0.01
NDF	3.36[c]	3.41[c,d]	3.72[d]	0.11
NDFD[a]	1.73[c]	1.84[c,d]	2.11[d]	0.10
ADF[a]	1.57[c]	1.60[c,d]	1.75[d]	0.05
DE (Mcal/d)[b]	13.19[c]	13.48[c,d]	14.42[d]	0.46
TDN[3, b]	2.99[c]	3.05[c,d]	3.27[d]	0.10
NEm[4]	6.10	6.29	6.80	0.28
NEg[3]	3.00	3.14	3.47	0.21

[1]Abbreviations: LRUP = Low RUP, MRUP = Medium RUP, HRUP = High RUP, MP = metabolizable protein, NDFD = digestible neutral detergent fiber.

[2] Calculated based on TDN and RUP (Beef Cattle NRC, 2000):
MP = (((TDN * 0.13)*0.64) + (RUP * 0.80))

[3] 1 kg TDN = 4.409 Mcal DE

[4] NE_m and NE_g values were calculated based on DE (Beef Cattle NRC, 1984):
ME = DE * 0.82;
$NE_m = (1.37 * ME – 0.138 * ME^2 + 0.0105 * ME^3 – 1.12)$;
$NE_g = (1.42 * ME – 0.174 * ME^2 + 0.0122 * ME^3 – 1.65)$

[a] Linear ($P < 0.05$)

[b] Linear ($P < 0.10$)

[c,d] Within a row, means lacking a common superscript letter differ ($P < 0.05$).

Table 3.7 Apparent digestibility of nutrients fed to steers consuming bermudagrass hay and different levels of supplemental rumen degradable protein

	Treatment			
Nutrient	**LRUP**	**MRUP**	**HRUP**	**SEM**
	----------%----------			
DM	58.23	59.23	59.28	1.06
OM	59.07	59.87	60.21	1.07
CP[b]	60.45	60.49	58.21	1.05
NDF[a]	51.48[a]	53.69[a,b]	56.57[b]	1.30
ADF[a]	47.73[a]	50.30[a,b]	54.44[b]	1.39
DE (Mcal/kg)	2.36	2.39	2.43	0.04
NE_m (Mcal/kg)[2]	1.09	1.11	1.14	0.03
NE_g (Mcal/kg)[2]	0.53	0.55	0.58	0.03

[1]Abbreviations: LRUP = Low RUP, MRUP = Medium RUP, HRUP = High RUP, MP = metabolizable protein.

[2] NE_m and NE_g values were calculated based on DE (Beef Cattle NRC, 2000):
ME = DE * 0.82;
$NE_m = (1.37 * ME - 0.138 * ME^2 + 0.0105 * ME^3 - 1.12)$;
$NE_g = (1.42 * ME - 0.174 * ME^2 + 0.0122 * ME^3 - 1.65)$

[a] Linear ($P < 0.06$)

[a, b] Within a row, means lacking a common superscript letter differ ($P < 0.05$).

Table 3.8 Nitrogen measurements in steers fed bermudagrass hay and different levels of supplemental rumen degradable protein[1]

	Treatment			
Item	**LRUP**	**MRUP**	**HRUP**	**SEM**
	---------- g/d ----------			
N intake	128.49	127.87	126.37	1.93
N output				
Urine[a]	27.24[a]	29.46[b]	23.82[a]	1.45
Fecal	50.72	50.51	52.56	0.96
Total	77.96	79.98	76.39	1.93
N retention[2]	50.52	47.88	49.97	2.13
N digested (%)[3,b]	60.45	60.49	58.21	1.05
N retained (% of dig.)[4]	63.52	61.79	66.58	1.99

[1]Abbreviations: LRUP = Low RUP, MRUP = Medium RUP, HRUP = High RUP.
[2] N retention = N intake - (Urine N + Fecal N)
[3] N digested = (N intake – Fecal N) / N Intake
[4] Apparent Biological Value = (g N retention / g N digested)*100
[a] Quadratic ($P < 0.05$)
[b] Linear ($P = 0.17$)
[a,b] Within a row, means lacking a common superscript letter differ ($P < 0.05$).

Table 3.9 Blood metabolites of steers fed bermudagrass hay and different levels of supplemental degradable protein[1]

	Treatment			
Item[2]	**LRUP**	**MRUP**	**HRUP**	**SEM**
BUN BF, mg/dl[2, b]	14.90	14.95	12.63	1.11
BUN AF, mg/dl	16.96	15.73	16.20	1.11
Glucose BF, mg/dl	68.54	67.37	65.78	2.43
Glucose AF, mg/dl	70.93	69.69	71.28	2.43
Insulin BF, μ IU/ml[3]	4.39	5.49	5.72	1.08
Insulin AF, μ IU/ml	6.41	5.08	5.25	1.08

[1]Abbreviations: LRUP = Low RUP, MRUP = Medium RUP, HRUP = High RUP.
[2] BF = steers bled immediately before feeding. AF = steers bled approximately 5 hours after feeding.
[2] BUN = Blood urea nitrogen.
[3] μ IU/ml = micro international units per milliliter
[b] Time effect ($P < 0.05$)

Table 3.10 Ingredient composition of supplements fed to beef steers during the performance study[1]

	Treatment[2]			
	Block		Meal	
Item	**LRUP**	**HRUP**	**LRUP**	**HRUP**
	% DM			
Cane molasses	35.0	35.0	5.0	5.0
Corn	0	6.0	26.3	35.2
Broiler litter	10.0	10.0	10.6	10.6
PPM	0	26.0	0	26.1
Soy hulls	0	23.0	0	23.0
Soybean meal	37.1	0	39.2	0
CGF	17.9	0	18.9	0

[1]Abbreviations: LRUP = Low RUP, MRUP = Medium RUP, HRUP = High RUP, PPM = poultry protein meal, CGF = corn gluten feed.

[2] LRUP = 100% soybean meal and corn gluten feed blend. MRUP = replace 50% soybean meal and corn gluten feed blend with poultry protein meal and soy hulls blend. HRUP = 100% poultry protein meal and soy hulls blend.

Table 3.11 Nutrient composition of Coastal bermudagrass hay and supplements fed to beef steers during performance study[1]

		Treatment			
		Block		Meal	
Nutrients	**Hay**	**LRUP**	**HRUP**	**LRUP**	**HRUP**
Estimated values	---------- % ----------				
DM	93.38	90.75	90.75	85.74	87.36
CP	12.00	25.94	25.94	27.69	26.81
RUP[2]	23.00	27.72	44.03	30.72	46.55
RUP (g/d)[3]	133.58	112.17	178.17	125.44	187.52
TDN	52.54	78.93	75.71	83.53	80.36
NDF	75.43	13.65	31.37	16.79	34.31
Ca	0.43	0.72	3.55	0.45	3.28
P	0.20	0.61	1.69	0.70	1.76
Laboratory values	---------- % ----------				
DM	87.77	89.50	89.91	87.50	87.82
CP	13.01	25.31	24.23	28.30	27.98
NDF	74.59	20.55	30.27	19.26	32.57
ADF	33.60	8.87	16.03	8.37	15.50

[1]Abbreviations: LRUP = Low RUP, MRUP = Medium RUP, HRUP = High RUP

[2] Percent of CP, Beef Cattle NRC (2000)

[3] RUP intake (g/d) was based on estimated DMI of 2.5% body weight.

Table 3.12 Dry matter intake of beef steers fed coastal bermudagrass hay and different supplemental rumen degradable protein during performance study[1]

	Treatment				
	Block		Meal		
Intake[2]	**LRUP**	**HRUP**	**LRUP**	**HRUP**	**SEM[2]**
Hay					
DM, kg	4.98	4.87	5.02	5.10	0.09
% BW	1.79	1.73	1.79	1.79	0.02
Concentrate					
DM, kg	1.51[a]	1.44[b]	1.50[a]	1.52[a]	0.01
% BW[a,b]	0.54[c]	0.51[d]	0.54[c]	0.53[c]	0.004
Total					
DM, kg	6.50[e,f]	6.32[e]	6.53[e,f]	6.63[f]	0.09
% BW[c]	2.33[c]	2.25[d]	2.34[c]	2.33[c]	0.02

[1]Abbreviations: LRUP = Low RUP, MRUP = Medium RUP, HRUP = High RUP.
[2] Dry matter basis
[2] SEM = standard error of the mean for form x protein.
[a] Protein effect ($P < 0.01$)
[b] Form and protein effect ($P < 0.05$)
[c] Protein effect ($P < 0.10$)
[a, b] Within a row, means lacking a common superscript letter differ ($P < 0.01$).
[c, d] Within a row, means lacking a common superscript letter differ ($P < 0.05$).
[e, f] Within a row, means lacking a common superscript letter differ ($P < 0.10$).

Table 3.13 Nutrient intake of steers fed coastal bermudagrass hay and different levels of supplemental rumen degradable protein during the performance study[1,2]

	Treatment			
	Block		Meal	
Nutrient	**LRUP**	**HRUP**	**LRUP**	**HRUP**
	---------- kg/d ----------			
CP	1.03	0.98	1.07	1.08
RUP[3]	0.25	0.30	0.28	0.35
MP[4]	0.52	0.54	0.54	0.60
NDF	4.02	4.06	4.03	4.30
ADF	1.80	1.86	1.81	1.94
TDN[5]	3.80	3.64	3.89	3.90

[1]Abbreviations: LRUP = Low RUP, MRUP = Medium RUP, HRUP = High RUP
[2] Calculated based on nutrient concentration and intake of hay and supplements.
[3] RUP = rumen undegradable protein. Value estimated from Beef Cattle NRC (2000)
[4] MP = metabolizable protein. MP = ((TDN * 0.13) * 0.64) + (RUP * 0.80), Beef Cattle NRC (2000)
[5] Estimated from the Beef Cattle NRC (2000)

Table 3.14 Average daily gain and gain to feed ratio of beef steers during performance study[1]

	Treatment				
	Block		Meal		
Item	**LRUP**	**HRUP**	**LRUP**	**HRUP**	**SEM**
ADG (kg)	0.66	0.65	0.66	0.69	0.05
Gain:feed	0.102	0.103	0.101	0.105	0.007

[1]Abbreviations: LRUP = Low RUP, MRUP = Medium RUP, HRUP = High RUP.

Table 3.15 Evaluation of diets fed to growing steers consuming coastal bermudagrass hay and different levels of supplemental RUP[1]

	Treatment[2]							
	Block				Meal			
	LRUP		HRUP		LRUP		HRUP	
Item	Req.	Diet	Req.	Diet	Req.	Diet	Req.	Diet
	g							
MP[3]	432	521	410	542	446	548	443	606
RDP[4]	495	774	474	699	506	797	507	736
	Allowable gain (kg)[5]							
ME	0.56		0.49		0.61		0.60	
MP	0.85		0.91		0.94		1.13	

[1] Diets were evaluated using the Beef Cattle NRC (2000) Model Level 1.
[2] Abbreviations: LRUP = low rumen undegradable protein, HRUP = high rumen undegradable protein, Req. = required amount of nutrients, Beef Cattle NRC (2000). Diet = nutrients furnished by each diet.
[3] Metabolizable protein. MP = ((TDN * 0.13) * 0.64) + (RUP * 0.80)
[4] Rumen degradable protein. RDP = TDN * 0.13
TDN = total digestible nutrients, values are expressed in Table 3.13
[5] Allowable gains estimated by Beef Cattle NRC (2000) Model Level 1 from metabolizable energy (ME) or from metabolizable protein (MP).

Table 3.16 Blood metabolites of beef steers fed coastal bermudagrass hay and different levels of supplemental rumen degradable protein during performance study[1]

	Treatment								
	Block				Meal				
	LRUP		HRUP		LRUP		HRUP		
Item	d 21	d 63	d 21	d 63	d 21	d 63	d 21	d 63	SEM
BUN, mg/dl[a, b]	12.48	14.72	11.33	13.17	13.88	15.16	10.80	12.95	0.34
Glucose, mg/dl[c]	68.43	66.30	79.63	83.49	87.19	90.49	70.36	69.40	2.28
Insulin, μ IU/ml[c,d]	6.03	5.06	6.50	9.15	9.82	4.95	3.82	4.24	1.63

[1] Abbreviations: LRUP = low rumen undegradable protein, HRUP = high rumen undegradable protein.
[a] Protein effect ($P < 0.01$)
[b] Period effect ($P < 0.01$)
[c] Form and protein effect ($P < 0.01$)
[d] Protein and period effect ($P < 0.10$)

CHAPTER 4

CONCLUSIONS

Levels of RUP supplementation were studied for steers consuming a high fiber basal forage diet in two experiments. In the first experiment, N metabolism was evaluated. Forage dry matter intake was increased with the highest level of supplemental RUP fed. Differences in digestibility could not be attributed to levels of RUP supplementation. Numerical differences for a lower concentration of urea N in blood and a significant decrease in N urine excretion were detected for steers consuming high RUP diets. However N retention results did not indicate differences in N utilization due to RUP.

The second experiment consisted of feeding similar levels of RUP used in the first study in a feedlot trial to test steer performance and blood parameters. Average daily gain and gain to feed ratio were not affected. Diet evaluation parameters predicted similar gains measured with the level of energy fed. However predicted MP allowable gains were higher than the estimated ME allowable gains. Blood urea N was lower in the steers fed the high RUP than the low RUP diets.

The overall results of these experiments do not demonstrate substantial effects of RUP levels fed on nutrient utilization and performance, although there were some indications of changes in N metabolism and hay DMI. Higher levels of supplemental energy along with the protein provided in the diets studied would likely enhance

performance of steers consuming forages having similar quality to those fed in this experiment.