

**EFFECT OF INCREASING PROTEIN SUPPLEMENTATION ON INTAKE  
AND DIGESTION OF BERMUDAGRASS HAYS OF DIVERGENT QUALITY  
BY BEEF CATTLE**

A Thesis

by

CATHERINE POMEROY PAYNE

Submitted to the Office of Graduate Studies of  
Texas A&M University  
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2011

Major Subject: Animal Science

Effect of Increasing Protein Supplementation on Intake and Digestion of Bermudagrass

Hays of Divergent Quality by Beef Cattle

Copyright 2011 Catherine Pomeroy Payne

**EFFECT OF INCREASING PROTEIN SUPPLEMENTATION ON INTAKE  
AND DIGESTION OF BERMUDAGRASS HAYS OF DIVERGENT QUALITY  
BY BEEF CATTLE**

A Thesis

by

CATHERINE POMEROY PAYNE

Submitted to the Office of Graduate Studies of  
Texas A&M University  
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Approved by:

Chair of Committee,  
Committee Members,

Head of Department,

Tryon A. Wickersham  
Larry A. Redmon  
F. M. Rouquette, Jr.  
Jason E. Sawyer  
H. Russell Cross

May 2011

Major Subject: Animal Science

**ABSTRACT**

Effect of Increasing Protein Supplementation on Intake and Digestion of Bermudagrass

Hays of Divergent Quality by Beef Cattle. (May 2011)

Catherine Pomeroy Payne, B.A., Vanderbilt University;

M.S.T., Pace University

Chair of Advisory Committee: Dr. Tryon A. Wickersham

Bermudagrass (*Cynodon dactylon* (L) Pers.), one of the predominant forages in the southeastern US, varies in nutritive value in response to management and environmental factors. Beef cattle supplementation decisions are complicated by this variability. Therefore, our objective was to determine the effect of four protein supplementation levels (0, 82, 119 and 155 mg N/kg BW) on the utilization of three bermudagrass hays (5.6, 6.3, and 8.1% CP). Thirteen ruminally fistulated Angus × Hereford steers (BW = 330 ± 19 kg) were used in a 13 × 4 incomplete Latin square design with 13 treatments. Treatments were arranged as a 3 × 4 factorial plus a control bermudagrass hay (10.8% CP). Hay was provided ad libitum and protein supplements were offered as range cubes once daily. Periods were 15 d with intake determinations made on d 10 through d 13 to correspond with fecal grab samples collected from d 11 through d 14. Acid detergent insoluble ash was used as an internal marker for determination of fecal output. Hay OM intake of unsupplemented steers increased linearly ( $P < 0.01$ ) as hay nutritive value increased from 75 to 77, 96 and 94 g/kg BW<sup>0.75</sup>

for 5.6, 6.3, 8.1 and 10.8% CP hays, respectively. A cubic increase ( $P = 0.03$ ) in OM digestibility for unsupplemented hays was observed with values ranging from 46 to 65%. This resulted in a linear increase ( $P < 0.01$ ) in total digestible OM intake in response to hay nutritive value from 35 to 45, 51, and 60 g/kg BW<sup>0.75</sup> for 5.6, 6.3, 8.1, and 10.8% CP hays, respectively. No significant effects on total digestible OM intake were observed when hays were supplemented with protein. There was a tendency for forage OM intake of the 6.3% CP hay to increase linearly with supplemental protein ( $P = 0.08$ ). Total OM intake increased linearly ( $P < 0.01$ ) when CP was supplemented to the 6.3% CP hay from 77 to 88, 92, and 98 g/kg BW<sup>0.75</sup> for 0, 82, 119, and 155 mg N/kg BW, respectively. We conclude that forage CP content was the primary driver in determining total digestible OM intake, and the effects of protein supplementation on utilization of bermudagrass hay were varied.

## DEDICATION

I dedicate this thesis to my Creator, King, and Savior Jesus Christ who guides and provides throughout life's adventures.

Psalm 16: 5-11

The LORD is my chosen portion and my cup; you hold my lot. The lines have fallen for me in pleasant places; indeed, I have a beautiful inheritance... You make known to me the path of life; in your presence there is fullness of joy; at your right hand are pleasures forevermore.

2<sup>nd</sup> Corinthians 9:8

And God is able to make all grace abound to you, so that having all sufficiency in all things at all times, you may abound in every good work.

## ACKNOWLEDGMENTS

I am here and not elsewhere because God planted a crazy idea in my mind to do something that would prosper me and give me a hope and a future, according to His design for my life. I wrote a thesis for a Masters in Animal Science at Texas A&M University instead of remaining in New York City as a Spanish teacher because this is the path that would bring Him honor. There would be no cause to celebrate everyone who played a part of this journey if the present circumstances were merely the products of chance. Probability would be the same or greater for an entirely different set of people to be acknowledged at present. Therefore, I can praise and thank my Almighty God for hand selecting each of you, because He has decided that you and only you were suitable for the job.

Dr. Tryon Wickersham read an email that began with, “I am responding to a lifelong call to unite my passion for teaching, health, and farming. I hope to enroll as a graduate student in the fall of 2009.” He gambled that he could turn this avant-garde liberal arts-trained city girl into a ruminant nutritionist, and I think he succeeded. Thank you for committing to this transformation and for the hours of teaching, debate, and conversation that have benefitted me. You have helped identify and hone my talents, and you acquainted me with people and causes which I can best serve. You have taught me true stewardship and you have done it in God’s name.

Dr. Larry Redmon forwarded Dr. Wickersham the email I mentioned above. You continued to excite my passion for sustainable agriculture through your conversations,

presentations, and books you recommended, like *A Sand County Almanac* and *Land of Bears and Honey*. You have prepared me to positively affect my generation in the pursuit of responsible management of our ecosystems and natural resources.

Dr. Jason Sawyer always made time for me. I don't know how, but he saw potential in me when I visited A&M as a prospective student and talked about the superiority of grass-finished beef. It took one raised eyebrow from Dr. Sawyer for me to suspect Michael Pollan didn't have it all figured out. Thank you for pushing me to do the Monensin meta-analysis even though I was afraid of failure. Thank you for honoring my efforts even when they are far from perfection. Thank you for never ceasing to challenge me mentally, even while "vacationing" in Estes Park, Colorado. You held me to high standards which have helped me grow tall in this field.

Dr. "Monte" Rouquette was the first professor I met at A&M. The day I spent at Overton became a fond memory, touring Tifton 85 bermudagrass paddocks and discussing the role of *Rhizobia* in your clover plots. When I had hay grating at my eyes and lungs during my project, it helped to think about just how much you loved that bermudagrass. I hope to be an expert someday like the way you are an expert in bermudagrass. I will also remember, as you told me, that the farmer has to be the best environmentalist there is.

Trey Warnock, you were an inextricable asset to my project. Thank you for getting up in the dark every day to help feed a baker's dozen of lazy steers in an air-conditioned barn, which made you usually end up with something injured. I'm not sure who was more painful to look at, me because I'm not a morning person, or you with



your random wounds. I also appreciate that you didn't make fun of my dust mask obsession, at least not to my face. Thanks, again and again, for your help.

Trey Dittmar, you have taught me just as much livestock management as I have probably taught you patience. You are the hardest working man I know, and I was probably the most clueless student you knew. Thank you for being there immediately whenever there was a problem. Thanks for answering your phone when you saw it was me about to tell you about a problem. You have been invaluable to so many projects, and you've been completely reliable for everything. If Trey Dittmar can't fix it, it's unfixable. Thanks for being the lab hero!

Merritt, Nikki, and Dusty, you were always willing to help me. Thank you for being so hardworking and focused, and when you're not focused, thanks for being funny. You have made our lab into a community, and I would not have looked as forward to coming to work every day without knowing you all would be there.

Greta, Kyle, and Rebecca, I am so proud of all of you for your work ethic. Greta, thanks for your bright smile every morning and for your light attitude throughout the project. Kyle and Rebecca, some of the sampling you did for me are unmentionable, but please know I am deeply (ignore pun) grateful. "But as for you, be strong and courageous, for your work shall be rewarded" (2 Chronicles 15:7).

Dear friends in New York City, thank you for your enthusiasm for my dreams and commitment to my success in realizing unusual ambitions. To my roommates, Kelly, Rachel, and Ashlee, who encouraged me when I was weak and served me hot food and hugs when I was tired, thank you. I thank my prayer group members, Tami, Lana, and

Kelly, for talking to God on my behalf. Thank you to my friends at Grace Bible for your constant fellowship.

Jonathan Webb slept on the floors and couches of strangers just so he could make me feel special on weekends I couldn't get away from work. He came to the barn with me a few mornings just so he wouldn't miss getting to know who I am in that element. I thank Jonathan for bearing things, believing things, hoping things, and enduring things. This is a man the King delights to honor. I am proud to know him well.

Mom and Dad, you taught me two things I will never depart from: you love me; God loves me. I know I have done and learned many foreign things that you may not understand, but thank you for supporting my decisions anyway. Even when you walked through the barn with eyes wide and hands clasped, I am touched that you drove three hours just to walk beside me in my work. I love you so much. "Train up a child in the way he should go; even when he is old he will not depart from it" (Proverbs 22:6). Any decisions I have made in the pursuit of goodness reflect the influential wisdom of my parents. I hope this final acknowledgement leaves a lasting impression of how their guidance, above all, has been impressed upon me. I am thankful to God for my family.

**NOMENCLATURE**

ADF	Acid detergent fiber
ADG	Average daily gain
BW	Body weight
C	Carbon
CP	Crude protein
d	Day
DDG	Dried distillers' grains
DIP	Degradable intake protein
DM	Dry matter
DMI	Dry matter intake
h	Hour
HOMI	Hay organic matter intake
MCP	Microbial crude protein
N	Nitrogen
NE <sub>m</sub>	Net energy for maintenance
NDF	Neutral detergent fiber
OM	Organic matter
PUN	Plasma urea nitrogen
SEM	Standard error of the mean
TDOMI	Total digestible organic matter intake

**NOMENCLATURE**

TDN	Total digestible nutrients
UIP	Undegradable intake protein
VFA	Volatile fatty acids
Wk	Week(s)
Yr	Year

## TABLE OF CONTENTS

	Page
ABSTRACT.....	iii
DEDICATION.....	v
ACKNOWLEDGMENTS.....	vi
NOMENCLATURE.....	x
TABLE OF CONTENTS.....	xii
LIST OF FIGURES.....	xiv
LIST OF TABLES.....	xvi
CHAPTER	
I INTRODUCTION AND LITERATURE.....	1
Forage characteristics of Coastal bermudagrass.....	2
Cattle performance on bermudagrass pasture.....	2
Stockpiled bermudagrass nutritive value.....	4
Bermudagrass hay: Effect of harvest interval and nutritive Value.....	6
Bermudagrass hay: Nitrogen fertilization and nutritive value...	14
Intake and digestion of forage by beef cattle.....	15
Degradable intake protein supplementation.....	16
Non-protein nitrogen as DIP supplementation.....	19
Undegradable intake protein supplementation.....	21
DIP versus UIP supplementation.....	21
Cottonseed meal supplementation.....	23
Soybean meal supplementation.....	26
Starch supplementation.....	31
Total nitrogen supplementation.....	36
Direction of study.....	37

CHAPTER	Page
II MATERIALS AND METHODS.....	39
Study description.....	39
Sampling periods.....	40
Laboratory analysis.....	41
Statistical analysis.....	42
III RESULTS.....	45
Bermudagrass hay: Effects of hay crude protein content on intake and digestion.....	45
Bermudagrass hay with supplemental N: Effects of supplemental N on intake and digestion.....	49
IV DISCUSSION.....	61
V CONCLUSION.....	67
LITERATURE CITED.....	68
APPENDIX.....	75
VITA.....	79

## LIST OF FIGURES

FIGURE	Page
1	Effect of N fertilization rate and clipping frequency on bermudagrass crude protein content..... 7
2	Effect of N fertilization rate and harvest date on bermudagrass crude protein content..... 10
3	Effect of N fertilization rate and harvest date on bermudagrass holocellulose content..... 10
4	Effect of bermudagrass plant component maturity on CP values..... 11
5	Effect of bermudagrass plant component maturity on neutral detergent fiber..... 11
6	Effect of bermudagrass plant component maturity on acid detergent fiber... 12
7	Effect of bermudagrass plant component maturity on lignin..... 12
8	Effect of hay crude protein content on hay organic matter intake and total digestible organic matter intake..... 46
9	Effect of hay crude protein content on total tract digestion of organic matter and neutral detergent fiber..... 47
10	Effect of hay crude protein content on ruminal pH..... 47
11	Effect of hay crude protein content on ruminal ammonia and plasma urea nitrogen..... 48
12	Effect of supplemental nitrogen and hay crude protein content on hay OM intake..... 50
13	Effect of supplemental nitrogen and hay crude protein content on hay neutral detergent fiber intake..... 52
14	Effect of supplemental nitrogen and hay crude protein content on total digestible organic matter intake..... 53

FIGURE		Page
15	Effect of supplemental nitrogen and hay crude protein content on total digestible neutral detergent fiber intake.....	54
16	Effect of supplemental nitrogen and hay crude protein content on total tract organic matter digestion.....	55
17	Effect of supplemental nitrogen and hay crude protein content on total tract neutral detergent fiber digestion.....	56
18	Effect of supplemental nitrogen and hay crude protein content on total crude protein intake.....	57
19	Effect of supplemental nitrogen and hay crude protein content on the ratio of crude protein to total digestible organic matter intake.....	58
20	Effect of supplemental nitrogen on ruminal ammonia concentration by hay crude protein content.....	60



**LIST OF TABLES**

TABLE		Page
1	Chemical composition of hays .....	42
2	Chemical composition of supplements.....	44
3	Effect of supplemental nitrogen and hay crude protein content on pH.....	59
4	Effect of supplemental nitrogen and hay crude protein content on plasma urea nitrogen.....	60
A-1	Effect of supplemental nitrogen and hay crude protein content on intake.....	76
A-2	Effect of supplemental nitrogen and hay crude protein content on digestibility.....	77
A-3	Effect of supplemental nitrogen and hay crude protein content on intake and digestibility.....	78
A-4	Effect of supplemental nitrogen and hay crude protein content on rumen fermentation characteristics and plasma urea nitrogen.....	79

**CHAPTER I**  
**INTRODUCTION AND**  
**LITERATURE REVIEW**

Beef cattle can utilize low-quality forages as sources of nutrients; however, their performance on high-fiber, low-protein (< 7% CP) forage, hay, or crop residue is often constrained by the failure to meet rumen microbial requirements. Products of microbial fermentation such as volatile fatty acids and microbial CP are used by the bovine host as the primary sources of energy and metabolizable protein. Although protein supplementation of ruminants is a routine agricultural practice, the environmental and economic cost of nitrogen (N) and feedstuffs necessitates precise nutrient delivery to reduce cost and prevent excessive nutrient excretion.

In the southeastern United States, bermudagrass (*Cynodon dactylon*, (L) Pers.) has become a predominant perennial warm-season forage for grazing and haymaking. It responds vigorously to N fertilizer by increasing DM production and CP content, provided adequate moisture is available. Bermudagrass withstands both drought and heavy grazing. These traits substantiate the heavy dependency on this grass for beef cattle production. High fiber content and variability in CP often reduce intake and digestion, ultimately hindering the animal's acquisition of nutrients. Nutritive value of bermudagrass, like all grasses, can fluctuate widely with maturity (Akin et al., 1977; Beaty et al., 1969; Burton et al., 1963; Knox et al., 1958; Prine and Burton, 1956).

---

This thesis follows the style of Journal of Animal Science.

Supplementation can potentially maintain and even promote cattle performance on a basal diet of actively growing, dormant, or harvested bermudagrass. However, producers often lack sufficient information to make informed supplementation decisions. They may spend money in vain on supplements too low in protein or digestible nutrients to generate a response in cattle productivity, or they may supplement forages of high nutritive value needlessly. The following review of literature will summarize the current understanding of bermudagrass utilization and protein supplementation of low-quality forage diets.

### **Forage characteristics of Coastal bermudagrass**

#### *Cattle performance on bermudagrass pasture*

During the growing season, bermudagrass pastures produce abundant DM yields especially in response to N fertilization. For example, the DM growth response to an application rate of  $448 \text{ kg N} \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$  was  $22 \text{ Mg bermudagrass} \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$ , and stocker steer gains totaled  $766 \text{ kg} \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$  in response to application of  $224 \text{ kg} \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$  (Burton, 1954). However, because warm-season forages decline in CP content and digestibility as they mature during the summer growing season, supplementation with energy and protein has been a prudent method for ensuring continued high ( $> 1 \text{ kg/d}$ ) animal weight gains (Huston et al., 2002).

From June to September, Coastal bermudagrass pasture (avg. 17.1% CP) was stocked with calves which were fed six different ad libitum supplementation treatments by Grigsby et al. in 1989. These consisted of a negative control (pasture only), 31.6% CP

condensed molasses block, 32.5% CP condensed molasses block formulated with fishmeal (low in DIP), 34.2% CP dry supplement, 30.7% CP dry supplement with lysine and methionine (both rumen-stable), 37.2% CP dry supplement with fishmeal and monensin. Steers and heifers gained an average of 0.5, 0.6, 0.6, 0.7, 0.6, and 0.9 kg/d, respectively. In a second trial, calves on Coastal bermudagrass pasture (avg. 11.7% CP) were given the following supplementation treatments: negative control (pasture only), 31.5% CP condensed molasses block, 44.4% CP dry supplement containing heat-treated soybean meal (low in DIP), 35.8% CP dry supplement with fishmeal (low in DIP), 35.8% CP dry supplement with fishmeal and monensin. These cattle gained 0.4, 0.5, 0.7, 0.6, 0.7 kg/d, respectively. A decrease in bermudagrass CP content coincided with a decrease in ADG for the following treatments between Trials 1 and 2: control pasture, condensed molasses block, and dry supplement with fishmeal and monensin. Protected methionine and lysine supplementation treatments did not result in greater gains than in calves consuming dry supplement; thus, these amino acids evidentially were not limiting factors for growth rates of calves. Equivalent feed:gain ratios occurred between the treatments that were repeated between trials, which were the condensed molasses block treatment and the dry supplement with fishmeal and monensin treatment, suggesting that supplementing cattle on bermudagrass pasture (averaging 11.7% or 17.1% CP) in the late summer and early fall leads to additive, not substitutive, effects of forage nutritive value and supplemental protein on animal performance. Given that protein supplements resulted in more efficient intake:extra gain ratios than did energy supplements, it was suggested that supplemental protein enhanced forage utilization (Grigsby et al., 1989).

Calves stocked on bermudagrass pasture from May to October gained 0.46 kg/d consuming forage alone or 0.57 kg/d if 0.9 kg/d corn was supplemented (Oliver, 1975). Crude protein values of bermudagrass paddocks were not reported in this study, but similar data was reported by Huston et al. (2002) on bermudagrass pastures with CP content between 10 and 14%. Calves gained 0.44 kg/d without supplementation (Huston et al., 2002). The addition of 1.2 kg DM of an 18% CP rice mill or mixed meal supplement to the diet resulted in 0.59 kg/d of gain. This effect on ADG was no different than the effect of adding 1.0 kg DM of a 32% CP supplement (0.63 kg/d). Results from this study suggest that the CP content of vegetative bermudagrass may suffice for fermentation requirements, and protein supplementation may not be required. Energy supplementation in a grazing setting, such as the 18% CP rice mill supplement, may be a more cost effective method for increasing productivity than a 32% CP supplement, especially if both treatments elicited similar gains in performance. Although protein and energy supplementation have led to positive results for animals grazing actively growing bermudagrass, unsupplemented and actively growing bermudagrass forage of CP content between 10 and 14% can support satisfactory ADG.

#### *Stockpiled bermudagrass nutritive value*

Bermudagrass can be left ungrazed and standing as it enters dormancy in the fall to provide forage higher in CP than native perennial cultivars would otherwise be, as evidenced by reports of dormant bermudagrass CP content in this portion of the review. Stockpiling bermudagrass is an alternative to feeding hay when the growing season for

C4 perennials has ceased. The following studies characterized the nutritive value of stockpiled bermudagrass, however, supplementation strategies were not evaluated. Knowledge regarding supplementation of stockpiled bermudagrass is in want of further evaluation.

Between the months of October and February in Overton, TX, Tifton 85 and Coastal bermudagrass were observed to contain 12.5% CP, 37.4% ADF and 11.6% CP, 33.0% ADF, respectively (Evers et al., 2004). The grasses had been fertilized with 325N-73P-263K-22Mg-22S, 336N-84P-252K, and 232N-87P-155K kg/ha the first, second, and third years, accordingly. Different management practices for stockpiling bermudagrass have been studied to determine the effects on forage nutritive value. Grazing and other methods of defoliation during the active growing season may improve stockpiled bermudagrass fiber digestibility but could lower protein content. Stockpiled bermudagrass fertilized at 345 kg N/ha, was either grazed or left ungrazed over the summer and was harvested for nutritive analysis monthly between October and January by Scarbrough et al. (2001). Dry matter and NDF degradation rates decreased in ungrazed relative to grazed stockpiled bermudagrass from October to November, but then did not change from December to January, when degradability was lowest. Crude protein in ungrazed grass decreased from 13.4% in October to 11.9% in December. In contrast, grazed bermudagrass was 10.0% CP in November which increased slightly to 11.5% in January (Scarbrough et al., 2001). Defoliation treatments altered the nutritive value of stockpiled bermudagrass by increasing degradability and decreasing CP content.

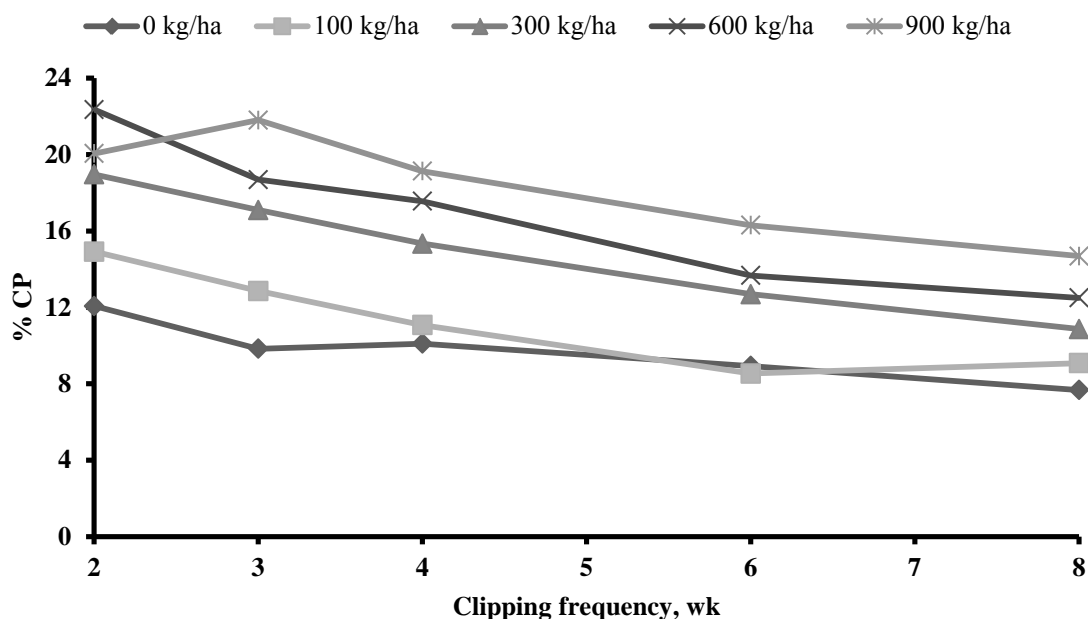
Scarborough et al. (2006) combined stockpiling initiation (August or September) and fertilization rate (0, 37, 74, 111 kg N/ha) and reported that DM yield decreased and NDF content increased with later stockpiling initiation dates. Increasing fertilization rate and deferring the stockpiling of bermudagrass to September instead of August lowered NDF content and increased CP content (Scarborough et al., 2006). Both reports by Scarborough et al. (2001, 2006) provide evidence for the potential need to keep bermudagrass vegetative with defoliation treatments and to increase N fertilization rates to compensate total plant N loss during each harvest.

*Bermudagrass hay: Effect of harvest interval and nutritive value*

As with dormant standing bermudagrass, nutritive value of bermudagrass hay can vary with harvest date. Dry matter yield and nutritive value of bermudagrass hay can be optimized when cutting intervals are between 4 and 6 wks (Taliaferro et al., 2004). Prine and Burton (1956) found that as clipping intervals increased from 1 to 8 wks, the DM yield and stem and leaf length increased. There was a reduction in crude protein content, but N recovery was constant (Figure 1). Cutting hay more often than every 8 wks could increase the leaf:stem ratio and keep forage nutritive value high (Prine and Burton, 1956).

Clipping frequency did not affect the lignin content of Coastal bermudagrass when N fertilizer was limited to less than 112 kg/ha; however, when N fertilization was above 112 kg/ha, lignin content increased with maturity (Knox et al., 1958). For example, when fertilized at a rate higher than 112 kg/ha and cut at 2 wks of age, lignin

was at 9.5% DM, but at 8 wks it was 12% of DM. Total digestible nutrients decreased from 70 to 59% when grass was cut at 2, 3, 4, 6, and 8 wks of age. The authors theorized that treatments favoring the growth of stems (eg., less frequent clipping) will yield higher concentrations of lignin in hay (Knox et al., 1958). This research confirms the results reported by Prine and Burton (1956) that hay cut every 2 wks will be higher in nutritive value than hay cut less often, every 8 wks.



**Figure 1.** Effect of N fertilization rate and clipping frequency on bermudagrass crude protein content (Prine and Burton, 1956).

Crude protein content tends to increase as harvest frequency increases. Frequent harvest stalls the onset of inflorescence, and bermudagrass cut once over the growing season (after 24 wks) had significantly lower CP than the more frequent cuttings (Burton et al., 1963). While CP decreased from 18.5 to 8.4%, crude fiber increased from 27.0 to



33.9% as frequency of cutting was reduced from every 3 wks to every 24 wks. Even when acknowledging the limitations of crude fiber analysis (i.e., dissolution of lignin, poor repeatability, tendency to underestimate) the observation of an overall fiber increase with harvest maturity cannot be denied, especially in light of other similar observations (Akin et al., 1977; Beaty et al., 1969; Webster et al., 1965). Stem length increased and leaf percentage decreased with increased cutting periods. Hay from growth that was 8 and 24 wks old had 50 and 36% less leaves, respectively, than did hay cut every 3 wks. This study supports recommendations for cutting bermudagrass for hay more often than every 8 wks to maximize nutritive value.

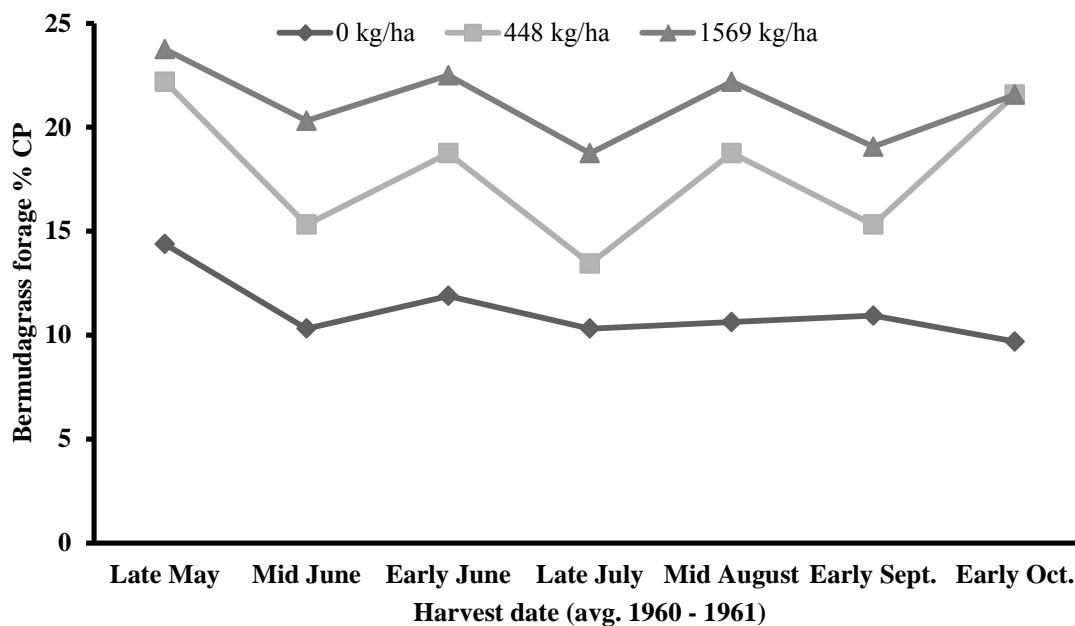
When multiple plots of bermudagrass were kept uncut until their allotted harvest dates, later cuttings had lower levels of CP. Hay made from a first cutting on June 3 was 14.0% CP (Hawkins et al., 1964). When that plot was allowed to grow for 53 more d and was then cut, its protein content was reduced to 10.5% CP (Hawkins et al., 1964). A second and third cutting of another Coastal bermudagrass hay field was 9.8 and 7.1% CP, respectively (Hawkins et al., 1964). Hay protein concentrations are likely to decrease with later cutting dates over the growing season.

Bermudagrass was observed for its nutritive value at 7 different maturities and 3 different fertilization regimes over two years (Webster et al., 1965). Figures 2 and 3 display observations of CP decreasing and NDF increasing with maturity and while CP increases and NDF increases with increasing N fertilization.

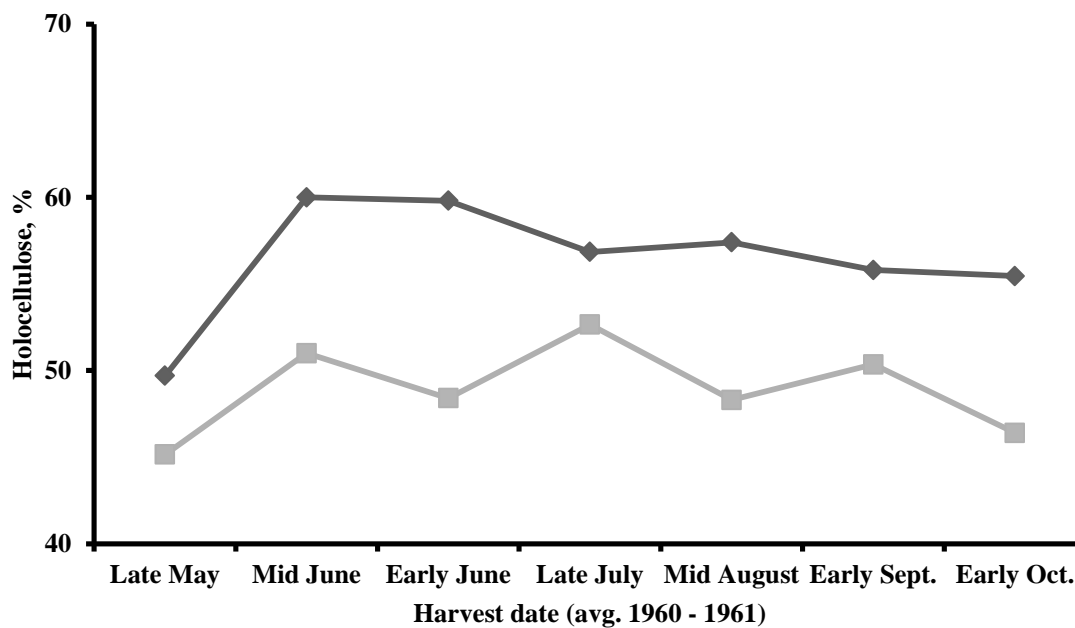
In a study comparing nutritive value after monthly clippings, bermudagrass fertilized with 56 kg N/ha at the initiation of the growing season and again after every

cutting produced the following CP values in May, June, August, September, and October: 16.1, 16.2, 15.4, 15.4, 10.9%, respectively (Beaty et al., 1969). Lignin values were 3.8, 3.9, 4.5, 4.4, 4.7%, respectively (Beaty et al., 1969). When bermudagrass is clipped, its growing points are removed so that an entirely new leaf is initiated for growth. This may explain its suitability for frequent cutting and maintenance of high protein concentrations during its recovery from defoliation (Beaty et al., 1969).

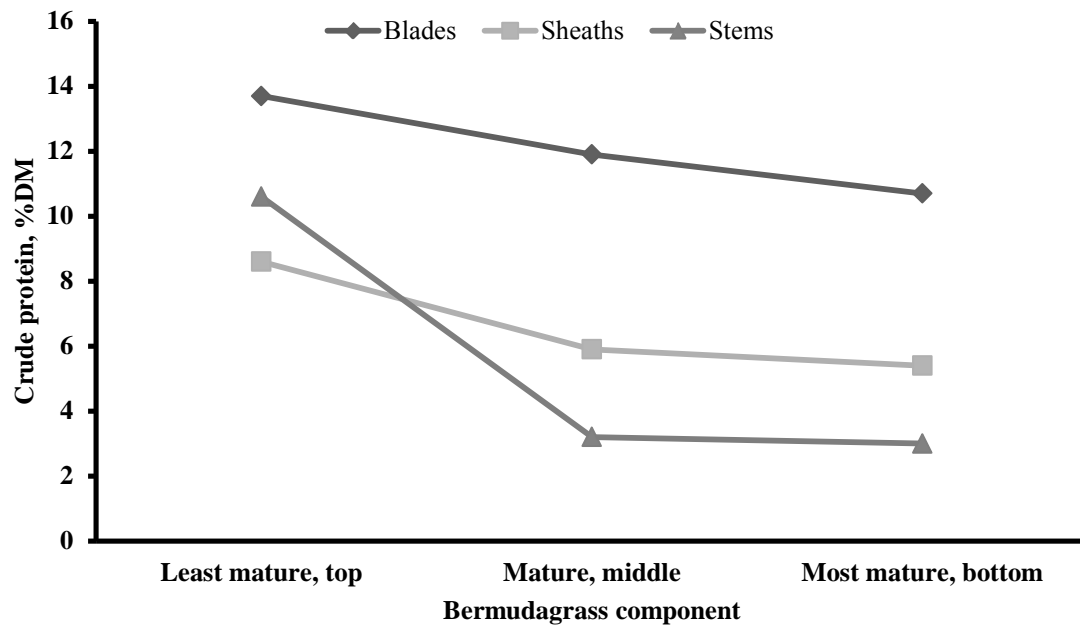
A study quantified the CP and fiber content of bermudagrass which was cut after being grown in a greenhouse over 5.5 months (Akin et al., 1977). The plant clippings were divided into three maturity segments: top (least mature), middle, bottom (most mature). Figures 4-7 display effects of maturity and plant component on CP fiber constituents. In stems, maturity had no effect on the percentage of lignified cells or of the vascular bundle content of phloem. Maturity had no effect on the proportion or location of lignin in the bermudagrass clippings. This data was taken from plants that had not been cut throughout the season. In contrast, studies reporting higher lignin concentrations in consistently clipped forage (e.g., Hawkins et al. (1964), Knox et al. (1958)) suggest that the primary stems are surviving the cuts and concentrate the lignin in their uncut portions. In the research performed by Akin et al. (1977), cell wall components changed significantly along the plant as stems from the more mature



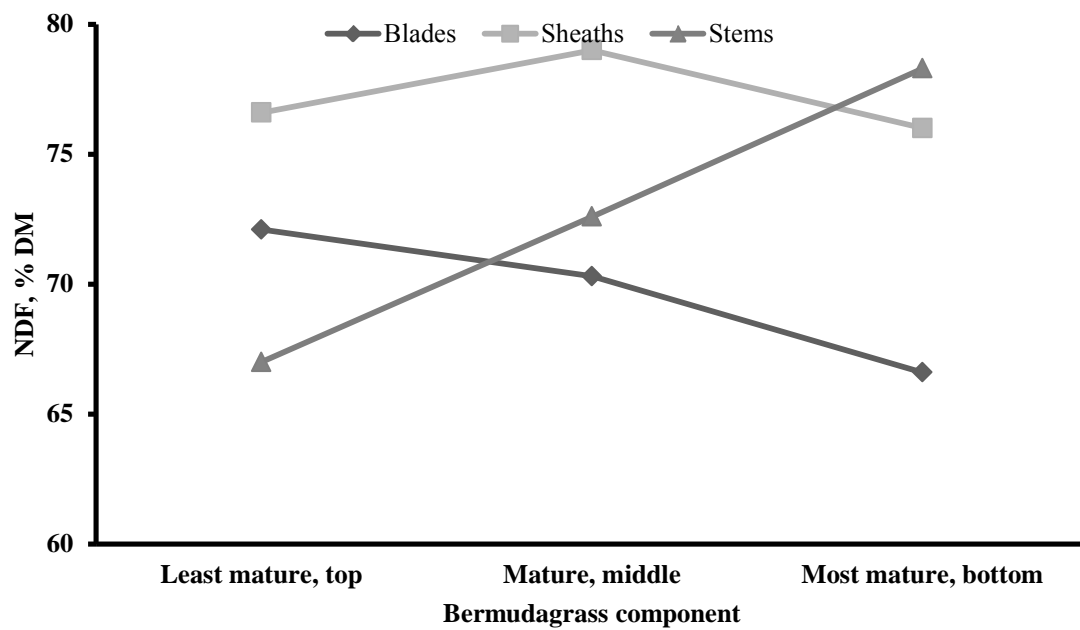
**Figure 2.** Effect of N fertilization rate and harvest date on bermudagrass crude protein content (Webster et al., 1965).



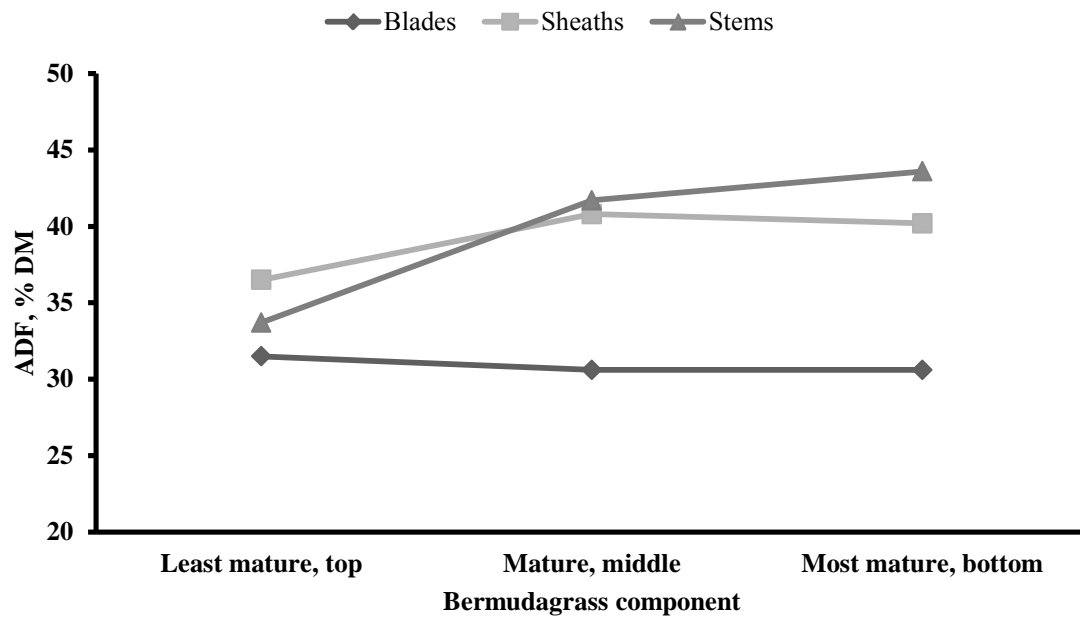
**Figure 3.** Effect of N fertilization rate and harvest date on bermudagrass holocellulose content (Webster et al., 1965).



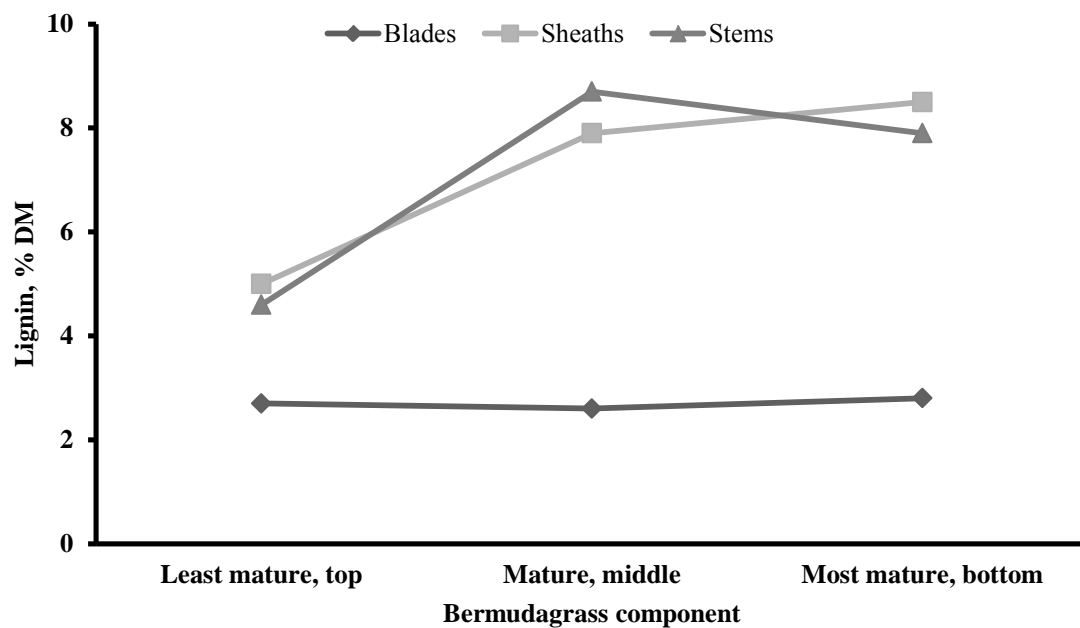
**Figure 4.** Effect of bermudagrass plant component maturity on CP values (Akin et al., 1977).



**Figure 5.** Effect of bermudagrass plant component maturity on neutral detergent fiber (Akin et al., 1977).



**Figure 6.** Effect of bermudagrass plant component maturity on acid detergent fiber (Akin et al., 1977).



**Figure 7.** Effect of bermudagrass plant component maturity on lignin (Akin et al., 1977)

segments decreased in CP content relative to higher, less mature segments. Blades had similar ADF and digestibility values between the maturities, but mature stems and sheaths had larger percentages of ADF and lower digestibility than the immature stems and sheaths. When temperature and water treatments were held constant in a greenhouse setting, grass blades did not significantly differ in nutritive quality among maturity levels, but stems and sheaths had lower digestibility with maturity, seemingly as a result of higher percentages of lignin (Akin et al., 1977).

Bermudagrass hays cut at 2 wk intervals had the highest CP, but DM production was greatest when cut every 12 wks (Overman and Scholtz, 2003). When cut at intervals longer than 12 wks, both DM production and nutritive value of the hay decreased (Overman and Scholtz, 2003). Additional research demonstrated that bermudagrass hay contains 78% leaves at 4 wks harvest, 65% leaves at 6 wks harvest, and 48% leaves at 12 wks harvest (Overman and Scholtz, 2005). Hay cut at shorter intervals possesses greater nutritive value because of the higher leaf (thus, higher CP, lower lignin) content (Overman and Scholtz, 2005).

Bermudagrass hay cut at a low (< 8 weeks) maturity was expected to have the highest nutritive value and be the most digestible because of less developed cell wall components and higher leaf-to-stem ratios. The earlier the harvest, the less likely hay will need supplementation to correct for a nutrition deficit.

*Bermudagrass hay: Nitrogen fertilization and nutritive value*

In addition to maturity at harvest, the nutritive components of bermudagrass cultivars are sensitive to N fertilizer application. Application of N fertilizer from 0 to 1059 kg N/ha increased DM yield, CP content, and stem and leaf length of Coastal bermudagrass; however, N recovery and percentage of leaf decreased with increased fertilization (Prine and Burton, 1956). A quadratic response of N uptake to fertilization was reported in this study by Prine and Burton (1956), revealing the upper limit of responsiveness to N fertilizer to be around 673 kg/ha for grass clipped every 2 wks up to every 8 wks.

Bermudagrass hay nutritive value at the same maturity could differ in response to N fertilization from 0 to 673 kg N/ha. Observations of nutritive value were made for two Coastal bermudagrass hays fertilized at rates of 56 and 112 kg N/ha and cut in October and again in December (Alexander et al., 1961). Fertilizing at 112 kg N/ha resulted in hays with a CP content of 8.9 (October, pre-frost) and 6.7% (December, post-frost). Administering only 56 kg N/ha yielded hays before and after the frost with 6.8 and 5.0% CP, respectively (Alexander et al., 1961). Digestion coefficients, obtained by in vivo digestion trials, differed between harvest dates and between fertilization regimens: 56 and 112 kg N/ha produced hays before the frost whose protein contents were 47.1 and 56.0% digestible before the frost, and 32.2 and 55.5% digestible after the frost, respectively (Alexander et al., 1961). In a second study, fertilizing Coastal bermudagrass at rates of 112 kg N/ha and 225 kg N/ha produced two hays with CP content of 8.9% and 11.2%, respectively (Alexander and Hentges, 1962). Protein from hay fertilized at 225

kg N/ha was more digestible (63 vs. 54%) than the 112 kg N/ha treatment (Alexander and Hentges, 1962).

Digestibility and nutritive value are consistently highest in early June across studies and decline into dormancy. Fertilization has an additive effect to maturity on digestibility and nutritive value as it is increased from 0 to 673 kg over the whole season, or from 0 to 78 kg N/ha per cutting.

### **Intake and digestion of forage by beef cattle**

Protein in ruminant diets is divided into two fractions: degradable intake protein (**DIP**) or undegradable intake protein (**UIP**). Nitrogen as DIP is first degraded by rumen microbes, while UIP bypasses ruminal degradation and is digested by the animal, then once it is metabolized, may return to the rumen for use as urea. If ruminally available N is deficient, then protein supplementation will increase microbial fermentation. Ultimately, this results in greater release of nutrients to the animal, increased passage rate, and the potential for increased forage intake. Improving digestibility of bermudagrass hays with protein supplementation will provide more nutrients to the ruminant consuming them. Increased energy availability from forages can improve animal performance (NRC, 1996).

Because utilizable N is a more limited resource than C, protein supplementation has been more expensive than carbohydrate supplementation. Protein supplementation studies have been conducted to refine the protein requirements of cattle in order to improve forage utilization while avoiding N waste. Supplementation of N is most



effective, i.e., produces the largest benefit, when the first increments of supplemental N are provided. This is because ruminal microbes are very efficient at capturing N when there is a ruminal N deficiency. Protein provided in excess of the requirement is utilized as a source for energy. Individual amino acids are deaminated, and the ammonia is absorbed and is synthesized into urea which can then be recycled to the gut or excreted in urine. Supplementing cattle with unnecessary protein is typically a cost-prohibitive way to supplement energy, and research has been performed in the way of avoiding this.

Satter and Slyter (1974) conducted an experiment aimed at determining threshold rumen  $\text{NH}_3$  requirement. They found that microbial CP (**MCP**) increased linearly as non-protein nitrogen (**NPN**) was supplemented until N was no longer limited for MCP synthesis at 3.57 mM rumen fluid (Satter and Slyter, 1974). Nitrogen was retained in concentrations of up to 3.57 mM, but beyond this point, N capture decreased (Slyter et al., 1979). It was found that MCP production was optimized in concentrations of between 1.43 to 3.57 mM (Slyter et al., 1979). Rumen fluid fermentation profiles measuring  $\text{NH}_3$  concentration can provide insight into ruminal N status.

#### *Degradable intake protein supplementation*

Microbial fibrolytic activity can be enhanced by supplementation with DIP. Mertens (1994) suggested that a significant response to protein supplementation is possible when forage NDF intake is less than  $12.5 \text{ g} \cdot \text{kg}^{-1} \text{ BW} \cdot \text{d}^{-1}$ , or when forage contains less than approximately 80% NDF. He proposed that with higher NDF content, the intake response to DIP supplementation becomes more subtle. When diets are

deficient in DIP, microbes are unable to grow at sufficient rates for potentially degradable fiber to be fermented. For bermudagrass, intake of digestible fiber is maximized at over 9 g/kg BW when DIP is present at just over 1 g/kg BW, or when the ratio of DIP to potentially digestible fiber is about 0.11 (Ellis et al., 2001). This finding is consistent with the study by Köster et al. (1996) who observed peak TDOMI when 11% of it was provided as DIP. The reduced effectiveness of DIP supplementation may be due to crystallinity and low surface area-to-volume ratios of highly concentrated fibers, so that microbes have a lower probability of adhering to exposed fiber substrates (Van Soest, 1994). Cattle consuming forages high enough in crude protein (> 8.2%, Mathis et al., 2000) will not respond to DIP supplementation by increasing their intake, since DIP requirements are likely to have been already met by the hay alone.

An experiment was designed to identify the required DIP as a proportion of total digestible OM intake (**TDOMI**) of cattle for optimal forage utilization. Köster et al. (1996) determined intake of low-quality forage (1.94% CP, 0.98% DIP, 76.6% NDF) by dry, open cows when supplemented with increasing levels of DIP as sodium caseinate. Sodium caseinate is a source of protein completely degradable by microbes. A broken-line model was generated based on the results of the study. At the breakpoint, which displayed the threshold for diminishing return for DIP supplementation, the DIP requirement was found to be 11.1% of DOM (Köster et al., 1996). Additionally, as DIP increased, the acetate:propionate ratios decreased, indicating a greater production of propionate was supplemented to cattle. This study was a major breakthrough for establishing protein supplementation standards for beef cattle.

Plant protein, such as soybean meal, is a commonly supplemented source of N in cattle diets. Although soybean meal is not totally ruminally degradable like sodium caseinate, it is a source of DIP and can stimulate forage intake (NRC, 1996). Soybean meal increased the intake of prairie hay (5.3% CP, 2.6% DIP, 69.4% NDF), increasing it cubically with increasing supplementation (Mathis et al., 1999). Forage organic matter intake was maximized at 0.16% BW/d SBM supplementation. In a companion performance study, gestating cows grazing dormant range (2.7% CP, 1.3% DIP, 76.0% NDF) were supplemented with soybean meal. Cattle maintained BW and BCS with 0.32% BW/d or greater supplemented soybean meal (Mathis et al., 1999). When less of the supplement was provided, cattle lost body condition. Feeding cattle 0.32% BW soybean meal would provide about 0.16% BW CP to cattle consuming very low-quality (2.7% CP) forage, a ration of supplemental CP that may be applicable to other scenarios for supplementing forage of a similar nutritive value.

Protein supplementation to higher-quality bermudagrass hay (8.2% CP, 70.8% NDF) was ineffective at stimulating intake or digestion (Mathis et al., 2000). When DIP was not supplemented, TDOMI was maximized. In this case, additional DIP elicited a negative response in intake. Ruminal ammonia concentrations increased linearly with increasing DIP supplementation. Acetate proportions decreased and propionate concentrations increased as DIP supplementation increased, consistent with the findings of Köster et al. (1996). Data from Mathis et al. (2000) supports the accepted dogma that the response surface to supplemental protein is small, if not nonexistent, in forages with

greater than or equal to 7% CP despite calculated DIP deficiencies. Furthermore, their data suggests that N-recycling mechanisms may overcome small DIP deficiencies.

#### Non-protein nitrogen as DIP supplementation

Urea may substitute for true protein in supplements that are intended to meet DIP requirements. Ruminant microbes utilize low-quality N sources such as urea to synthesize amino acids and proteins which are digested and absorbed by the animal to meet growth and maintenance requirements. Köster et al. (1997) outlined the response of cattle to increasing levels of urea. Steers consuming prairie hay (2.35% CP, 75.5% NDF) responded to increasing amounts of urea substituted for casein (0, 25, 50, 75, 100%) within the DIP fraction of their supplement by reducing OM and NDF digestibility quadratically (Köster et al., 1997). The lowest TDOMI occurred at the highest inclusion rate of urea (100% of DIP as urea). Fiber digestion decreased when urea inclusion surpassed 50%. Although there was no change in forage or total intake, ruminal fermentation characteristics were altered by the incremental replacement of casein with urea. Urea inclusion had no effect on ruminal pH. Cellulolytic microbes preferentially use ruminal ammonia as their N source (Russell et al., 1992), but ammonia concentrations were always sufficient for fibrolysis, suggesting that the depression of OM digestibility with greater NPN proportions was the result of other factors. Butyrate, isobutyrate, valerate, and isovalerate proportions of VFA decreased with increasing urea, propionate was unaffected, and acetate increased. The percentage of acetate increased linearly with the inclusion rate of urea (Köster et al., 1997). They suggested that urea

should make up no more than 50% of DIP. Urea can be a low-cost alternative to other true protein sources that may elicit the same results in beef cattle when fed properly.

Currier et al. (2004a) supplemented urea or biuret at 0.04% BW to beef cows in order to satisfy 90% of DIP requirements for a 13% microbial efficiency (NRC, 1996). The supplements failed to stimulate greater intake of hard fescue straw (4.3% CP, 73.8% NDF; Currier et al., 2004a) The carriers for urea and biuret supplements contributed to dietary NDF since they were 57.9 and 55.4% NDF, respectively. Body condition scores and weights were greater in supplemented cows than in control cows, and N retention improved for supplementation frequencies of every day and every other day (Currier et al., 2004a). Performance was increased by supplementation although intake of forage was not stimulated. Supplementing to maximize forage intake is typically not a feasible goal and emphasis should be placed on optimizing overall animal performance.

Currier et al. (2004b) investigated performance response to NPN source and to frequency of supplementation. Steers consuming 4.3% CP hay were supplemented with urea or biuret at 0.04% BW daily or 0.08% BW every other day. The same results were obtained for both NPN sources. Total OM intake, but not forage intake, increased. Microbial CP production improved and duodenal flow of MCP increased (Currier et al., 2004b). In an additional study, NPN-supplementation significantly increased passage rate regardless of frequency, but the response tended to be stronger with daily supplementation than with supplementation every two days (Currier et al., 2004c).

Urea, as a source of DIP, may be included to improve efficiency of N supplementation and reduce cost, but it will reduce animal performance if it comprises

more than 40% of the DIP supplemented (Köster et al. 1997, 2002). Once it was established that DIP supplementation could enhance the utilization of low-quality forage by cattle, comparing the effect of protein degradability (DIP versus UIP) on forage utilization was assessed by several of the following studies.

#### *Undegradable intake protein supplementation*

##### DIP versus UIP supplementation

To compare the effects of DIP versus UIP supplementation on intake and digestion, steers that consumed 3.4% CP, 76.6% NDF prairie hay were given ruminal (DIP) or postruminal (UIP) infusions of 400 g/d sodium caseinate. Both DIP and UIP treatments significantly increased intake and digestion. Ruminally administered casein increased forage consumption by 62%, while postruminal infusion increased it by 28%. Concentrations of ruminal ammonia were highest for ruminally infused steers, second highest for postruminally infused steers, and lowest for control steers. Plasma urea N concentrations were similar between infused steers and were at least twice as high as control groups (Bandyk et al., 2001).

Wickersham et al. (2004) conducted a study to illuminate the differences in response to high-quality, degradable protein either exposed to the rumen environment or bypassed to the abomasum. Sodium caseinate was ruminally infused at doses of 0, 0.29, 0.58, 0.87, 1.16, 1.45 g/kg BW combined with a postruminal treatment of sodium caseinate infusions at 0 and 0.87 g/kg BW to cattle fed 5.3% CP, 71.7% NDF prairie hay. Forage and total OM intake and digestibilities significantly increased with ruminal

administration of casein. Forage OM tended to increase while total OMI and TDOMI increased with postruminal infusions of casein (Wickersham et al., 2004). These results suggest that protein supplementation is effective at stimulating forage utilization when rumen microbes have primary access to it, especially in the form of peptides rather than secondary access through urea recycling. The experiment by Bandyk et al. (2001) noted a significant response in forage intake to UIP supplementation while Wickersham et al. (2004) reported a tendency for forage intake to increase. This likely occurred because the hay used by Bandyk et al. had a greater N deficiency to be addressed by protein supplementation.

Steer performance on hay (6.0% CP) with three levels of UIP supplements was observed by Reed et al. (2007). The protein supplements contained 8.3, 203.8, and 422.2 g UIP/d, each one with DIP content always between 19 and 25% of DM. Total supplement CP increased from 25.6 to 41.7 to 59.8% of DM. Each provided equal amounts of energy (1.77 Mcal NE<sub>m</sub>/kg). While intake and digestibility of forage improved in cattle receiving supplements compared to cattle not receiving any, there were no differences among supplemented cattle with respect to NDF digestion, OM intake, total ruminal VFA, or MCP synthesis. For steers consuming higher levels of UIP, plasma insulin and urea concentrations were greater (Reed et al., 2007). The total protein content of the low-level UIP supplement was likely to be meeting the animal's protein requirements, whereas the supplements with greater levels of UIP were likely to be surpassing the protein requirements of the animal. Because the intake results for each

supplement were confounded by DIP's impact on forage utilization, the impact of UIP level alone could not be determined.

Infusions of abomasally-infused casein resulted in a quadratic increase in forage and total OM intake (Wickersham et al., 2009). The four amounts of casein were 0, 62, 124, and 186 mg N/kg BW·d<sup>-1</sup> to steers consuming low-quality prairie hay. Nitrogen intake and retention as well as fecal and urinary excretion of N increased linearly with increased provision of casein. Urea production by the liver increased linearly with UIP infusion. As UIP increased, MCP synthesis from recycled urea tended to increase. Total fecal excretion of recycled urea N increased, although as a fraction of gut entry, it did not differ between UIP levels. Microbial incorporation of recycled urea increased quadratically with greater levels of UIP, demonstrating the ability of UIP to supply ruminally available N (Wickersham et al., 2009).

It can be expected that both UIP and DIP fractions of protein from a variety of forage and supplement sources can exert a change in low-quality forage utilization. Even without supplementation, cattle may be able to address small dietary DIP deficiencies through N recycling as possibly evidenced in the study by Mathis et al. (2000) while feeding 8.2% CP bermudagrass hay.

#### *Cottonseed meal supplementation*

Oilseed supplements like cottonseed and soybean meal provide affordable and manageable alternatives to fine-powdered casein, or urea, which is unpalatable and must be precisely rationed. Experiments on stimulating forage intake with oilseed co-products



have occurred since the early half of the last century. Feeding 454 g of cottonseed meal (41% CP, 77.2% digestible) to steers consuming prairie hay (3.56% CP) increased DMI from 3.25 kg to 4.51 kg/d (Briggs et al., 1946). Cottonseed meal fed at 0.6 kg/d resulted in increased weight gain by about 17% and increased hay (4.6% CP) OM intake by 19% (Hennessy and Murison, 1982).

Research has focused on determining the optimum level of cottonseed meal to supplement forage-fed cattle by using several supplementation levels within each experiment for different forage qualities. Gallup and Briggs (1948) supplemented cottonseed meal (43.3 - 46.3% CP) to cattle fed little and big bluestem hay (3.01-5.85% CP). Supplement was fed at levels of 0.0, 0.23, 0.45, 0.68, 0.91, 1.0 and 1.4 kg/d to the experimental steers (248 – 347 kg BW). Dry matter and crude fiber digestibility of unsupplemented hay ranged from 46 to 60% and from 56 to 69%, respectively, as hay CP rose from 3 to 6%. Intake of hay increased at all levels of supplementation. Fecal N represented 0.55% in steers consuming control rations and up to 0.71% in steers consuming cottonseed meal supplements (Gallup and Briggs, 1948). A higher level of fecal N results from increased passage of undigested feed protein and undigested microbial protein of ruminal and hindgut origin. Provision of 0.23 kg cottonseed meal to steers significantly improved utilization of hay. Because forage intake responds quadratically to supplementation, impact of protein supplementation is significant at very small levels like 0.23 kg. A quadratic response also suggests a maximum response to supplementation, beyond which no further increases in forage utilization are expected.

Not only does cottonseed meal effectively stimulate forage intake, but it improves fermentation characteristics, as evidenced by the findings of McCollum and Galyean (1985). Steers consumed prairie hay (6.1% CP, 67.7% NDF) and were fed cottonseed meal at 0 or 800 g/d. Supplementation did not change rumen pH, although ruminal ammonia was greater in supplemented steers than in unsupplemented steers. Molar proportion of acetate was reduced and molar proportion of propionate was enhanced by cottonseed meal supplementation. Rate of passage increased as did forage DM intake (+ 27.2%) for the supplemented steers (McCollum and Galyean, 1985).

While cottonseed meal increases the intake and digestibility of low-quality forage, it provides additional high quality protein that can lead to greater gains in supplemented cattle. For cattle consuming dormant grass having a CP content between 7.7 (January) to 12.6% CP (March) and supplemented with 1.7 kg/hd cottonseed cake, ADG of heifers was 0.24 kg/d compared to the control treatment which was -0.3 kg/d (Judkins et al., 1987). However, forage intake was not increased by supplementation; rather, total dry matter intake increased with the supplementation, thereby providing more nutrients to the treated heifers (Judkins et al., 1987). If animal weight gain on additional CSM is profitable, supplementing 7-12% CP forage may be effective, but possibly not as economical as supplementing with an energy source having a lower CP concentration.

Finally, steers consuming a lower quality hay (5.6% CP, 70.2% NDF) ad libitum were given 600g of a 45% CP supplement (cottonseed meal), 600 or 1200 g of 22% CP supplement (corn grain and cottonseed meal). Ruminal ammonia increased with higher

supplementation levels, but the 600g of 22% CP treatment ammonia level was not different than the control. Hay intake did not increase with any of the supplement treatments (Freeman et al., 1992). The starch from grain may have interfered with forage utilization, and it is possible that steers did not receive enough cottonseed meal to display a significant response in forage intake.

The studies with conclusive results showed that 500 g cottonseed meal increases intake and digestibility of 3-5% CP hay (Gallup and Briggs, 1948), 800 g cottonseed meal supplementing 6% CP hay will increase intake and digestibility (McCollum and Galyean, 1985) and 1.7 kg cottonseed cake will increase gains in cattle consuming forage between 7 and 12% CP (Judkins et al., 1987). The studies performed on cottonseed meal have contributed to its inclusion in range cubes, which are commonly fed to cattle.

#### *Soybean meal supplementation*

Soybean meal, another oilseed extraction co-product, has consistently improved the utilization of low-quality forage for beef production. Less soybean meal can be supplemented than cottonseed meal because of its higher protein content. The following studies have documented the results of supplementing forage with soybean meal.

During the winter of 1976, Kartchner (1980) compared cattle consuming low-quality winter range (6.1-7.0% CP) among treatment groups of no supplementation, 0.75 kg cottonseed meal, and 0.70 kg soybean meal/d, fed at 2 or 3-d intervals. Cracked barley was also fed in an isocaloric amount to another treatment group of cows.

Differences in performance between cottonseed, barley, soybean meal, and control groups were deemed insignificant (Kartchner, 1980). However, forage intake was greater for both protein supplements (8 kg forage consumed) than for energy or control diets (6.3 and 6.8 kg, respectively). Digestibility of forage was reduced by grain supplementation but increased with oilseed meal supplementation (Kartchner, 1980). Kartchner (1980) noted that 0.75 kg cottonseed meal and a lesser amount, 0.70 kg, of soybean meal led to an equal improvement in forage intake, likely due to the protein offered by each as opposed to the energy content.

Soybean meal increased utilization of wheat straw (3.8% CP, 49.0% ADF, 7.8% lignin). Straw intake increased quadratically with increasing SBM. Intake was greatest at 72.6 g/kg BW<sup>0.75</sup> when 3 g of CP/kg BW were provided as SBM (Church and Santos, 1981). This study did for soybean meal what Gallup and Briggs (1948) did for cottonseed meal, in that the quadratic effect for supplementation level to a low-quality basal diet was documented.

Utilization of a prairie hay diet (5.2% CP, 47.9% ADF) was enhanced by soybean meal as observed by Guthrie and Wagner (1988). Soybean meal was fed to steers at 0, 121, 241, 362, and 603 g of dry matter daily. Intake of prairie hay increased quadratically. At 603 g SBM, DMI was greatest at 7.9 kg/d, in stark contrast to the control 4.7 kg/d. Dry matter digestibility increased linearly with additional soybean meal. Ruminal ammonia increased quadratically with incremental addition of soybean meal (Guthrie and Wagner, 1988). At 603 g/d SBM supplementation, Guthrie and Wagner (1988) observed that ruminal ammonia concentrations were 2.46 mM which was

in the acceptable range of 1.43 to 3.57 (Slyter et al., 1979) and above the relatively low level of 1 mM (McCullum and Galyean, 1985). In sum, the quadratic effect of soybean meal on forage utilization was more precisely documented, and it was seen that 603 g DM soybean meal lead to the greatest increase in intake of 5.2% CP forage. This occurred with limited N waste as ammonia concentrations stayed below 3.57 mM, the upper limit for N conservation (Slyter et al., 1979).

In another experiment by Hannah et al. (1991), soybean meal improved utilization of low-quality hay (2.3% CP, 79.1% NDF). Steers were supplemented with 2.7 kg/d alfalfa pellets (17.5% CP) or with low (12.8% CP) or moderate (27.1% CP) protein mixes of grain sorghum and soybean meal and were fed at 1.8 kg/d per head. Intake of hay and total OM digestibility increased with supplementation of moderate protein and alfalfa but did not increase for low protein-supplemented steers (Hannah et al., 1991). The energy-protein combination in the 12% CP supplement did not exert positive effects on forage utilization, most likely because a 12% CP supplement would only be enough to meet microbial requirements to ferment the supplement, according to Köster et al. (1996). Steers on average gained 0.4, 0.3, -0.6, and -1.1 kg/d while consuming alfalfa, moderate protein, low protein, and control rations, respectively. Nitrogen intake was less than duodenal N flow for the low protein and unsupplemented steers, revealing negative N balances (Hannah et al., 1991). At negative N balances, cattle must catabolize their own endogenous proteins and recycle the urea to the rumen in order to meet ruminal N requirements. It was concluded that 1.7 kg of a sorghum and

soybean meal-based supplement of 27% CP but not 12% CP significantly increased the intake of low-quality forage.

Similar to the objectives of Hannah et al. (1991), several of the proceeding studies combine elements of energy and protein in the form of soybean meal to determine the effects of different supplement formulations on forage utilization. It was generally found that forage intake was depressed when energy was high but protein was low, unchanged when energy and protein were both low, and increased when protein was high regardless of energy level. This was confirmed by DelCurto et al. (1990a; 1990b; 1990c) who found that when protein concentration of a soybean meal-based supplement increased from 12-40%, more total protein was provided to the animal which improved intake and digestion of low quality forage (2.9% CP, 80.8% NDF).

More precise manipulations of soybean-based supplemental protein concentrations have shown that supplements increased forage and total intake. DelCurto et al. (1990b) observed the effects of no supplementation, low protein (12% CP), moderate protein (28% CP), and high protein (41% CP) on steer performance while consuming 2.9% CP, 80.8% NDF dormant bluestem hay. The supplements consisted of different compositions of soybean meal and dry-rolled sorghum grain. These were fed at 0.4% BW and low protein, moderate protein, and high protein supplement rations provided 28%, 58%, and 88% of recommended total crude protein requirements, respectively, for steers gaining 0.23 kg/d, or 0.1% BW/d (NRC, 1996). As expected, forage and total steer intakes were greater for high and moderate protein-supplements than for low protein-supplement and unsupplemented. Supplementation also increased

ruminal fill and neutral detergent fiber digestibility in a quadratic manner. Low protein supplements decreased NDF digestibility. Total VFA production increased in supplemented steers (DelCurto et al., 1990b). This study demonstrated that when protein concentration of supplements increased from 12% to 41%, forage intake and digestibility increased. Additionally, when 7.8% CP dormant prairie grass was consumed, the 25% CP supplement maximized intake, whereas the 30% CP supplement decreased intake.

Providing 65% of its CP as DIP (NRC, 1996), soybean meal consistently and effectively increases total DM intake of low-quality hay. When the amount of supplemental DIP from soybean meal (49% CP) added to a prairie hay diet (6.1% CP) increased from addressing 0% to 100% of the DIP requirement with 1.2 g/kg BW DIP, the total OM intake increased from 15.6 to 24.7 g/kg BW (Bodine et al., 2000). Each steer received approximately 1.22 kg soybean meal per d, or 0.38% BW. The prairie hay initially supplied 7.1% of TDN as DIP, but adding soybean meal increased DIP to 14.7% of TDN, 100% of DIP required (Bodine et al., 2000). Meeting DIP requirements with soybean meal supplementation increased total DM intake by 58%.

Different forage qualities can incur different responses to soybean meal supplementation when compared in the same study. In a study by Anderson et al. (2001), lactating cattle receiving rations of crested wheat grass hay (4.3% CP, 67% DIP) were given soybean meal (75% DIP) to supply 100% of the DIP requirement. Cows increased their rate of weight gain, but when supplemented with DIP beyond what was required, weight gain of cow or calf did not increase. Additional UIP from rumen-protected soybean meal did not increase cow weight either (Anderson et al., 2001). When trials

occurred again with different hay (5% CP, 53% TDN) and DIP was supplemented, cows and calves gained more weight than when not supplemented. When UIP was supplemented, cows gained additional weight. Forage quality apparently interacted with the effect of protein supplement on weight gain, whereas adding UIP to 5% CP hay led to additional weight gain but adding it to 4.3% CP hay did not (Anderson et al., 2001). This could be because the TDN in the 4.3% CP hay diet with supplemented UIP was not enough to support a gain response.

For optimizing intake and digestibility of low-quality forage, soybean meal can be fed to supplement cattle at daily amounts of 0.16% BW for 5% CP forage, and 32% BW for 2.5% CP forage. Studies using forage greater than 7% CP did not show conclusive evidence that soybean meal provision will increase forage intake. Soybean meal successfully addresses DIP deficiencies in low-quality forage diets for cattle.

### *Starch supplementation*

Starch sources are offered to cattle to provide supplemental energy. Its impact on intake and digestion, especially when combined with supplemental protein, has been studied carefully. High levels of starch in grazing cattle can depress fibrolytic activity in the rumen as competition for DIP increases and pH decreases, both of which can lead to depressions in forage intake as fiber digestibility decreases (Orskov and Ryle, 1990). However, feeding starch in combination with adequate DIP has mitigated the negative effect of starch on fiber digestion and has enhanced the performance response to protein supplementation when fed appropriately.



Several research trials have undertaken the study of combining energy and protein in formulating supplements. Cattle grazing dormant native range were supplemented with combinations of soybean meal (1.16, 2.07, and 3.00 g CP/kg  $BW^{0.75} \cdot d^{-1}$ ) and corn or cornstarch (0.020, 0.041, 0.061, and 0.081 Mcal DE /kg  $BW^{0.75} \cdot d^{-1}$ ). No differences were observed between intakes of cattle fed different protein levels. Lower forage intakes corresponded to cattle consuming greater amounts of starch (Rittenhouse et al., 1970). Forage intake was negatively impacted by starch intake. Total DMI, however, increased with increased provision of starch. Forage intake did not improve with addition of dietary protein, likely because the lowest protein level satisfied any deficiency, although DM digestibility improved with greater provision of protein (Rittenhouse et al., 1970). Feeding starch can lead to cattle replacing their dependency on forage for dependency on starch for the energy to meet growth and maintenance requirements.

In another study seeking to augment dietary energy without interfering with digestibility, beef cows received supplemental rations of 0, 1, 2, or 3 kg/d ground corn while on a basal diet of native prairie hay (4.2% CP, 52.5% ADF). Supplements included cottonseed meal to provide cattle with 256 g/d of supplemental protein. Hay intake, NDF digestion, and passage rate decreased linearly to the amount of supplemented corn (Chase and Hibberd, 1987). Total digestible OM intake increased cubically and peaked when 1 kg corn was fed, beyond which a negative response to corn supplementation resulted. Total digestible OM intake was similar to control levels for corn fed at 2 and 3 kg. Concentration of ruminal ammonia decreased as corn inclusion

increased and low levels (less than 0.71 mM) indicated a DIP deficiency (Chase and Hibberd, 1987). Akin to the results of Rittenhouse et al. (1970), starch was substituted for forage in the diet during this study when corn was fed at 1 kg/hd or greater with equal amounts of supplemental protein.

It was unknown how supplementing DIP together with energy would affect intake and digestion of low-quality forage. Heldt et al. (1999) determined the effect of energy source and DIP level for supplemented cattle on forage-based diets. Steers fed a 5.7% CP hay received 0.031 or 0.122% BW of DIP/d combined with a second factor, carbohydrate source, which was starch, glucose, or oat fiber. The third factor was level of carbohydrate: 0.15 or 0.30% BW. They reported that within low-level DIP treatments, forage intake and total intake were greater for starch than for fiber and glucose treatments (Heldt et al., 1999). When DIP was high, intake was greater for fiber treatments than for starch treatments. Overall, increasing supplemental DIP increased forage intake by 11.4% and total intake by 14.5%. The greatest forage intake occurred with the highest DIP inclusion rate combined with the lowest glucose inclusion level. Increasing carbohydrate decreased forage intake but had no effect on total intake (Heldt et al., 1999). Increasing DIP or CHO decreased ruminal pH, so that all supplemented steers had lower pH values than unsupplemented steers. Supplemental DIP increased ruminal ammonia concentrations from 0.78 mM (control) to as high as 7.05 mM while greater carbohydrate inclusion lowered it (Heldt et al., 1999). The ratios of energy and DIP fed in this experiment were 91:9 (decreased forage intake, total intake unchanged), 83:17, 71:29, and 29:71 (greatest forage intake), respectively. When adequate DIP is

provided to digest dietary carbohydrates, intake and digestibility increase over control levels, even when starch is included.

Continuing the protein and starch investigation, cattle consuming tallgrass prairie hay (4.9% CP, 72.3% NDF), received supplements containing one of three levels of starch grits (0, 0.15, and 0.30% BW) combined with one of four levels of sodium caseinate (0.03, 0.06, 0.09, and 0.12% BW). Steers receiving supplements consumed more hay and total OM than steers receiving no supplements (Olson et al., 1999). Increasing DIP brought about a linear increase in forage intake. Intake was maximized when DIP was fed at 11.6% total DOM intake. Adding starch to the diet was associated with a linear decrease in hay and total OM intake. As there was no interaction between starch and DIP levels and their effect on intake, it seemed that additional DIP could not mitigate the inhibitive effects of starch on low-quality forage intake. They suggested that if less than 0.15% BW of starch is added with DIP supplements, there may be no depression of low-quality forage intake (Guthrie and Wagner, 1988; Olson et al., 1999; Pordomingo et al., 1991).

Pursuant of an ideal ratio of starch to DIP, an experiment observed the effects of supplemental starch to DIP ratios on steer intake and digestibility of low-quality prairie hay (4.9% CP, 75.3 % NDF). Treatments combined cornstarch grits levels of 0 or 0.3% BW with sodium caseinate levels of 0, 0.015, 0.051, 0.087, 0.123, 0.159, and 0.195% BW. As expected, DIP supplementation increased forage OM intake, total OM intake, and NDF digestibility quadratically, with peak forage, NDF, and total OM intakes occurring at the DIP supplementation level 0.123% BW (Klevesahl et al., 2003).

Consistent with previous findings, forage OM and NDF intake decreased when starch was administered. An interaction was observed for starch and DIP inclusion rates, whereas the effect of one factor on NDF digestion depended upon the inclusion level of the other. Inclusions of 0.3% BW starch and 0.123, 0.159, and 0.195% BW DIP supplementation produced little effect on NDF digestion. Total tract OM digestibility was not different between starch and non-starch treatments when steers were fed 0.087% BW DIP. Because of the maximization of TDOMI seen at the inclusion of 0.123% BW DIP with 0.3% BW starch, adequate DIP supplied to the rumen will counteract the negative effects of starch on OM digestibility by addressing a DIP limitation for fermentation (Klevesahl et al., 2003).

In further pursuit of the ideal supplemental energy source for a combination energy and protein supplement formulation, a study compared the effect of dextrose or starch (fed at 3.0g/kg BW) and DIP level (casein; 0, 0.15, 0.51, 0.87, 1.23, 1.59, 1.95 g/kg BW) on intake and digestion of prairie hay (5.1% CP, 76.2% NDF). While there were no factorial interactions, TDOMI increased quadratically with increased DIP (Arroquy et al., 2004a). Forage and total OM intake increased in a linear manner in response to DIP provision. No significant effect of carbohydrate source was observed for forage OM intake, total OM intake, or TDOMI. Digestion of NDF decreased with supplemental starch and dextrose at casein inclusions of 0, 0.15, and 0.51 g/kg BW, but was not effected at greater levels of DIP inclusion. When DIP was included at an adequate rate, starch or dextrose supplementation did not depress intake or digestibility (Arroquy et al., 2004a). Arroquy et al. (2004a) support the observation of Köster et al.

(1996) that 11.1% of TDOMI should be provided as DIP. The inclusion of a small portion of starch (i.e., 0.15 g/kg BW) will not affect forage intake. This study also showed that dextrose behaves similarly to starch in rumen environments.

A second study by Arroquy et al. (2004b) compared the effect of non-fiber carbohydrate type and DIP source on low-quality hay (5.3% CP, 74.8% NDF) intake and digestion. Either starch or dextrose was combined with six compositions of urea and casein, fed at 0.87 g/kg BW, whose urea:casein ratios were 0:100, 20:80, 40:60, 60:40, 80:20, and 100:0. A linear decrease in total and forage intake ensued with increasing proportions of urea (Arroquy et al., 2004b). The type of non-fiber carbohydrate resulted in no significant effect on intake, although digestibility of NDF was greater for dextrose than starch-supplemented diets. Responses in digestibility were more closely related to nonstructural carbohydrate source, while responses in intake corresponded more closely to DIP composition (Arroquy et al., 2004b). The second study showed a positive effect of dextrose instead of starch on fiber digestion, likely because urea, a N source efficiently used by fibrolytic microbes, was included in DIP. Overall, including higher amounts of DIP as urea brought on a negative linear total and forage intake response.

#### *Total nitrogen supplementation*

Research has aimed at facilitating protein supplementation strategies so that recommendations may be made to producers based on knowledge of CP content (N content  $\times$  6.25) of forage and supplements without knowing DIP and UIP fractions. Forage intake decreases when CP content is less than 8 percent. The depression of intake

may denote a total CP deficiency, and it has been suggested that fermentative microbes need a 4:1 ratio of digestible OM to CP (Moore and Kunkle, 1995). Other research has recommended threshold ratios as high as 6:1 and 8:1 for supplementing CP, or when between 13 and 17% of digestible OM is CP (McCollum, 1997; Moore et al., 1999). When more than 21% of digestible OM is CP, N retention efficiency diminishes (Poppi and McLennan, 1995). There is evidence that type of supplemental protein, whether DIP or UIP, may not influence the productivity of preparturient cattle as long as total animal protein requirements are met (Alderton et al., 2000).

A total N supplementation optimization point applicable to both dried distillers' grains (**DDG**) and cottonseed meal on 7.4% bermudagrass hay was determined by Rambo et al. (2010). Dried distillers' grains were compared to cottonseed meal in order to evaluate the respective supplemental effects of each co-product on bermudagrass hay (7.4% CP, 77.0% NDF) intake. Dried distillers' grains contained 31% CP while CSM contained 50% CP. A quadratic response was reported and TDOMI was maximized at 28 g/kg BW<sup>0.75</sup> DDG. Forage DMI was maximized when either supplement type was fed to supply 156 mg N/kg BW (Rambo et al., 2010). This maximal point at 156 mg N/kg BW for supplementing 7.4% CP hay provided a guideline for addressing the N needs of the cattle consuming three different hay qualities in our project.

### **Direction of study**

Management of beef cattle on forage-based production systems routinely involves protein supplementation to improve and maintain animal productivity, because

improving forage intake elevates the intake of total energy. Bermudagrass forage declines in CP content with maturity, and supplementation has yet to be empirically optimized for each level of CP content. Beef cattle producers often supplement their cattle with range or breeder cubes, which contain a mixture of DIP and UIP protein with fiber, starch and sugar-based energy sources. Supplementation is often performed independently of the variation in forage quality of the basal diet, and both over and under-supplementation can be costly mistakes. The most effective pairing of cubed protein supplements with bermudagrass forage CP content merits further investigation. Range and breeder cubes are sold containing several different CP fractions. The results of the current study may encourage appropriate supplementation to improve return-on-investment or omit unnecessary supplementation altogether in order to manage cattle more cost-effectively.

## CHAPTER II

### MATERIALS AND METHODS

#### **Study description**

This study evaluated the effects of increasing provision of supplemental protein on the utilization of three Coastal bermudagrass hays (*Cynodon dactylon*, (L) Pers.) of divergent nutritive value. Thirteen ruminally fistulated Angus × Hereford steers ( $330 \pm 19$  kg BW, 3 y) were used in a  $13 \times 4$  incomplete Latin square (Cochran and Cox, 1957) involving 13 treatments and 4 periods. Treatments were arranged as a  $3 \times 4$  factorial plus a positive control, which consisted of high crude protein (10.8% CP; see table on p. 41) bermudagrass hay. Nutritive value of three bermudagrass hays (5.6, 6.3, and 8.1% CP; see table on p. 41) represented the first factor. The second factor consisted of 4 levels of supplemental protein provision (0, 82, 119, 155 mg N/kg BW daily), with the highest level of supplementation equal to the level of N from cottonseed meal that maximized bermudagrass hay (7.4% CP) utilization in Rambo et al. (2010). All steers receiving supplement were fed 0.24% of BW daily as a 20, 30, or 40% CP supplement (table on p. 42). The 20 and 40% CP supplements were purchased (Producers COOP, Bryan, TX), while the 30% CP supplement was made by blending a 1:1 ratio of the 20 and 40% supplements. All hays were produced at the Texas A&M University McGregor Research Station, McGregor, TX. All fields were fertilized to soil test with 108, 0, and 0 kg/ha of N, P, and K, respectively. Hays were subsequently harvested at 4, 6, 8, and 10 wks after fertilization resulting in hays of 10.8, 8.1, 6.3, and 5.6% CP, respectively. Prior to



feeding, hay was chopped through a 75 mm × 75 mm screen and fed daily at 130% of the previous 4-d average intake to ensure that access to forage did not restrict intake. Protein supplements were fed once daily at 0645h. Hay was fed immediately afterward at 0700h.

The experimental protocol was approved by the Institutional Animal Care and Use Committee at Texas A&M University and included the use of anesthesia when surgical procedures were performed.

Steers were housed in a continuously lighted, enclosed and climate-controlled (21°C) barn in individual stalls (2 m × 3 m) with ad libitum access to water and a trace mineral salt block (composition: 96.0% NaCl, 1% S, 25 ppm Co, 150 ppm Cu, 90 ppm I, 1,500 ppm Fe, 3,000 ppm Mn, 10 ppm Se, 2,500 ppm Zn; United Salt Corp.).

### **Sampling periods**

Experimental periods were 15 d long with 9 d for adaptation and 7 d for sample collection and intake determination. Intake and digestion were determined from d 10 to 16. Hay and supplement samples (400g each) were collected from d 10 to 13 immediately before feeding, orts (400g) were collected from d 11 to d 14 at 0600h, and a total of 12 fecal grab samples (150mL) were collected every 8 h between d 11 and 14. Fecal sampling was advanced 2 h every day to gather representative samples from each even hour of the day. Partial DM of hay, orts, and fecal samples was determined by drying samples at 55°C for 96 h in a forced-air oven. Samples were subsequently ground (No. 4 Wiley mill, Thomas Scientific, Swedesboro NJ) to pass a 1 mm screen. Samples

of hay and supplement were composited across days within period and ort and fecal samples were composited across days within steer for each period. Digestion coefficients were calculated using acid detergent insoluble ash (**ADIA**) as an internal marker as described by Cochran and Galyean (1994).

A rumen fermentation profile was conducted on d 15. Samples of rumen fluid were collected just prior to feeding (0 h) and at 3, 6, 9, 12, and 18 h postfeeding with a suction strainer (Raun and Burroughs, 1962); 19 mm diameter, 1.5 mm mesh. A combination electrode (Thermo Fisher Scientific, Waltham, MA) was used to measure rumen pH immediately after sample collection. Eight mL of rumen fluid was mixed with 2 mL of 25% (wt/vol) metaphosphoric acid and frozen (-20°C) for VFA and ammonia analysis.

A 10 mL blood sample was obtained via Vacutainer tubes (BD, Franklin Lakes, NJ) from each steer at 1900, 12 hours after feeding, on day 15 from the jugular vein. Tubes containing blood samples were immediately stored upright in ice until they were centrifuged at 5,000× g for 15 minutes after samples were taken from all steers. Plasma was retained and frozen (-20°C) for determination of urea-N concentration.

### **Laboratory analysis**

Hay, supplement, orts, fecal, and ruminal content samples were dried for 24 h at 105°C in a forced-air oven to calculate DM and then combusted for 8 h at 450°C in a muffle furnace to determine OM (Tables 1 and 2). Crude protein was calculated as 6.25 × % N, which was determined by total combustion (Rapid N Cube, Elementar Americas,

Inc., Mt. Laurel, NJ) on hay and supplement samples. The ANKOM-Fiber Analyzer (Ankom-Technology, Fairport, NY) was used to determine NDF and ADF of hay, supplement, orts, fecal, and ruminal content samples, with sodium sulfite omitted and without correction for residual ash. To determine ADIA of hay, supplement, orts, fecal, and ruminal content samples, Ankom bags from the ADF analysis were combusted for 12 h at 450°C in a muffle furnace. Ruminal VFA were determined by GLC as described by Vanzant and Cochran (1994). Colorimetric determination of ruminal ammonia (Broderick and Kang, 1980) and plasma urea (Marsh et al., 1965) were made using a UV/VIS IDV 730 UV/VIS Spectrometer, (Bechman Coulter, Inc., Fullerton, CA).

**Table 1.** Chemical composition of hays

Nutritive Analysis	Bermudagrass hays, % CP			
	5.6	6.3	8.1	10.8
	-----% of DM-----			
OM	91.5	92.1	87.8	92.1
NDF	73.5	71.6	71.0	70.4
ADF	45.0	38.8	39.3	38.0
Acid detergent insoluble ash	5.4	3.2	3.4	3.5

### Statistical analysis

Intake, digestion, and plasma urea nitrogen (**PUN**) data were analyzed with PROC MIXED (SAS, 2002). Period and treatment were included in the model as fixed effects with steer included as a random term. Fermentation profile variables were analyzed using PROC MIXED. Fixed terms in the model were treatment, period, hour,

and hour  $\times$  treatment, with steer and treatment  $\times$  period  $\times$  steer included as random terms. The repeated term was hour with treatment  $\times$  steer serving as the subject. Compound symmetry was used for covariance structure. Treatment means were calculated using the LSMEANS option. Orthogonal contrasts were used to separate treatment means. The following contrasts were used: 1) linear effect of supplemental N; 2) quadratic effect of supplemental N; 3) linear effect of hay CP content; 4) quadratic effect of hay CP content; 5) supplemental N (linear)  $\times$  hay CP content (linear) interaction; 6) supplemental N (quadratic)  $\times$  hay CP content (linear) interaction; 7) supplemental N (linear)  $\times$  hay CP content (quadratic) interaction; 8) supplemental N (quadratic)  $\times$  hay CP content (linear) interaction; 9) supplemental N (quadratic)  $\times$  hay CP content (quadratic) interaction; 10) linear effect of unsupplemented hays; and 11) quadratic effect of unsupplemented hays. Hay 10.8% CP was only included in contrasts 10 and 11. Interaction means were assessed for any significant *F*-tests ( $P \leq 0.05$ ) and interactions were interpreted as appropriate.

**Table 2.** Chemical composition of supplements

Nutritive Analysis	Supplement protein content <sup>1</sup>		
	20 <sup>2</sup>	30	40 <sup>3</sup>
	-----% of DM-----		
CP	22.9	33.1	43.4
OM	89.9	89.6	89.0
NDF	31.9	28.1	21.1
ADF	11.2	11.6	12.6
Acid detergent insoluble ash	0.5	0.5	0.5

<sup>1</sup> 30% Supplement was created by mixing 20 and 40% supplements at a ratio of 1:1. All supplements were fed at 2.28 g DM/kg BW.

<sup>2</sup>20% range cube major ingredients: 39% wheat middlings, 15% corn gluten feed, 5% dried distillers' grains

<sup>3</sup>40% range cube major ingredient: 51% cottonseed meal

## CHAPTER III

### RESULTS

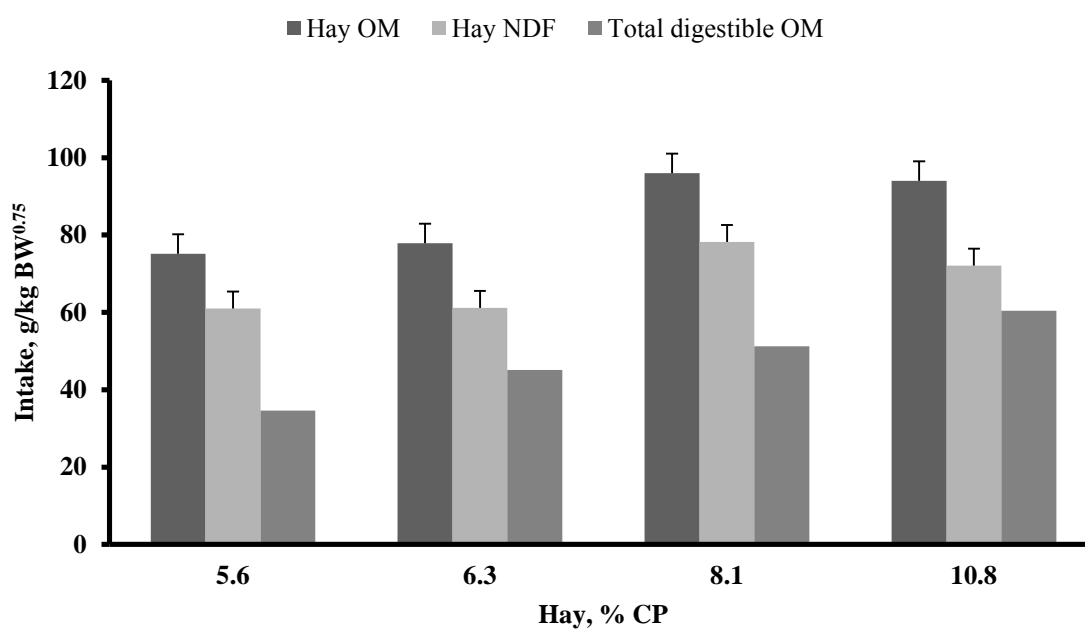
#### **Bermudagrass hay: Effects of hay crude protein content on intake and digestion**

Hay OM intake (**HOMI**) increased quadratically ( $P = 0.05$ ; Figure 8) as hay CP content increased. The largest increase in HOMI, 23%, was observed between the 6.3 and 8.1% CP hays, which drove much of the response. Hay NDF intake increased quadratically ( $P = 0.02$ ; Figure 8) with hay CP content. This was driven by increased hay intake, not by increased NDF content. Hay CP content had a linear effect ( $P < 0.01$ ) on total CP intake, 4.6, 5.4, 8.7, and 10.8 g/kg BW<sup>0.75</sup> for 5.6, 6.3, 8.1, and 10.8% CP hays, respectively.

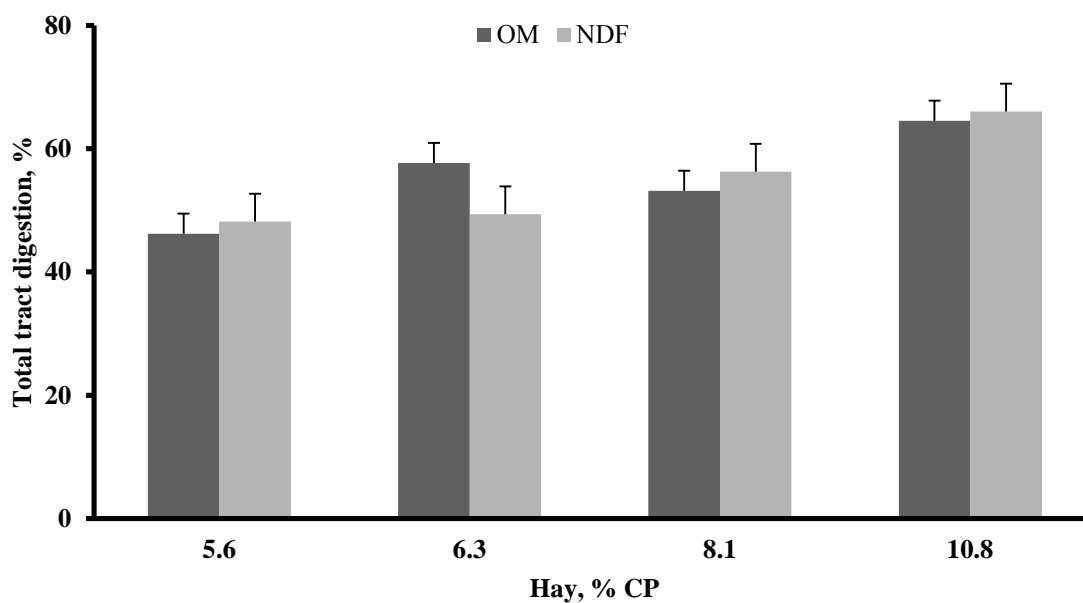
Total tract OM digestibility increased in a cubic fashion ( $P = 0.03$ ; Figure 9), whereas NDF digestibility increased linearly ( $P < 0.01$ ) in response to hay CP content. The combined effect of intake and digestion, TDOMI, increased linearly ( $P = 0.01$ ) in response to hay CP. Increases in TDOMI were 30.3, 13.7, and 17.9% between 5.6 and 6.3, 6.3 and 8.1, and 8.1 and 10.8% CP hays, respectively. These are in contrast to the increases in HOMI which were 3.6, 23.4, and -2.1% from 5.6 to 6.3, 6.3 to 8.1, and 8.1 to 10.8% CP hays, respectively. Total intake of digestible NDF increased (linear,  $P < 0.01$ ) with increasing hay CP content.

There was not a significant ( $P = 0.62$ ) treatment  $\times$  time interaction for ruminal pH (Figure 10). A linear decrease ( $P < 0.01$ ) in ruminal pH was observed as hay CP content increased. The highest average pH, 6.71, was observed in 5.6% CP hay while the

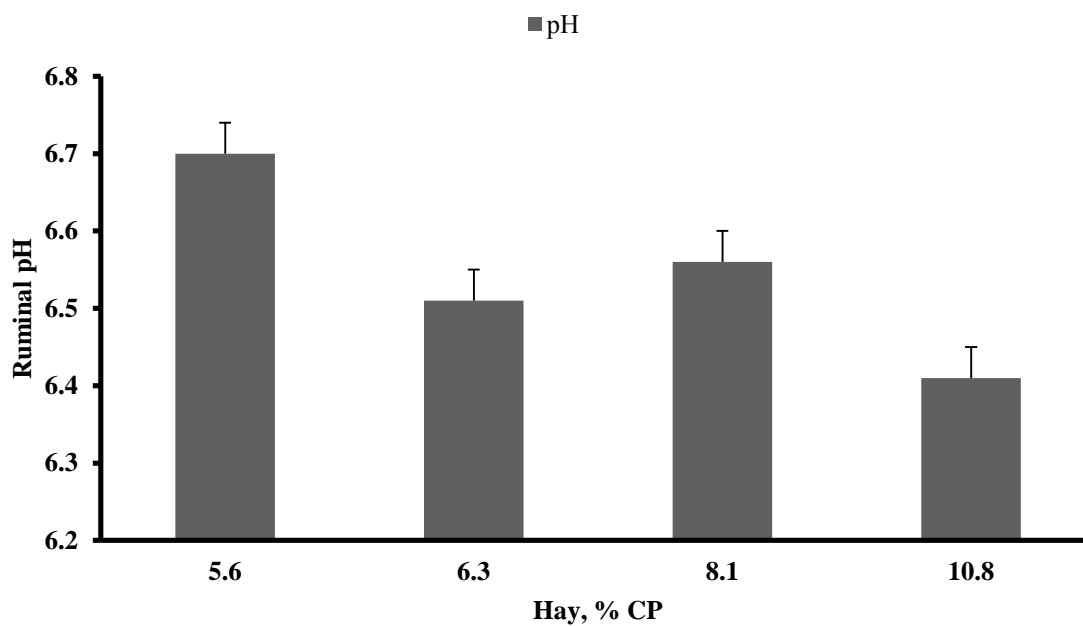
lowest average pH, 6.41, was observed in 10.8% CP hay. Nadir pH for 10.8% CP hay was 6.24 at hour 12. A treatment  $\times$  time interaction was observed for ruminal  $\text{NH}_3$  concentration ( $P < 0.01$ ), but this interaction was largely the result of the difference between treatments at different times, rather than changes in treatment rankings. As such, treatment means averaged across time are presented (Figure 11). Ammonia concentrations increased linearly with hay CP content ( $P < 0.01$ ). A linear response ( $P = 0.02$ ) was observed for plasma urea nitrogen as hay CP content increased (Table 4).



**Figure 8.** Effect of hay crude protein content on hay organic matter intake and total digestible organic matter intake. Quadratic effect ( $P = 0.05$ ) on hay organic matter intake. Linear effect ( $P = 0.01$ ) on total digestible organic matter intake. Quadratic effect ( $P = 0.02$ ) on hay neutral detergent fiber intake.

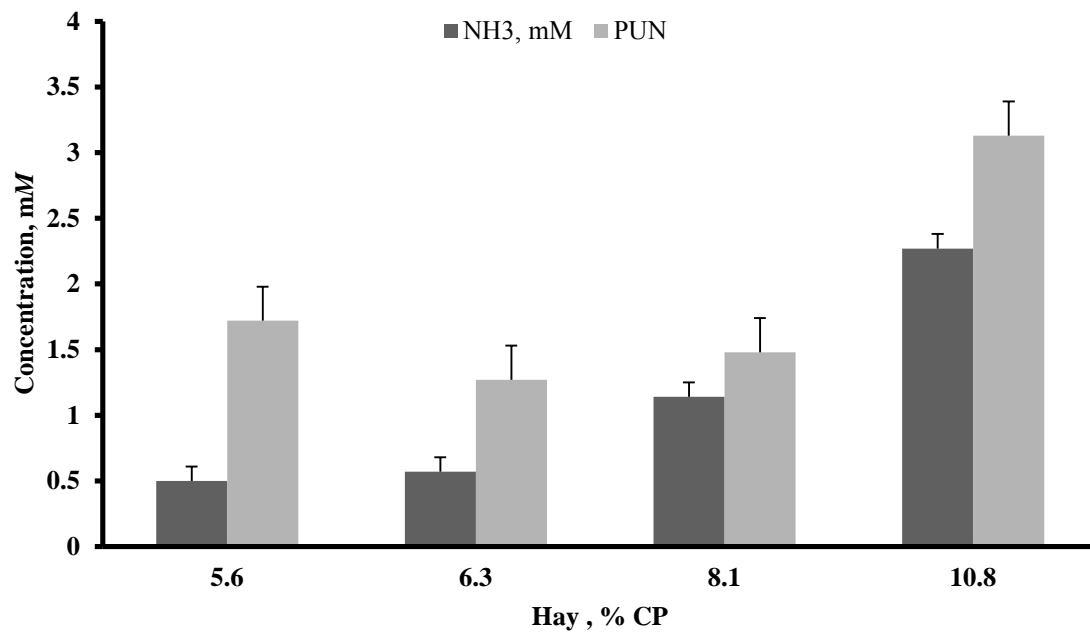


**Figure 9.** Effect of hay crude protein content on total tract digestion of organic matter and neutral detergent fiber. Cubic effect ( $P = 0.03$ ) on organic matter digestion. Linear effect ( $P < 0.01$ ) on neutral detergent fiber digestion.



**Figure 10.** Effect of hay crude protein content on ruminal pH. Linear effect ( $P < 0.01$ ).



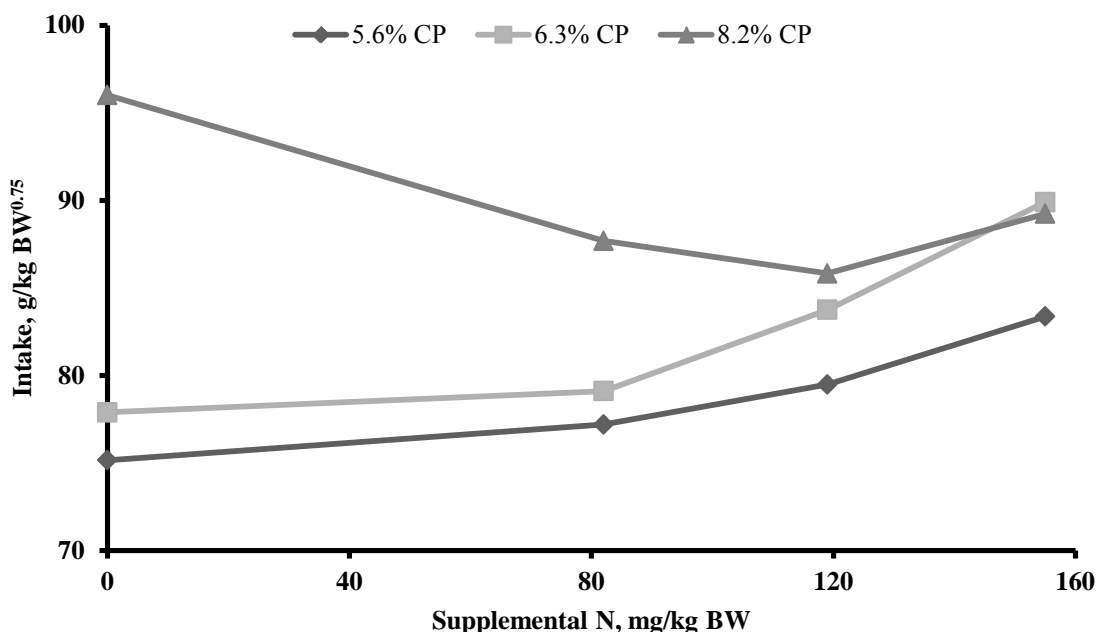


**Figure 11.** Effect of hay crude protein content on ruminal ammonia and plasma urea nitrogen. Linear effect ( $P < 0.01$ ) on ruminal ammonia. Linear effect ( $P = 0.02$ ) on plasma urea nitrogen.

### **Bermudagrass hay with supplemental N: Effects of supplemental N on intake and digestion**

A significant ( $P = 0.04$ ) supplemental N  $\times$  hay CP content interaction was observed for both HOMI (Figure 12) and total OM intake (**TOMI**). This interaction can be attributed to the following reasons: i) linear ( $P < 0.01$ ) increases in HOMI and TOMI in response to increasing hay CP content, ii) a tendency ( $P = 0.08$ ) for increased HOMI and TOMI with increasing supplemental N when hay 6.3% CP was fed, and iii) no significant response to supplemental N for hays 5.6 and 8.1% CP. In contrast, no significant interactions ( $P \geq 0.35$ ; Figure 13) were observed for TDOMI.

Supplemental N resulted in no significant ( $P \geq 0.17$ ) effect on HOMI. However, HOMI tended ( $P = 0.08$ ) to increase when 6.3% CP hay was supplemented with N. Hay OM intake increased 2, 6, and 7% between N levels 0 to 82, 82 to 119, and 119 to 155 mg/kg BW. Hay and total OM intake increased with increasing hay CP content (linear,  $P < 0.01$ ; Figures 5, 6). Supplemental N increased TOMI (linear,  $P < 0.01$ ). This response was driven by linear ( $P < 0.03$ ) increases in TOMI when supplemental N was delivered to 5.6 and 6.3% CP hays. Total OM intake increased within 5.6% CP hay treatments from 75.1 to 85.8, 88.1, and 91.9 g/kg BW<sup>0.75</sup> for N levels 0, 82, 119, and 155 mg/kg BW, respectively. Total OM intake increased within 6.3% CP hay treatments from 77.9 to 87.7, 92.3, and 98.4 g/kg BW<sup>0.75</sup> for N levels 0, 82, 119, and 155 mg/kg BW, respectively. No significant response in total OM intake to supplemental N was observed in 8.1% CP hay.



**Figure 12.** Effect of supplemental nitrogen and hay crude protein content on hay OM intake. Linear hay crude protein  $\times$  linear supplemental nitrogen interaction ( $P = 0.04$ ). Linear effect ( $P < 0.01$ ) of hay crude protein content. Linear tendency ( $P = 0.08$ ) of supplemental nitrogen for 6.3% CP hay. SEM = 5.07.

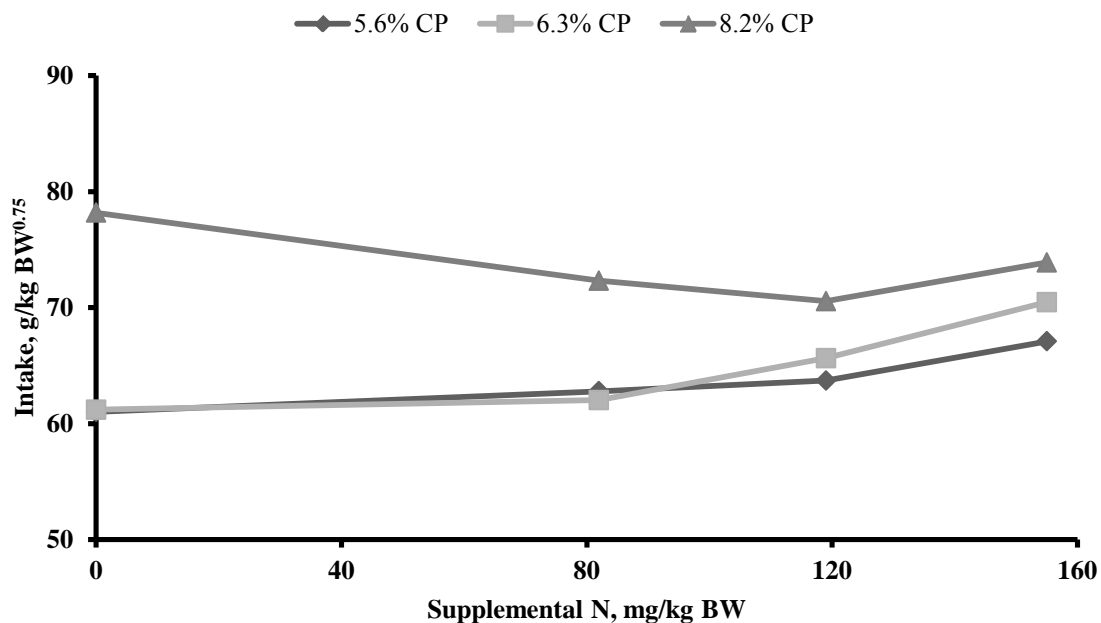
A tendency ( $P = 0.08$ ) for a linear hay CP content  $\times$  linear supplemental N interaction for hay NDF intake was observed (Figure 13). This is attributable to the linear effect ( $P < 0.01$ ) of hay CP content on hay NDF intake combined with a tendency for a linear ( $P = 0.10$ ) increase in NDF intake when the 6.3% CP hay was supplemented; whereas, there was no significant effect of supplemental N on NDF intake of 5.6 and 8.1% CP hays.

There were no hay CP content by supplemental N interactions observed for TDOMI, digestible NDF intake, or total tract digestion of OM and NDF. Total digestible OM intake increased linearly ( $P < 0.01$ ) as hay CP content increased. Supplemental N

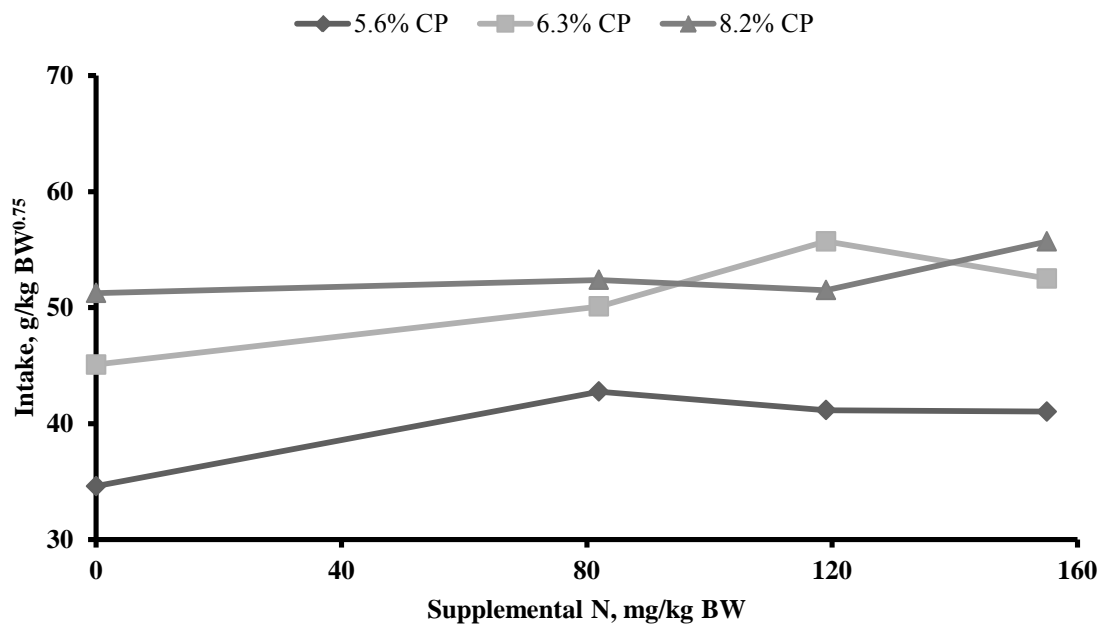
tended to increase TDOMI (linear,  $P < 0.07$ ; Figure 14). No significant ( $P \geq 0.25$ ) responses of total digestible NDF intake to supplemental N occurred, although total digestible NDF intake increased linearly ( $P < 0.01$ ; Figure 15) with hay CP content.

Supplemental N did not significantly ( $P \geq 0.39$ ) affect total tract OM and NDF digestion (Figures 16, 17). Total OM percent digestion values demonstrated a quadratic ( $P < 0.01$ ) response to hay CP content (Figure 16). Hay CP content stimulated a linear increase in NDF percent digestion ( $P < 0.01$ ; Figure 17).

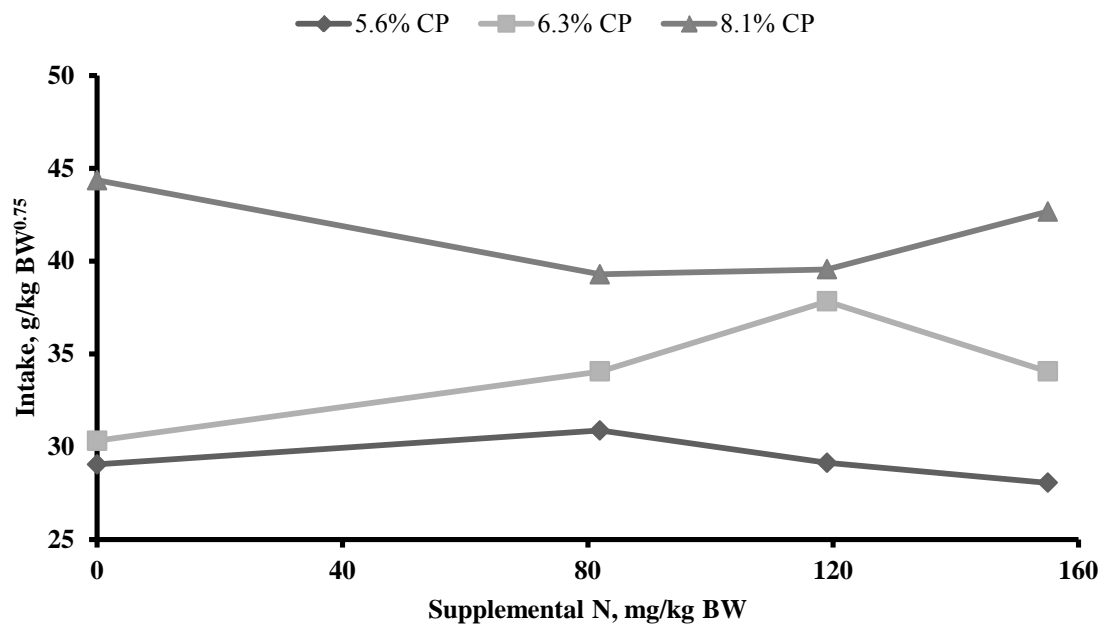
Both supplemental N and hay CP content increased total CP intake (linear,  $P < 0.02$ ; Figure 18). A linear ( $P < 0.01$ ) increase ensued for percent CP of TDOMI for increasing hay CP content and supplemental N, but no interaction was observed (Figure 19). Maximum TDOMI occurred for 5.6% CP hay at 16%, for 6.3% CP hay at 17%, and for 8.2% CP hay at 23% of TDOMI as CP, respectively.



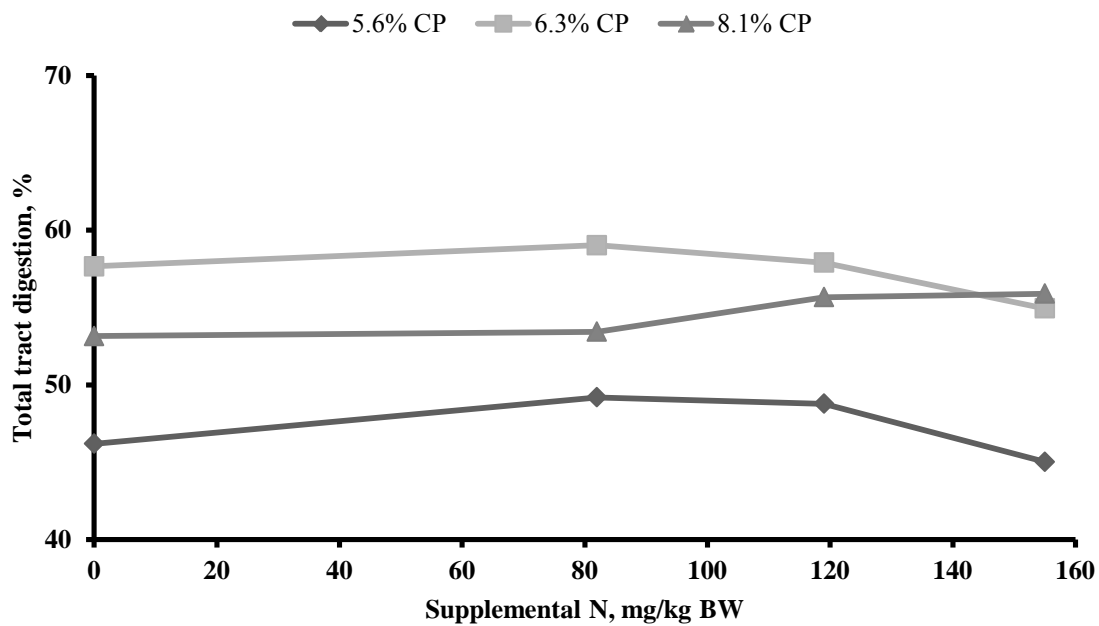
**Figure 13.** Effect of supplemental nitrogen and hay crude protein content on hay neutral detergent fiber intake. Linear hay crude protein  $\times$  linear supplemental nitrogen interaction tendency ( $P < 0.08$ ). Linear effect ( $P < 0.01$ ) of hay crude protein content. Linear tendency ( $P = 0.10$ ) of supplemental nitrogen on 6.3% CP hay neutral detergent fiber intake. SEM = 4.14.



**Figure 14.** Effect of supplemental nitrogen and hay crude protein content on total digestible organic matter intake. Linear effect ( $P < 0.01$ ) of hay crude protein content. Linear tendency ( $P = 0.07$ ) of supplemental nitrogen. SEM = 4.38.

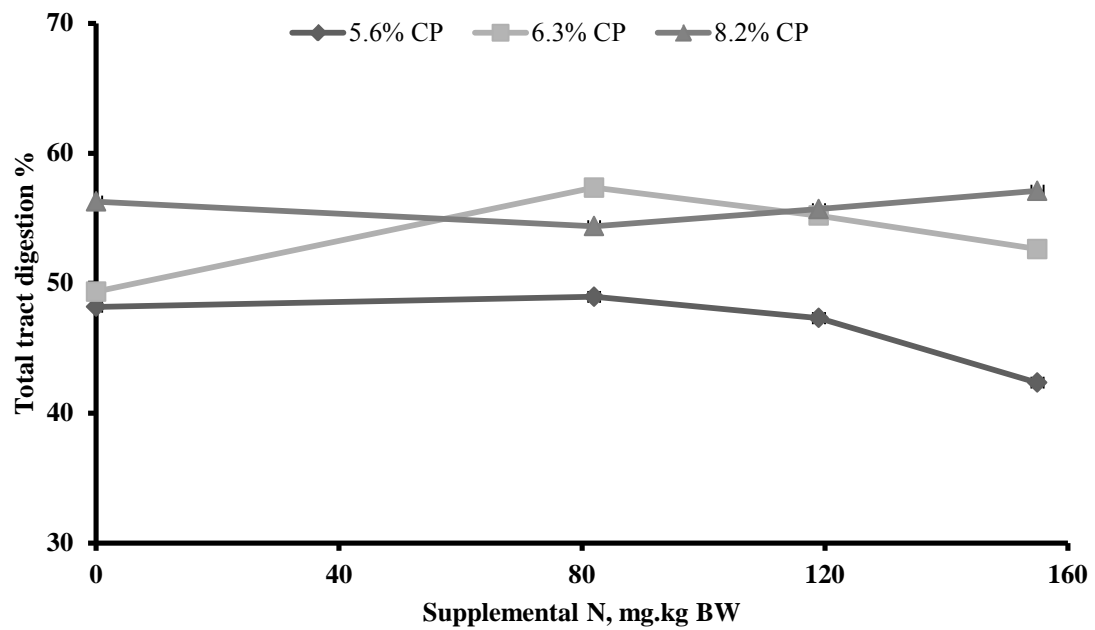


**Figure 15.** Effect of supplemental nitrogen and hay crude protein content on total digestible neutral detergent fiber intake. Linear effect ( $P < 0.01$ ) of hay crude protein content. SEM = 4.14.

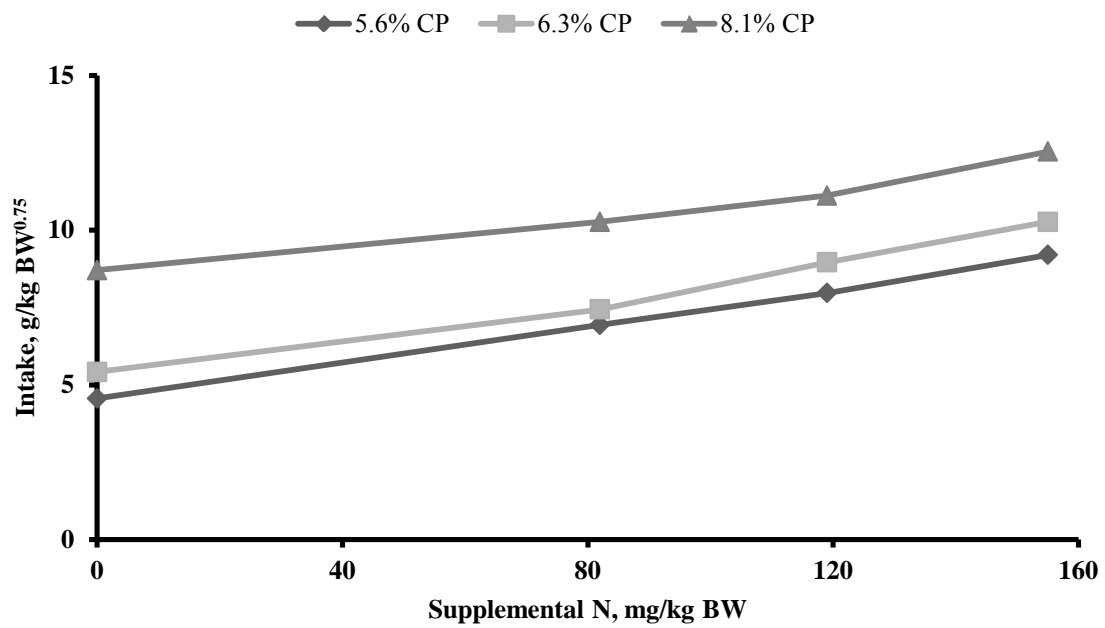


**Figure 16.** Effect of supplemental nitrogen and hay crude protein content on total tract organic matter digestion. Quadratic effect ( $P < 0.01$ ) of hay crude protein content. SEM = 3.26

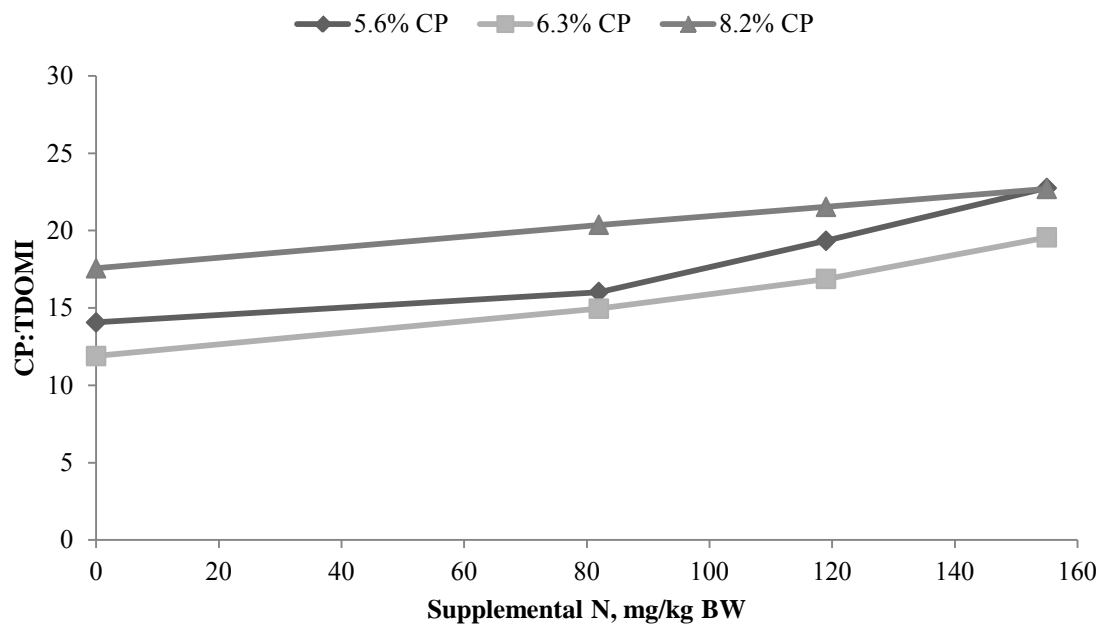




**Figure 17.** Effect of supplemental nitrogen and hay crude protein content on total tract neutral detergent fiber digestion. Linear effect ( $P < 0.02$ ) of hay crude protein content. SEM = 4.51.



**Figure 18.** Effect of supplemental nitrogen and hay crude protein content on total crude protein intake. Linear effect ( $P < 0.01$ ) of hay crude protein content. Linear effect ( $P < 0.01$ ) of supplemental nitrogen. SEM = 0.49.



**Figure 19.** Effect of supplemental nitrogen and hay crude protein content on the ratio of crude protein to total digestible organic matter intake. Linear effect ( $P < 0.01$ ) of hay crude protein content. Linear effect of supplemental nitrogen ( $P < 0.01$ ). SEM = 1.45.

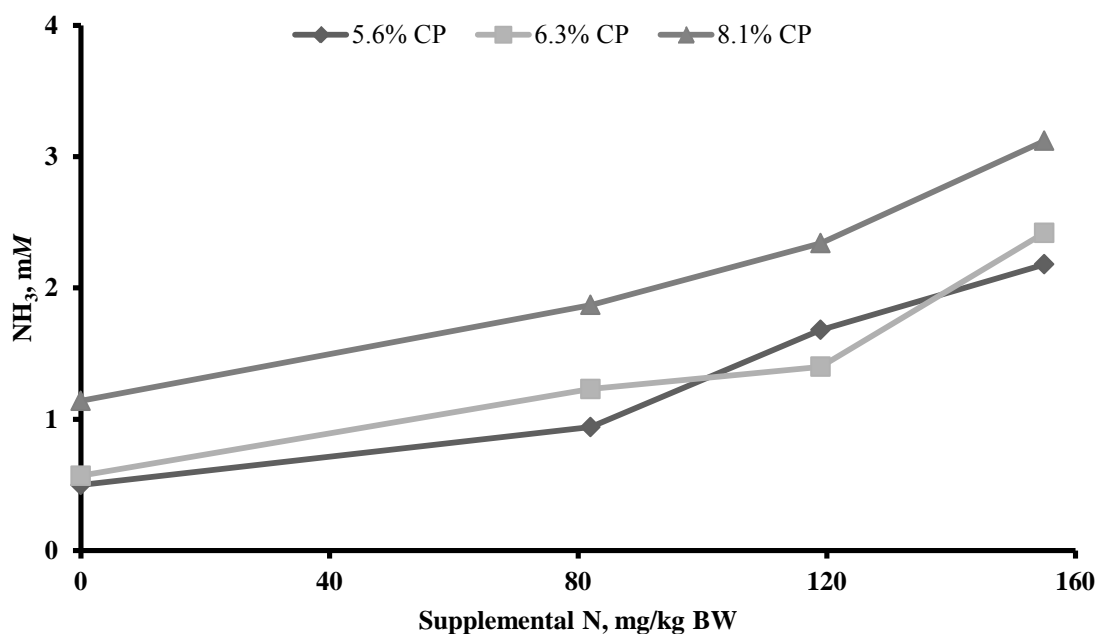
Treatment  $\times$  time interactions for fermentation variables were previously discussed. A quadratic ( $P < 0.01$ ) response of pH to supplemental N was observed in 8.2% CP hay, and a linear response to supplemental N was observed in 5.6% CP hay. No significant response to supplemental N for ruminal pH in steers consuming 6.3% CP hay occurred (Table 3). Ammonia concentrations increased linearly with supplemental N ( $P < 0.01$ ; Figure 20). Supplemental N within each hay CP content also displayed linear responses ( $P < 0.01$ ). There was a tendency ( $P = 0.07$ ) for PUN levels to respond in a quadratic manner to rising hay CP content. No significant effects ( $P \geq 0.11$ ) of supplemental N on PUN were displayed (Table 4).

**Table 3.** Effect of supplemental nitrogen and hay crude protein content on pH

Hay % CP	<sup>2</sup> Supplemental N, mg/kg BW				SEM	Main Effects ( $P =$ )			
	0	82	119	155		Trt	Hr	Trt $\times$ Hr	
	pH <sup>1,2</sup>								
5.6	6.70	6.55	6.52	6.57	0.04	< 0.01	< 0.01	0.62	
6.3	6.51	6.46	6.44	6.48					
8.2	6.56	6.45	6.42	6.58					

<sup>1</sup>Quadratic effect ( $P < 0.01$ ) of hay crude protein content

<sup>2</sup>Linear effect ( $P < 0.01$ ) of supplemental nitrogen



**Figure 20.** Effect of supplemental nitrogen on ruminal ammonia concentration by hay crude protein content. Linear effect ( $P < 0.01$ ) of supplemental nitrogen. SEM = 0.26.

**Table 4.** Effect of supplemental nitrogen and hay crude protein content on plasma urea nitrogen

<sup>1</sup> Hay % CP	Supplemental N, mg/kg BW				SEM
	0	82	119	155	
	Plasma urea nitrogen, mM				
5.6	1.72	1.32	2.25	2.07	0.11
6.3	1.27	0.95	0.77	2.10	
8.2	1.48	1.75	2.30	2.39	
10.8	3.13	--	--	--	

<sup>1</sup>Linear effect ( $P = 0.02$ ) of hay crude protein content

## CHAPTER IV

### DISCUSSION

Our objective was to quantify the utilization of bermudagrass hays of differing CP content and the response to increasing provision of supplemental N in cattle fed these forages. Four hays: 5.6, 6.3, 8.1 and 10.8% CP (45, 39, 39, and 38% ADF, respectively) were fed and increases in HOMI (quadratic) and TDOMI (linear) were observed with increasing hay nutritive value. The largest increase (23%) in HOMI was observed between hays 6.3 and 8.1% with only a small increase (3.6%) between 5.6 and 6.3%, and a decrease (-2.1%) between 8.1 and 10.8%. In contrast, increases in TDOMI were consistently larger (30.3, 13.7, and 17.9% between 5.6 and 6.3, 6.3 and 8.1, and 8.1 and 10.8%, respectively). The TDOMI responses observed between 5.6 and 6.3% as well as 8.1 and 10.8% were driven by increased OM digestibility (46 vs 58% for 5.6 and 6.3%, and 53 vs 65% for 8.1 and 10.8%, respectively). In contrast, greater TDOMI between the 6.1 and 8.1% hays was driven by increased HOMI (78 vs 96 g/kg BW<sup>0.75</sup>, respectively) accompanied by a reduction in OM digestibility (58 vs 53%, respectively). Previous research (Burton et al., 1963) reported that when bermudagrass is harvested at increasing maturities, both CP content and in vitro digestibility may be reduced, which supports our observations. Additionally, as lignin content increases, voluntary intake decreases (Van Soest, 1965). In accordance with our observations of increased total tract OM digestion with increasing hay CP content, total tract OM digestions of 41, 50, 53, and 63% of OM were reported when hays with CP contents of 5.2, 5.3, 7.6, and 8.2%

were fed by Guthrie and Wagner (1988), Mathis et al. (1999), Rambo (2010), and Mathis et al. (2000), respectively. Overall, as hay quality increases, an increase in total OM digestible intake and in OM digestibility is expected.

An interaction of hay CP content and supplemental N was observed for hay OM intake and total OM intake. An interaction was anticipated based on previous observations, which suggested that the response to supplemental protein was dependent upon hay quality. Specifically, increased forage utilization was expected with supplementation when ruminally available N (DIP or recycled urea N) is inadequate in the basal diet to support fermentation of the forage resource. We hypothesized that provision of supplemental N would produce the largest increase in intake for the 5.6% CP hay, followed by a tempered response in the 6.3% CP hay, and little to no response when delivered to cattle consuming the 8.1% CP hay, thus resulting in a hay CP  $\times$  supplemental N interaction. This hypothesis was, in part, based on the observations of Rambo (2010) where supplementation with cottonseedmeal increased intake of bermudagrass (7.4% CP), and Mathis et al. (2000) who reported no increase in the utilization of bermudagrass (8.2%) with supplemental protein. Additionally, when forages other than bermudagrass with CP contents of ~5%, namely native range, have been supplemented with protein, the increases in intake have been substantial. Guthrie and Wagner (1988), Heldt et al. (1999), and Mathis et al. (1999) observed 8, 15, and 29% increases in HOMI within hays of 41, 50, and 50% OM digestibility with the first increment of N supplementation.

In contrast to our hypothesis, increases in HOMI of the 5.6% CP hay with supplemental N were not observed. This was likely because the CP:TDOMI ratio of this hay was 0.14, 0.16, 0.19, and 0.23 for supplemental N increments of 0, 82, 119, and 155 mg N/kg BW, respectively. All these ratios are greater than the critical value of 0.13 that was proposed by McCollum (1997) and Moore et al. (1999) to be the point at which a forage utilization response to supplemental N is expected. At a CP:TDOMI ratio of 0.14 without supplemental N, this hay was already appropriately balanced for rumen microbial fermentation requirements. This forage was “balanced” not because it contained an ideal level of protein, but because total tract OM digestion was 46%. Thus HOMI and TDOMI were constrained by digestibility, not inadequate CP. The incline of TOMI as N was supplemented within 5.6% CP hay was attributable not to the increasing HOMI but rather the increased OM intake from supplemental N. Prairie hays of 5.3 and 5.7% CP were both higher in digestible OM (50%), and HOMI and TDOMI of these hays increased with supplemental N because CP was the limiting factor (Heldt et al., 1999; Mathis et al., 1999).

We observed a tendency for a linear response of 6.3% CP HOMI. The proportions of TDOMI as CP were 0.12, 0.15, 0.17, and 0.20 for supplemental N increments of 0, 82, 119, and 155 mg N/kg BW, respectively. These values demonstrate a CP deficiency within the 6.3% CP hay and correspond with the observation of HOMI increasing in response to CP supplementation. In fact, TDOMI of 5.6% and 6.3% CP hays peaked at percent TDOMI as CP ratios of 0.16 and 0.17, respectively, after which



greater levels of supplemental N reduced TDOMI. Intake and digestion of the 6.3% CP hay was constrained by CP availability rather than by digestibility.

Hay 8.1% CP ratios of CP:TDOMI were 0.18, 0.20, 0.22, 0.23 for supplemental N levels 0, 82, 119, 155, respectively. Hay OM intake of 8.1% CP hay was at a maximum value when no supplemental N was provided, and decreased with delivery of supplemental N. Likewise, Mathis et al. (2000) supplemented 8.2% CP bermudagrass hay and found that supplemental N depressed HOMI and TDOMI. The maximum TDOMI value in the study by Mathis et al. (2000) was  $59.8 \text{ g/kg BW}^{0.75}$  in unsupplemented steers, where CP:TDOMI was already 0.14. Both Mathis et al. (2000) and Klevesahl et al. (2003) witnessed a depression of HOMI and TDOMI when protein supplementation as DIP was in excess of the requirement. A similar decrease in HOMI from 96 to 88, 86, and 89  $\text{g/kg BW}^{0.75}$  occurred in the current study when 8.1% CP hay was supplemented with 0, 82, 119, and 155 mg N/kg BW. The observations of this study and of Mathis et al. (2000) comply with the critical window values of 0.13 and 0.16 (CP:TDOMI). A CP to digestible OM ratio of 0.16 provides a practical target for addressing a forage CP deficit with supplemental N from common protein sources (McCollum, 1997; Moore et al., 1999). However, as demonstrated by the current study, Mathis et al. (2000), and Klevesahl et al. (2003), a 0.14 ratio was unlikely to generate a HOMI response to N supplementation.

The maximum TDOMI value for 6.3% CP hay occurred at 0.17 CP:TDOMI when 119 mg N/kg BW was supplemented. For 5.6% CP hay, maximum TDOMI occurred at 0.16 CP:TDOMI, when 83 mg N/kg BW was supplemented. This % of

TDOMI as CP was supported by the optimal CP fraction, or 16% of TDOMI, as advised by McCollum (1997) and Moore et al. (1999). Both UIP and DIP are being provided as CP in the treatment diets with a cottonseed meal-based supplement. In addition to DIP, supplemental CP provided as UIP can encourage a significant response in intake of hays ranging from 3.6 to 7.2% CP. The contributions of UIP to increasing HOMI have been demonstrated by Bandyk et al. (2001) and Wickersham et al. (2009). Although TDOMI was at a maximum for unsupplemented 8.1% CP hay at 0.23 of TDOMI as CP, it was no different than TDOMI for 6.3% CP hay with 119 mg N/kg BW (55.69 vs. 55.70 g/kg BW<sup>.75</sup>, respectively). The 20% range cube, although being grain-based, did not elicit a significant drop in hay OM intake across hay qualities. Therefore, the CP requirement for TDOMI had been met by dietary CP provision so as to not promote a deleterious impact of supplemental carbohydrate on forage digestion (Arroquy et al., 2004a; Guthrie and Wagner, 1988; Olson et al., 1999; Pordomingo et al., 1991).

All treatment pH levels remained high enough (above 6.1) to be conducive to fiber fermentation (Mould et al., 1983). Although Heldt et al. (1999) reported that supplemental DIP may lower pH, the lowest recorded pH for all treatments, 6.2, occurred for unsupplemented control hay (10.8% CP), so that pH was likely to have never played a role in inhibiting NDF digestion. Reductions in pH as total dietary CP increased denoted increases in ruminal fermentation.

In following the results of Guthrie and Wagner (1988), ruminal ammonia concentrations in the current study increased quadratically with higher supplementation levels. Ruminal ammonia concentrations greater than 1 mM were sufficient for microbial

proliferation and fiber digestion (Hoover, 1986). The relatively low overall ruminal  $\text{NH}_3$  concentrations may depict the remarkable ability of ruminal microbes to utilize ammonia during the fermentative processes in the rumen. More available energy sources in the rumen often depress  $\text{NH}_3$  production because N becomes the limiting factor (Heldt et al., 1999). Values in 8.1% hay treatments and 10.8% CP hay averaged 2.12 and 2.24 mM, respectively while mean values in 5.6% and 6.3% CP hay treatments remained at lower levels (1.32 and 1.41 mM, respectively). A decrease in ruminal  $\text{NH}_3$  may also signal a decreasing proportion of TDN as DIP, and lowest ruminal  $\text{NH}_3$  (less than 1mM) concentrations are often associated with rations that are DIP deficient (Chase and Hibberd, 1987). Consistent with the finding of Chase and Hibberd (1987), the lowest ammonia mM values occurred when DIP was suspected to be deficient (unsupplemented 5.6 and 6.3% CP hays). The highest ammonia value occurred at 8.1% CP hay + 155 mg N/kg BW supplemented (5.16 mM) which is beyond the upper threshold amount (3.57 mM) for optimal N capture by rumen microbes (Satter and Slyter, 1974; Slyter et al., 1979), deeming the treatment an inefficient method for optimizing forage intake.

## CHAPTER V

### CONCLUSION

We undertook this project to improve our ability to make CP supplementation recommendations to beef cattle producers utilizing bermudagrass hays as their forage source. A significant relationship was observed between increasing quality of bermudagrass hay and increasing utilization. However, the effect of N supplementation was more difficult to discern. Utilization of low-quality bermudagrass hays was for the 5.6% CP hay more inhibited by limited digestibility than by inadequate ruminal N. In contrast, utilization of the 6.3% CP hay was improved by N supplementation. Furthermore, recommendations of CP supplementation are hindered by the interaction of hay CP content on OM digestibility. This study underscores the importance of establishing the digestible OM content of bermudagrass hay before making supplement recommendations. When the DIP content is unknown in forage and protein supplements and its assessment is impractical, analysis for CP content can provide a less precise guide for achieving a target CP:TDOMI ratio of 0.16 to maximize digestible OM intake. The information derived from such analyses of hay will allow producers to depend more on fiber-based energy rather than protein or grain-based energy to mitigate feeding costs.

**LITERATURE CITED**

- Akin, D.E., E.L. Robinson, F.E. Barton, and D.S. Himmelsbach. 1977. Changes with maturity in anatomy, histochemistry, chemistry, and tissue digestibility of bermudagrass plant parts. *J. of Agric. and Food Chem.* 25:179-186.
- Alderton, B.W., D.L. Hixon, B.W. Hess, L.F. Woodard, D.M. Hallford, and G.E. Moss. 2000. Effects of supplemental protein type on productivity of primiparous beef cows. *J. Anim. Sci.* 78:3027-3035.
- Alexander, R.A., and J.F. Hentges, Jr. 1962. Physical form and composition of hay on lactation, rumen development and digestibility. *J. Anim. Sci.* 21:439-443.
- Alexander, R.A., J.F. Hentges, Jr., J.T. McCall, H.W. Lundy, N. Gammon, Jr., and W.G. Blue. 1961. The nutritive value of fall-harvested coastal bermudagrass hay as affected by rate of nitrogen fertilization and stage of maturity. *J. Anim. Sci.* 20:93-98.
- Anderson, L.P., J.A. Paterson, R.P. Ansotegui, M. Cecava, and W. Schmutz. 2001. The effects of degradable and undegradable intake protein on the performance of lactating first-calf heifers. *J. Anim. Sci.* 79:2224-2232.
- Arroquy, J.I., R.C. Cochran, M. Villarreal, T.A. Wickersham, D.A. Llewellyn, E.C. Titgemeyer, T.G. Nagaraja, D.E. Johnson, and D. Gnad. 2004a. Effect of level of rumen degradable protein and type of supplemental non-fiber carbohydrate on intake and digestion of low-quality grass hay by beef cattle. *Anim. Feed Sci. and Tech.* 115:83-99.
- Arroquy, J.I., R.C. Cochran, T.A. Wickersham, D.A. Llewellyn, E.C. Titgemeyer, T.G. Nagaraja, and D.E. Johnson. 2004b. Effects of type of supplemental carbohydrate and source of supplemental rumen degradable protein on low quality forage utilization by beef steers. *Anim. Feed Sci. and Tech.* 115:247-263.
- Bandyk, C.A., R.C. Cochran, T.A. Wickersham, E.C. Titgemeyer, C.G. Farmer, and J.J. Higgins. 2001. Effect of ruminal vs postruminal administration of degradable protein on utilization of low-quality forage by beef steers. *J. Anim. Sci.* 79:225-231.
- Beaty, E.R., J.D. Powell, and J.H. Edwards, Jr. 1969. Forage and animal gains of Coastal bermuda and Pensacola bahia. *J. of Range Manag.* 22:318-321.

- Bodine, T.N., H.T. Purvis, 2nd, C.J. Ackerman, and C.L. Goad. 2000. Effects of supplementing prairie hay with corn and soybean meal on intake, digestion, and ruminal measurements by beef steers. *J. Anim. Sci.* 78:3144-3154.
- Briggs, H.M., W.D. Gallup, and A.E. Darlow. 1946. The nutritive value of cottonseed meal, soybean meal, and peanut meal when used separately and together to supplement the protein of prairie hay in experiments with steers. *J. Agric. Res.* 73:167-176.
- Broderick, G.A., and J.H. Kang. 1980. Automated simultaneous determination of ammonia and total amino acids in ruminal fluid and in vitro media. *J. Dairy Sci.* 63:64-75.
- Burton, G.W. 1954. Coastal bermuda grass. *Bull. N.S. 2. Georgia Agric. Exp. Stn., Athens.*
- Burton, G.W., J.E. Jackson, and R.H. Hart. 1963. Effects of Cutting Frequency and Nitrogen on Yield, in vitro Digestibility, and Protein, Fiber, and Carotene Content of Coastal Bermudagrass. *Agron. J.* 55:500-502.
- Chase, C.C., Jr., and C.A. Hibberd. 1987. Utilization of Low-Quality Native Grass Hay by Beef Cows Fed Increasing Quantities of Corn Grain. *J. Anim. Sci.* 65:557-566.
- Church, D.C., and A. Santos. 1981. Effect of graded levels of soybean meal and of a nonprotein nitrogen-molasses supplement on consumption and digestibility of wheat Straw. *J. Anim. Sci.* 53:1609-1615.
- Cochran, R.C., and M.L. Galyean. 1994. Measurements of in vivo forage digestion by ruminants. Page 613 in *Forage Quality, Evaluation, and Utilization*. G. C. Fahey, Jr., M. C. Collins, D. R. Mertens and L. E. Moser, eds. ASA-CSSA-SSSA, Madison, WI.
- Cochran, W.G., and G.M. Cox. 1957. *Experimental Design* (2nd Ed.). John Wiley and Sons, Inc., New York.
- Currier, T.A., D.W. Bohnert, S.J. Falck, and S.J. Bartle. 2004a. Daily and alternate day supplementation of urea or biuret to ruminants consuming low-quality forage: I. Effects on cow performance and the efficiency of nitrogen use in wethers. *J. Anim. Sci.* 82:1508-1517.
- Currier, T.A., D.W. Bohnert, S.J. Falck, C.S. Schauer, and S.J. Bartle. 2004b. Daily and alternate-day supplementation of urea or biuret to ruminants consuming low-quality forage: II. Effects on site of digestion and microbial efficiency in steers. *J. Anim. Sci.* 82:1518-1527.

- Currier, T.A., D.W. Bohnert, S.J. Falck, C.S. Schauer, and S.J. Bartle. 2004c. Daily and alternate-day supplementation of urea or biuret to ruminants consuming low-quality forage: III. Effects on ruminal fermentation characteristics in steers. *J. Anim. Sci.* 82:1528-1535.
- DelCurto, T., R.C. Cochran, L.R. Corah, A.A. Beharka, E.S. Vanzant, and D.E. Johnson. 1990a. Supplementation of dormant tallgrass-prairie forage: II. Performance and forage utilization characteristics in grazing beef cattle receiving supplements of different protein concentrations. *J. Anim. Sci.* 68:532-542.
- DelCurto, T., R.C. Cochran, D.L. Harmon, A.A. Beharka, K.A. Jacques, G. Towne, and E.S. Vanzant. 1990b. Supplementation of dormant tallgrass-prairie forage: I. Influence of varying supplemental protein and(or) energy levels on forage utilization characteristics of beef steers in confinement. *J. Anim. Sci.* 68:515-531.
- DelCurto, T., R.C. Cochran, T.G. Nagaraja, L.R. Corah, A.A. Beharka, and E.S. Vanzant. 1990c. Comparison of soybean meal/sorghum grain, alfalfa hay and dehydrated alfalfa pellets as supplemental protein sources for beef cattle consuming dormant tallgrass-prairie forage. *J. Anim. Sci.* 68:2901-2915.
- Ellis, W.C., J.H. Matis, D. Herd, H. Lippke, F.M. Rouquette, Jr., D.P. Poppi, and R.J. Wallace. 2001. A role for rumen degraded protein in regulating intake rate of digested fiber. *J. Anim. Sci.* (abs) 84:(1):123.
- Evers, G.W., L.A. Redmon, and T.L. Provin. 2004. Comparison of bermudagrass, bahiagrass, and kikuyugrass as a standing hay crop. *Crop Sci.* 44:1370-1378.
- Freeman, A.S., M.L. Galyean, and J.S. Caton. 1992. Effects of supplemental protein percentage and feeding level on intake, ruminal fermentation, and digesta passage in beef steers fed prairie hay. *J. Anim. Sci.* 70:1562-1572.
- Gallup, W.D., and H.M. Briggs. 1948. The apparent digestibility of prairie hay of variable protein content, with some observations of fecal nitrogen excretion by steers in relation to their dry matter intake. *J. Anim. Sci.* 7:110-116.
- Grigsby, K.N., F.M. Rouquette, Jr., W.C. Ellis, and D.P. Hutcheson. 1989. Self-limiting protein supplements for calves grazing bermudagrass pastures. *Journal of Production Agriculture* 2:222.
- Guthrie, M.J., and D.G. Wagner. 1988. Influence of protein or grain supplementation and increasing levels of soybean meal on intake, utilization and passage rate of prairie hay in beef steers and heifers. *J. Anim. Sci.* 66:1529-1537.
- Hannah, S.M., R.C. Cochran, E.S. Vanzant, and D.L. Harmon. 1991. Influence of protein supplementation on site and extent of digestion, forage intake, and

- nutrient flow characteristics in steers consuming dormant bluestem-range forage. *J. Anim. Sci.* 69:2624-2633.
- Hawkins, G.E., G.E. Paar, and J.A. Little. 1964. Composition, intake, digestibility, and prediction of digestibility of Coastal bermudagrass hays. *J. of Dairy Sci.* 47:865-870.
- Heldt, J.S., R.C. Cochran, C.P. Mathis, B.C. Woods, K.C. Olson, E.C. Titgemeyer, T.G. Nagaraja, E.S. Vanzant, and D.E. Johnson. 1999. Effects of level and source of carbohydrate and level of degradable intake protein on intake and digestion of low-quality tallgrass-prairie hay by beef steers. *J. Anim. Sci.* 77:2846-2854.
- Hennessy, D., and R. Murison. 1982. Cottonseed meal and molasses as sources of protein and energy for cattle offered low quality hay from pastures of the North Coast of New South Wales. *Aust. J. Exp. Agric.* 22:140-146.
- Hoover, W.H. 1986. Chemical factors involved in ruminal fiber digestion. *Journal of Dairy Science* 69:2755-2766.
- Huston, J.E., F.M. Rouquette, Jr., W.C. Ellis, H. Lippke, and T.D. Forbes. 2002. *Supplementation of Grazing Beef Cattle*. Texas Agr. Exp. Stn. TM-12 8-02, College Station, TX.
- Judkins, M.B., J.D. Wallace, M.L. Galyean, L.J. Krysl, and E.E. Parker. 1987. Passage rates, rumen fermentation, and weight change in protein supplemented grazing cattle. *J. of Range Manag.* 40:100-105.
- Kartchner, R.J. 1980. Effects of protein and energy supplementation of cows grazing native winter range forage on intake and digestibility. *J. Anim. Sci.* 51:432-438.
- Klevesahl, E.A., R.C. Cochran, E.C. Titgemeyer, T.A. Wickersham, C.G. Farmer, J.I. Arroquy, and D.E. Johnson. 2003. Effect of a wide range in the ratio of supplemental rumen degradable protein to starch on utilization of low-quality, grass hay by beef steers. *Anim. Feed Sci. and Tech.* 105:5-20.
- Knox, F.E., G.W. Burton, and D.M. Baird. 1958. Forage quality, effect of nitrogen rate and clipping frequency upon lignin content and digestibility of Coastal bermuda grass. *J. Agric. and Food Chem.* 6:217-219.
- Köster, H.H., R.C. Cochran, E.C. Titgemeyer, E.S. Vanzant, I. Abdelgadir, and G. St-Jean. 1996. Effect of increasing degradable intake protein on intake and digestion of low-quality, tallgrass-prairie forage by beef cows. *J. Anim. Sci.* 74:2473-2481.
- Köster, H.H., R.C. Cochran, E.C. Titgemeyer, E.S. Vanzant, T.G. Nagaraja, K.K. Kreikemeier, and G. St Jean. 1997. Effect of increasing proportion of



- supplemental nitrogen from urea on intake and utilization of low-quality, tallgrass-prairie forage by beef steers. *J. Anim. Sci.* 75:1393-1399.
- Marsh, W.H., B. Fingerhut, and H. Miller. 1965. Automated and manual direct methods for the determination of blood urea. *Clin. Chem.* 11:624-627.
- Mathis, C.P., R.C. Cochran, J.S. Heldt, B.C. Woods, I.E. Abdelgadir, K.C. Olson, E.C. Titgemeyer, and E.S. Vanzant. 2000. Effects of supplemental degradable intake protein on utilization of medium- to low-quality forages. *J. Anim. Sci.* 78:224-232.
- Mathis, C.P., R.C. Cochran, G.L. Stokka, J.S. Heldt, B.C. Woods, and K.C. Olson. 1999. Impacts of increasing amounts of supplemental soybean meal on intake and digestion by beef steers and performance by beef cows consuming low-quality tallgrass-prairie forage. *J. Anim. Sci.* 77:3156-3162.
- McCollum, F.T., and M.L. Galyean. 1985. Influence of cottonseed meal supplementation on voluntary intake, rumen fermentation and rate of passage of prairie hay in beef steers. *J. Anim. Sci.* 60:570-577.
- McCollum, F.T., III. 1997. Supplementation strategies for beef cattle, Texas Agric. Ext. Serv., College Station. TX B-6067.
- Mertens, D.R. 1994. Regulation of forage intake. Page 450 in *Forage Quality, Evaluation, and Utilization*. G. C. Fahey, Jr., ed. Am. Soc. Agronomy, Inc., Crop Sci. Soc. Am., Inc., Soil Sci. Soc. Am., Inc., Madison, WI.
- Moore, J.E., M.H. Brant, W.E. Kunkle, and D.I. Hopkins. 1999. Effects of supplementation on voluntary forage intake, diet digestibility, and animal performance. *J. Anim. Sci.* 77:122-135.
- Moore, J.E., and W.E. Kunkle. 1995. Improving forage supplementation programs for beef cattle. Page 65 in *Proc. 6th Annual Florida Ruminant Nutrition Symposium*, Univ. of Florida, Gainesville.
- Mould, F.L., E.R. Orskov, and S.O. Mann. 1983. Associative effects of mixed feeds. I. Effects of type and level of supplementation and the influence of the rumen fluid pH on cellulolysis in vivo and dry matter digestion of various roughages. *J. Anim. Feed Sci. Technol.* 10:15-30.
- NRC. 1996. *Nutrient Requirements of Beef Cattle*. 7th ed. Natl. Acad. Press, Washington, DC.
- Oliver, W.M. 1975. Effect of monensin on gains of steers grazed on Coastal bermudagrass. *J. Anim. Sci.* 41:999-1001.

- Olson, K.C., R.C. Cochran, T.J. Jones, E.S. Vanzant, E.C. Titgemeyer, and D.E. Johnson. 1999. Effects of ruminal administration of supplemental degradable intake protein and starch on utilization of low-quality warm-season grass hay by beef steers. *J. Anim. Sci.* 77:1016-1025.
- Orskov, E.R., and M. Ryle. 1990. *Energy Nutrition in Ruminants*. Elsevier Science Publ., New York.
- Overman, A.R., and R.V. Scholtz. 2003. Dry matter production and cutting interval for perennial grasses. *Comm. in Soil Sci. and Plant Anal.* 34:225 - 229.
- Overman, A.R., and R.V. Scholtz. 2005. Model of dry matter and plant nitrogen partitioning between leaf and stem for Coastal bermudagrass. I. Dependence on harvest interval. *J. Plant Nutr.* 27:1585 - 1592.
- Poppi, D.P., and S.R. McLennan. 1995. Protein and energy utilization by ruminants at pasture. *J. Anim. Sci.* 73:278-290.
- Pordomingo, A.J., J.D. Wallace, A.S. Freeman, and M.L. Galyean. 1991. Supplemental corn grain for steers grazing native rangeland during summer. *J. Anim. Sci.* 69:1678-1687.
- Prine, G.M., and G.W. Burton. 1956. The effect of nitrogen rate and clipping frequency upon the yield, protein content and certain morphological characteristics of Coastal bermudagrass (*Cynodon dactylon*, (L) Pers.). *Agron. J* 48:296-301.
- Rambo, Z.J., J.E. Sawyer, C.L. Skaggs, and T.A. Wickersham. 2010. Assigning a value to dried distillers' grains as a protein supplement in cattle consuming low-quality forage, M. S. thesis, Texas A&M University, College Station.
- Raun, N.S., and W. Burroughs. 1962. Suction strainer technique in obtaining rumen fluid samples from intact lambs. *J. Anim. Sci.* 21:454-457.
- Reed, J.J., M.R. O'Neil, G.P. Lardy, K.A. Vonnahme, L.P. Reynolds, and J.S. Caton. 2007. Effect of undegradable intake protein supplementation on intake, digestion, microbial efficiency, in situ disappearance, and plasma hormones and metabolites in steers fed low-quality grass hay. *J. Anim. Sci.* 85:1092-1101.
- Rittenhouse, L.R., D.C. Clanton, and C.L. Streeter. 1970. Intake and digestibility of winter-range forage by cattle with and without supplements. *J. Anim. Sci.* 31:1215-1221.
- Russell, J.B., J.D. O'Connor, D.G. Fox, P.J. Van Soest, and C.J. Sniffen. 1992. A net carbohydrate and protein system for evaluating cattle diets: I. Ruminal fermentation. *J. Anim. Sci.* 70:3551-3561.

- Satter, L.D., and L.L. Slyter. 1974. Effect of ammonia concentration on rumen microbial protein production in vitro. *Brit. J. Nutr.* 32:199-208.
- Scarborough, D.A., W.K. Coblenz, K.P. Coffey, D.S. Hubbell, III, T.F. Smith, J.B. Humphry, J.A. Jennings, R.K. Ogden, and J.E. Turner. 2006. Effects of forage management on the nutritive value of stockpiled bermudagrass. *Agron. J.* 98:1280-1289.
- Scarborough, D.A., W.K. Coblenz, K.P. Coffey, J.E. Turner, G.V. Davis, D.W. Kellogg, and D.H. Hellwig. 2001. Effects of calendar date and summer management on the in situ dry matter and fiber degradation of stockpiled forage from bermudagrass pastures. *J. Anim. Sci.* 79:3158-3169.
- Slyter, L.L., L.D. Satter, and D.A. Dinius. 1979. Effect of ruminal ammonia concentration on nitrogen utilization by steers. *J. Anim. Sci.* 48:906-912.
- Taliaferro, C.M., F.M.J. Rouquette, and P. Mislevy. 2004. Bermudagrass and stargrass. Page 417 in *Warm-season (C<sub>4</sub>) Grasses*. L. E. Moser, B. L. Burson and L. E. Sollenberger, eds. ASA, CSSA, SSSA, Agronomy Monograph #45.
- Van Soest, P.J. 1965. Symposium on factors influencing the voluntary intake of herbage by ruminants: Voluntary intake in relation to chemical composition and digestibility. *J. Anim. Sci.* 24:834-843.
- Van Soest, P.J. 1994. *Nutritional Ecology of the Ruminant*, 2nd ed. Cornell University Press, Ithaca, NY.
- Vanzant, E.S., and R.C. Cochran. 1994. Performance and forage utilization by beef cattle receiving increasing amounts of alfalfa hay as a supplement to low-quality, tallgrass-prairie forage. *J. Anim. Sci.* 72:1059-1067.
- Webster, J.E., J.W. Hogan, and W.C. Elder. 1965. Effect of rate of ammonium nitrate fertilization and time of cutting upon selected chemical components and the in vitro rumen digestion of bermudagrass forage. *Agron. J.* 57:323-325.
- Wickersham, T.A., R.C. Cochran, E.C. Titgemeyer, C.G. Farmer, E.A. Klevesahl, J.I. Arroquy, D.E. Johnson, and D.P. Gnad. 2004. Effect of postruminal protein supply on the response to ruminal protein supplementation in beef steers fed a low-quality grass hay. *Anim. Feed Sci. and Tech.* 115:19-36.
- Wickersham, T.A., E.C. Titgemeyer, R.C. Cochran, and E.E. Wickersham. 2009. Effect of undegradable intake protein supplementation on urea kinetics and microbial use of recycled urea in steers consuming low-quality forage. *Brit. J. Nutr.* 101:225-232.

## APPENDIX

**Table A-1.** Effect of supplemental nitrogen and hay crude protein content on intake

	Hay % CP	Supplemental N, mg/kg BW				SEM
		0	82	119	155	
-----Hay Intake, g/kg BW <sup>0.75</sup> -----						
DM	5.6	81.80	83.79	85.86	90.56	5.67
	6.3	84.00	85.20	90.24	96.88	
	8.2	109.35	100.63	97.96	103.00	
	10.8	100.78	--	--	--	
OM	5.6	75.16	77.20	79.48	83.37	5.07
	6.3	77.89	79.11	83.75	89.90	
	8.2	96.01	87.69	85.83	89.23	
	10.8	94.01	--	--	--	
NDF	5.6	61.01	62.78	63.71	67.08	4.14
	6.3	61.20	62.03	65.64	70.46	
	8.2	78.18	72.32	70.55	73.88	
	10.8	72.08	--	--	--	
ADF	5.6	36.69	37.51	38.31	40.68	2.29
	6.3	32.92	33.19	35.20	38.00	
	8.2	42.85	40.09	38.45	40.64	
	10.8	38.71	--	--	--	
-----Total Intake, g/kg BW <sup>0.75</sup> -----						
TDM	5.6	81.74	93.39	95.48	100.12	5.68
	6.3	84.01	94.71	99.81	106.48	
	8.2	109.33	110.19	107.60	112.52	
	10.8	100.78	--	--	--	
TOM	5.6	75.11	85.82	88.13	91.87	5.08
	6.3	77.88	87.67	92.33	98.45	
	8.2	95.99	96.29	94.46	97.70	
	10.8	94.02	--	--	--	
TNDF	5.6	61.02	65.83	66.45	69.12	4.15
	6.3	61.15	65.09	68.33	72.47	
	8.2	78.17	75.37	73.23	75.84	
	10.8	72.10	--	--	--	
TADF	5.6	36.68	38.59	39.42	41.88	2.29
	6.3	32.93	34.25	36.32	39.20	
	8.2	42.85	41.16	39.58	41.85	
	10.8	38.71	--	--	--	

**Table A-2.** Effect of supplemental nitrogen and hay crude protein content on digestibility

	Hay % CP	mg N/kg BW Supplemented				SEM
		0	82	119	155	
<i>---Total tract digestion, g/kg BW<sup>75</sup>----</i>						
DM	5.6	35.21	39.10	37.60	49.51	4.56
	6.3	46.84	47.16	52.72	49.51	
	8.2	59.25	54.32	54.54	58.90	
	10.8	62.29	--	--	--	
OM	5.6	34.61	42.75	41.15	41.03	4.38
	6.3	45.09	50.09	55.70	52.50	
	8.2	51.25	51.50	52.39	55.59	
	10.8	60.43	--	--	--	
NDF	5.6	29.05	30.88	29.14	28.06	4.14
	6.3	30.33	34.06	37.82	35.53	
	8.2	44.36	39.29	39.56	42.67	
	10.8	47.28	--	--	--	
ADF	5.6	13.19	14.17	12.50	13.57	1.93
	6.3	15.80	14.13	17.45	14.90	
	8.2	18.80	17.32	17.60	18.42	
	10.8	20.27	--	--	--	
<i>---Total tract digestion, % intake---</i>						
DM	5.6	42.95	46.09	45.79	41.76	3.23
	6.3	55.92	57.18	55.84	52.74	
	8.2	53.95	54.00	55.72	56.45	
	10.8	61.90	--	--	--	
OM	5.6	46.20	49.19	48.78	45.03	3.26
	6.3	57.67	59.03	57.90	54.95	
	8.2	53.16	53.44	55.67	55.90	
	10.8	64.53	--	--	--	
NDF	5.6	48.18	48.95	47.31	42.34	4.51
	6.3	49.35	57.35	55.2	52.62	
	8.2	56.28	54.38	55.70	57.11	
	10.8	66.04	--	--	--	
ADF	5.6	36.69	36.42	34.34	33.67	4.08
	6.3	46.42	45.66	45.76	40.07	
	8.2	44.07	42.92	46.51	44.47	
	10.8	53.12	--	--	--	

**Table A-3.** Effects of supplemental nitrogen and hay crude protein content on intake and digestion<sup>1</sup>

	<i>P</i> -value										
	Effect of supplemental N		Effect of hay CP content		Supplemental N × hay CP content				Effect of unsupplemented hay CP content		
	Linear	Quadratic	Linear	Quadratic	LL	QL	LQ	QQ	Linear	Quadratic	Cubic
<i>Intake</i>											
DM	0.33	0.16	< 0.01	0.71	0.06	0.72	0.72	0.83	< 0.01	0.01	--
OM	0.31	0.17	< 0.01	0.78	0.04	0.74	0.74	0.79	< 0.01	0.05	--
NDF	0.33	0.20	< 0.01	0.50	0.08	0.73	0.73	0.78	0.01	0.02	--
ADF	0.28	0.16	0.03	< 0.01	0.06	0.89	0.89	0.81	0.10	0.09	--
<i>Total intake</i>											
DM	< 0.01	0.85	< 0.01	0.71	0.06	0.72	0.72	0.82	< 0.01	0.01	--
OM	< 0.01	0.90	< 0.01	0.78	0.04	0.74	0.74	0.77	< 0.01	0.05	--
NDF	0.09	0.58	< 0.01	0.49	0.08	0.74	0.74	0.79	0.01	0.02	--
ADF	0.07	0.25	0.03	< 0.01	0.06	0.88	0.88	0.81	0.10	0.09	--
<i>Total tract digestion</i>											
DM	0.65	0.80	< 0.01	0.03	0.59	0.30	0.30	0.97	< 0.01	0.04	--
OM	0.06	0.61	< 0.01	0.01	0.64	0.35	0.35	0.97	< 0.01	0.36	--
NDF	0.76	0.97	< 0.01	0.50	0.62	0.29	0.29	0.78	< 0.01	0.23	--
ADF	0.89	0.77	< 0.01	0.46	0.86	0.61	0.61	0.98	0.01	0.34	--
<i>Percent digested</i>											
DM	0.97	0.34	< 0.01	< 0.01	0.55	0.31	0.31	0.95	< 0.01	0.45	--
OM	0.94	0.36	0.03	< 0.01	0.51	0.36	0.36	0.95	< 0.01	0.86	0.02
NDF	0.97	0.39	0.01	0.13	0.68	0.31	0.31	0.59	< 0.01	0.92	--
ADF	0.47	0.62	0.01	0.01	0.49	0.75	0.75	0.64	< 0.02	0.94	--
<i>Fermentation and plasma profile</i>											
NH <sub>3</sub>	< 0.01	0.02	< 0.01	0.36	0.60	0.90	0.90	0.84	< 0.01	0.47	--
pH	< 0.01	< 0.01	0.01	< 0.01	0.15	0.22	0.22	0.17	< 0.01	0.36	--
PUN	0.11	0.17	0.39	0.07	0.60	0.60	0.60	0.38	0.02	0.14	--

<sup>1</sup>*P*-values for linear, quadratic, and cubic effects of increasing supplemental N and hay CP content on intake and digestion

**Table A-4.** Effects of supplemental nitrogen and hay crude protein content on rumen fermentation characteristics and plasma urea nitrogen<sup>1</sup>

	<i>P</i> -value										
	Effect of supplemental N		Effect of hay CP content		Supplemental N × hay CP content				Effect of unsupplemented hay CP content		
	Linear	Quadratic	Linear	Quadratic	LL	QL	LQ	QQ	Linear	Quadratic	Cubic
<i>Fermentation characteristics and plasma urea nitrogen</i>											
NH <sub>3</sub>	< 0.01	0.02	< 0.01	0.36	0.60	0.90	0.90	0.84	< 0.01	0.47	--
pH	< 0.01	< 0.01	0.01	< 0.01	0.15	0.22	0.22	0.17	< 0.01	0.36	--
PUN	0.11	0.17	0.39	0.07	0.60	0.60	0.60	0.38	0.02	0.14	--

<sup>1</sup>*P*-values for linear, quadratic, and cubic effects of increasing supplemental N and hay CP content on ruminal ammonia, ruminal pH, and plasma urea nitrogen

**VITA**

Name: Catherine Pomeroy Payne

Address: Department of Animal Science  
c/o Tryon Wickersham  
Texas A&M University  
2471 TAMU  
College Station, TX 77843-2471

Email address: catherine.p.payne@gmail.com

Education: B.A., Spanish; Child Development, Vanderbilt University, 2006  
M.S.T., Education, Pace University, 2008  
M.S., Animal Science, Texas A&M University, 2011