EVALUATION OF WINTER SUPPLEMENTATION OF BYPRODUCT FEEDSTUFFS FOR BEEF COWS CONSUMING LOW-QUALITY FORAGE

By

SARA JANE WINTERHOLLER

Bachelor of Science
Oklahoma State University
Stillwater, Oklahoma
2004

Master of Science
Kansas State University
Manhattan, Kansas
2006

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
DOCTOR OF PHILOSOPHY
July, 2009

EVALUATION OF WINTER SUPPLEMENTATION OF BYPRODUCT FEEDSTUFFS FOR BEEF COWS CONSUMING LOW-QUALITY FORAGE

Dissertation Approved:

Dr. David L. Lalman

Dr. Gerald W. Horn

Dr. Clinton R. Krehbiel

Dr. Damona Doye

Dr. A. Gordon Emslie

TABLE OF CONTENTS

LIST OF TABLES vii

LIST OF FIGURES ix

ACKNOWLEDGMENTS x

FORWARD xii

CHAPTER I

Review of Literature 1

Introduction 2

Lipid Metabolism in the rumen 2

Fat and fiber digestion 4

Efficacy of fat supplementation to range cattle 7

Influence of fat on reproductive performance 9

Summary and conclusions 10

Literature cited 12

CHAPTER II

Use of dried distillers grains in preconditioning programs for weaned beef calves and subsequent impact on wheat pasture and feedlot performance and carcass characteristics 16

Abstract 17

Introduction 18

Materials and methods 19

Animals 19

Treatments and diet delivery 21

Hay intake, DDGS intake and nutrient analysis 22

Cattle management following preconditioning....22
Statistical analysis....23
Results and discussion....24
Preconditioning phase....24
Wheat pasture phase....29
Feedlot performance and carcass characteristics....30
Implications....32
Literature cited....40

CHAPTER III

***In situ* degradation characteristics of byproduct feedstuffs for beef cattle consuming low-quality forage**....43

Abstract....44
Introduction....45
Materials and methods....46
Production of byproduct feedstuffs....46
In situ experimental procedures....47
Animals....47
Feedstuffs....47
Degradation kinetics....49
Passage rate....49
Statistical analyses....50
Results and discussion....50
Nitrogen disappearance....50
Disappearance of NDF and calculations for TDN....53
Disappearance of DM....55
Literature cited....61

CHAPTER IV

Supplemental energy and extruded-expelled cottonseed meal as a supplemental protein source for beef cows consuming low-quality forage 65

Abstract 66
Introduction 68
Materials and methods 69
Production of delinted, extruded-expelled cottonseed meal 69
Experiment 1 70
Animals 70
Statistical analysis 73
Experiment 2 74
Animals 74
Statistical analysis 75
Experiment 3 76
Animals 76
Statistical analysis 77
Results and discussion 77
Experiment 1 77
Cow body weight and body condition score 77
Calf performance 79
Reproductive performance 80
Experiment 2 81
Experiment 3 83
Literature cited 91

CHAPTER V

Supplementation of dried distiller's grains with solubles to beef cows consuming low quality forage during late gestation and early lactation.....97

Abstract.....98

Introduction.....100

Materials and methods.....101

Experiment 1.....101

Animals.....101

Statistical analysis.....105

Experiment 2.....106

Animals.....106

Statistical analysis.....107

Experiment 3.....108

Animals.....108

Statistical analysis.....109

Results and discussion.....110

Experiment 1.....110

Cow body weight and body condition score.....110

Calf performance.....112

Reproductive performance.....113

Blood urea nitrogen.....115

Experiment 2.....117

Experiment 3.....121

Literature cited.....131

LIST OF TABLES

CHAPTER II

Table 1. Average nutrient composition of DDGS and prairie hay 33

Table 2. Effect of level of DDGS during preconditioning on performance and hay intake of beef steers 34

Table 3. Effect of level of DDGS during preconditioning on performance and hay intake of beef heifers.....34

Table 4. Effect of level of DDGS during the preconditioning phase on wheat pasture performance of steers.....35

Table 5. Effect of DDGS during the preconditioning phase on steer feedlot performance and carcass characteristics.....35

Table 6. Effect of DDGS during preconditioning on heifer feedlot performance and carcass characteristics.....36

CHAPTER III

Table 1. Nutrient composition of *in situ* feedstuffs 58

Table 2. Chemical composition of dietary ingredients fed to steers during the *in situ* experiment.....58

Table 3. *In situ* ruminal N degradation characteristics of byproduct feedstuffs fed to beef cattle consuming low-quality forage.....59

Table 4. *In situ* ruminal NDF degradation characteristics of byproduct feedstuffs fed to beef cattle consuming low-quality forage.....59

Table 5. *In situ* ruminal DM degradation characteristics of byproduct feedstuffs fed to beef cattle consuming low-quality forage.....60

CHAPTER IV

Table 1. Supplement composition and amount of nutrients supplied daily during gestation 85

Table 2. Effect of winter supplement on cow BW and BCS 86

Table 3. Effect of winter supplement on calf performance 87

Table 4. Effect of winter supplement on cow reproductive performance.....88

Table 5. Effect of early-lactation supplement on hay intake and apparent total tract digestibility of dietary components (DM basis; Exp. 2)…….89

Table 6. Effect of supplement on beef cow milk production and composition…..90

CHAPTER V

Table 1. Supplement composition and amount of nutrients supplied daily during gestation and lactation 124

Table 2. Effect of supplementation with dried distiller's grains with solubles on cow BW and BCS 125

Table 3. Effect of supplementation with dried distiller's grains with solubles on calf performance 126

Table 4. Effect of supplementation with dried distiller's grains with solubles on cow reproductive performance (Exp.. 1) 127

Table 5. Effect of supplementation with dried distiller's grains with solubles on blood urea N concentration of beef cows during gestation and late lactation (Exp. 1) 128

Table 6. Effect of supplementation with dried distiller's grains with solubles on prairie hay intake and diet digestibility.....129

Table 7. Effect of supplementation with dried distiller's grains with solubles on milk production and composition of beef cows 130

LIST OF FIGURES

CHAPTER II

Figure 1. The partitioning of DM intake during preconditioning for steers 33

Figure 2. The partitioning of DM intake during preconditioning for heifers 34

Figure 3. The effect of feeding level of dried distillers grains with solubles on the partitioning of preconditioning and wheat pasture gain 34

ACKNOWLEDGMENTS

To begin, I would like to thank the faculty, staff and graduate students in the Department of Animal Science at Oklahoma State University for their relentless guidance and assistance throughout my time here. Thank you to my committee: Drs. Damona Doye, Clint Krehbiel and Gerald Horn for taking the time to serve on my committee. In addition to my committee, I have sincere gratitude to my advisor, Dr. David Lalman. I appreciate the countless hours that he has spent mentoring and guiding me through my studies. I am extremely thankful for the patience, professionalism, and commitment to quality that Dr. Lalman has shared with me over the past three years. Working with Dr. Lalman has given me the knowledge base and confidence that I need to make meaningful contributions to the beef cattle industry. Additionally, I would like to thank Dr. Gerald Horn for the time he took to work with me as I prepared for job interviews, for sharing his perspective and offering advice, and for providing unwavering support of my future endeavors.

I have been fortunate to have encountered several lifelong friends throughout my tenure as a graduate student and have relied on their strength, support and expertise during my Ph.D. studies. During my Master's program I was privileged to work with Dr. Kelly Brown who helped me understand the true value in taking time to help others, working hard and maintaining a positive attitude. Likewise, I have relied on the friendship of Dr. Jessica Starkey and sincerely appreciate her advice, insight and support

as I made life-choices. Finally, I am inspired by and am grateful for the friendship of my very dear Norwegian Viking friend, Dr. Kari Kjellerød Lundblad.

Lastly, I owe my love of beef cattle production to my parents, Mike and Pam Winterholler, and I am truly blessed to have had their love and support over the past nine years of higher education. I know that I would not have achieved the goals that I had set out to accomplish without the characteristics of dedication, responsibility and work ethic which I learned from these two wonderful individuals. It is my ultimate goal to return to the family ranch; however, I am thankful to my parents for challenging me to step away for awhile to explore and learn more about the industry and apply my knowledge base of production agriculture to a broader scope.

FORWARD

This dissertation was written in the form of four separate manuscripts that serve as chapters II, III, IV and V. Chapter II evaluated the utilization of dried distiller's grains with solubles during preconditioning and the subsequent impacts on wheat pasture performance, feedlot performance and carcass characteristics. This chapter was prepared to follow the guidelines suggested for contributors to the *Professional Animal Scientist.* Chapter III is comprised of data collected from an *in situ* study which measured the ruminal degradation characteristics of byproduct feedstuffs. This chapter has been submitted to the *Journal of Animal Science.* The data in Chapter IV is from a beef cow winter supplementation study that evaluated the efficacy of extruded-expelled cottonseed meal as supplement for beef cows consuming low-quality forage. This chapter has been submitted to the *Journal of Animal Science.* Chapter V consists of data collected to understand how dried distiller's grains with solubles can be used in beef cow/calf production systems that rely on low-quality forage. This chapter was prepared to follow the guidelines suggested for contributors to the *Journal of Animal Science*

CHAPTER I

REVIEW OF LITERATURE

INTRODUCTION

Dietary fat utilization by the ruminant is a unique process that is comprised of several diverse, complex steps. Inclusion of dietary fat provides a dense, economically efficient energy source. However, due to the intricate nature of the rumen microbial population, fat supplementation has diverse effects on animal performance. The goals and impacts of fat supplementation differ across various production segments of the cattle industry.

The effects of including of supplemental fat to beef cattle consuming high forage diets has been revisited recently due to the surplus of byproduct feedstuffs from the biofuel industry. Compared to feedstuffs such as cottonseed meal or soybean meal, which have been traditionally utilized in winter supplementation programs for beef cows, the fat content of biofuel-byproduct feedstuffs is 5-7% greater than traditional feedstuffs (NRC, 1996). To target the evaluation of biofuel feedstuffs as supplements for beef cattle consuming high forage diets, the focus of this review will be on the impacts that supplemental fat has on range cattle production

Lipid Metabolism in the Rumen

Fat intake by cattle grazing rangeland is of two major forms: glycolipids and phospholipids. Glycolipids are the predominant form as they comprise 40-50% of total plant lipid (Byers and Schelling, 1988). Moreover, fat constituents of plants are made primarily of unsaturated fatty acids of which linoleic and linolenic are the most abundant (Harfoot, 1978). When the ruminant animal consumes dietary lipid, the metabolic processes by ruminal microorganisms that follow are complex and multifaceted.

Once lipids enter the rumen, lipases from ruminal lipolytic bacteria hydrolyze lipid into free fatty acids and glycerol (Jenkins, 1993). Ruminal protozoa do not have a large role in ruminal lipolysis (Girard and Hawke, 1978). Unsaturated fatty acids rapidly undergo biohydrogenation by the rumen microbes to saturated fatty acids (Palmquist and Jenkins 1980). Cleaved glycerol is converted to propionic acid for energy (Chalupa et al., 1986). Further, the amount of bacteria present for lipolysis and biohydrogenation is largely impacted by diet; research has shown that high grain diets decrease the concentrations of these organisms (Latham et al., 1972).

Unsaturated fatty acids are detrimental to the growth of many species of ruminal microbes (Henderson, 1973), and accordingly, the process of biohydrogenation is pivotal for the existence of many species of ruminal microbes. The biohydrogenation process cannot be initiated without the presence of a free carboxyl group which is provided by the initial hydrolysis step (Kepler et al., 1970). Stearic acid is the most predominant end product of biohydrogenation (Bickerstaffe et al., 1972) and various rumen microbes, including protozoa, are capable of hydrogenating oleic, linoleic and linolenic acid to stearic acid (Byers and Schelling, 1988). The biohydrogenation process is also beneficial by assisting in the reduction of methane production by providing a mechanism for the rumen to clear H ions through the saturation process (Byers and Schelling, 1988). In addition, the biohydrogenation process may provide means for energy conservation as the majority of bacterial lipid is saturated, and with biohydrogenation, bacteria can readily integrate saturated end products without additional energy expenditure (Harfoot, 1978).

The extent of ruminal biohydrogenation is largely impacted by the environmental conditions of the rumen. Kellens et al. (1986) indicated that the complete formation of

stearic acid is enhanced by feed particles and cell-free ruminal fluid. Whereas the biohydrogenation process can be inhibited by high concentrations of linoleic acid (Harfoot et al., 1973). Additional research has supported this notion. *In vitro* data showed a greater concentration of stearic acid in control (bromegrass hay only) samples after 48-h of incubation compared to bromegrass hay treated with soybean oil. Greater concentrations of linoleic acid in the bromegrass hay treated with soybean oil were observed after 48-h, which supports the aforementioned concepts (Whitney et al., 2000). Furthermore, the population of ruminal microflora can affect the degree of biohydrogenation as reductions in rate and extent of hydrogenation have been reported when protozoal numbers are low (Byers and Schelling, 1988).

Finally, when dietary lipid levels are low, ruminal bacteria are capable of *de novo* fatty acid synthesis of long-chain fatty acids (Palmquist and Jenkins, 1980). Ruminal bacteria do not store triglycerides, and the most predominant forms of lipid in rumen bacteria are either free fatty acids or phospholipids which serve as major cell membrane constituents (Viviani, 1970). Microbes synthesize primarily stearic and palmitic acid (Jenkins, 1993). Rate of fatty acid synthesis is greater when dietary lipid concentration is lower (Byers and Schelling, 1988) as dietary fatty acids are easily integrated into bacterial cellular lipid following biohydrogenation (Palmquist and Jenkins, 1980).

Fat and Fiber Digestion

Addition of fat to high-forage diets is a presumably favorable means of increasing dietary energy intake. However, due to the sophistication of the rumen microbe population, there are some characteristics of lipids that make supplementation detrimental to fiber digestion. Evidence of inhibitory impacts that fat has on cellulose digestion was

presented by Brooks et al. (1954) who found that *in vitro* cellulose digestion was reduced 40 to 94 percent when 10 to 170 mg of corn oil was added to 1 g of DM that was comprised of 50% cellulose. Additionally, when sheep were fed either 32 or 64 g of corn oil, *in vivo* cellulose digestion was 20% and 12.3%, respectively, which was significantly lower than for the 41.9% cellulose digestion for the control diet (Brooks et al., 1954).

Several studies have shown that there are various factors that impact the ruminant's ability to maintain fiber digestion with supplemental dietary fat. Some of the inhibitory effects of lipid on fiber digestion may be due to fat coating of fiber particles which results in the inability of bacteria to adhere to them (Brooks et al., 1954). Similarly, Harfoot (1978) indicated that long chain fatty acids have negative impacts on the rumen fermentation process as they quickly bind to feedstuffs, which ultimately decreases the ability of bacteria to bind to the particle. Brokaw et al. (2001) indicated that the concentration of ruminal NH_3 was greater for heifers supplemented with soybean oil compared to corn supplemented heifers. These workers attributed higher NH_3 levels of soybean supplemented heifers to the inhibition of bacterial attachment by supplemental fat and subsequent inability for bacteria to bind to the feed particle in order to release nutrients from associated feedstuffs.

Moreover, evidence has suggested that unsaturated fatty acids have toxic effects on fibrolytic bacteria as Palmquist and Jenkins (1980) found that the accumulation of unsaturated fatty acids inhibits growth of these bacterial species. *In vitro* research supported these findings as *in vitro* DM disappearance of bromegrass hay was reduced with the addition of 6% degummed soybean oil compared with no additional soybean oil (Whitney et al., 2000). Other reasons for a reduction in fiber digestion were examined by

Devendra and Lewis (1974) who showed that fiber digestion may be inhibited by the ability of ruminal surface-active agents to rapidly emulsify fat. Additionally, these researchers indicated that fat supplementation caused a reduction in cation availability due to the formation of insoluble complexes with long chain fatty acids which also has inhibitory effects on microbial growth (Devendra and Lewis 1974).

By understanding these inhibitory factors, animal scientists have investigated ways to intervene in the process of ruminal lipid metabolism. When alfalfa ash was fed with 32 g of corn oil, cellulose digestion was similar to control, but when alfalfa ash was added to 64 g of corn oil, cellulose digestion was decreased. Researchers speculated that the buffering capacity of alfalfa ash assisted in cellulose digestion, or that alfalfa ash is capable of assisting in fat emulsification which in turn prevents fat from coating the fiber so that microbes are able to attach (Brooks et al., 1954). The, magnitude of cellulose digestion is also impacted by fat source. In the aforementioned study by Brooks et al. (1954), they observed that feeding 32 or 64 g of lard did not suppress cellulose digestion to the same magnitude as feeding supplemental corn oil.

The addition of divalent cations to high fat diets reduces the extent of depression in cellulose digestibility as calcium salts of long chain fatty acids form from hydrolyzed fat making them insoluble and virtually non-toxic to cellulose degrading bacteria (Garton et al., 1958). Grainger et al. (1961) supported this data by illustrating that feeding wethers 7% corn oil depressed cellulose digestibility, but when 4.4 g of calcium was added to the 7% corn oil diet, cellulose digestion was significantly increased. Additionally, these researchers observed that 6.2 g of iron in addition to 7% corn oil helped increase cellulose digestion, but was not as effective as supplemental calcium.

Various factors impact the extent to which the addition of divalent cations increases fiber digestion. Jenkins and Palmquist (1982) evaluated the effects of calcium source on *in vitro* formation of insoluble soaps and showed that the addition of calcium chloride to a 10% tallow substrate was more effective at forming insoluble soaps and increasing digestibility than adding dicalcium phosphate to a 10% tallow substrate. The formation of insoluble soaps requires time, and the efficacy of increasing fiber digestion by adding calcium to high fat diets may be largely impacted by particulate passage rate (Jenkins and Palmquist, 1982). Also, degree of saturation and chain length can impact the formation of insoluble soaps. Jenkins and Palmquist (1982) speculate that saturated fatty acids are less toxic to rumen microbes because of their ability to readily form insoluble soaps.

Efficacy of Fat Supplementation to Range Cattle

Providing supplemental energy to cowherds is often necessary during winter months or when forage quality is low to ensure proper energy balance through early lactation. Fat is a relatively inexpensive, dense source of supplemental energy. However, amount and type of supplemental fat can have tremendous impacts on forage intake and digestion. Moore et al. (1986) indicated that for cattle consuming high roughage diets, supplemental fat was efficacious at 4% of diet DM, but when fat was added at 6.3% of diet DM, regardless of source, it was detrimental to intake and fiber digestibility.

Furthermore, when evaluating fat supplementation at different levels, Whitney et al. (2000) reported that the inclusion of 3% soybean oil increased feed efficiency in heifers consuming bromegrass hay compared to controls, but feed efficiency was lowered

when 6% supplemental soybean oil was added. This research suggests that the higher level of soybean oil decreased diet digestibility. However, in diets today, fat is traditionally supplemented at no more than 5% of diet DM (Palmquist and Jenkins, 1980).

Research has shown little difference in the effects of fat supplementation in situations where cattle consume different types or maturities of forages. Krysl et al. (1991) reported that ruminal infusion of 150 mL of soybean oil to heifers consuming chopped fescue/orchardgrass hay *ad libitum* decreased ruminal and total tract organic matter digestibility but did not alter fiber digestion. Total tract and ruminal digestibility was lower for heifers ruminally infused with soybean oil but duodenal infusion had no effect on total tract fiber digestibility.

Similarly, no differences in forage intake or ruminal NDF disappearance were noted in heifers fed high-quality forage and provided a supplement comprised of cracked corn, corn gluten meal and soybean oil at 0.30% BW compared with heifers receiving no supplement (Brokaw et al., 2001). Kouakou et al. (1994) compared feeding supplemental corn or soybean oil to cannulated cattle consuming either long-stemmed alfalfa hay or orchardgrass hay and reported that supplemental soybean oil at 0.125% BW had no effect on feed intake, but when combined with ground corn (0.5% BW) feed intake was lowered suggesting that soybean oil is capable of changing rumen metabolic properties. Additionally, there were no adverse effects on NDF digestion with corn or soybean oil supplementation alone, but when fed together, total tract NDF digestion was decreased (Kouakou et al., 1994).

A final consideration of providing supplemental fat in range cow diets is the effect that it has on metabolizable protein level, which dramatically impact cow performance and nutrient utilization. Brokaw et al. (2001) indicated that fat supplementation caused a reduction in nitrogen flow to the duodenum and a subsequent decrease in metabolizable protein. A similar reduction in duodenal nitrogen flow was reported by Bock et al. (1991) when supplemental tallow or soybean oil soapstock was fed to cattle consuming a high-grain diet.

Influence of Fat on Reproductive Performance

The underlying dogma suggests that additional energy from fat increases reproductive performance; however there is evidence that fat source has a negative impact on reproduction in beef cows. In a meta-analysis, Hess et al. (2002) indicated that overall pregnancy rate was increased 9.8% for fat supplemented heifers compared to heifers receiving no supplemental fat. Growth and development of ovarian follicles was increased for beef cows fed supplemental soybean oil (Thomas et al., 1997). Yet, providing supplemental fat beyond meeting the protein and energy requirements for beef cows of moderate BCS had no bearing on reproductive performance (Alexander et al., 2002).

Supplementation with fat sources containing high levels of 18:2n-6 in the early postpartum period may have negative effects on reproductive rates. Postpartum supplementation of high-linoleate safflower seeds (255 g/d of 18:2n-6) increased the concentration of 18:2n-6 in the oviduct (Scholljegerdes et al., 2007), which potentially could negatively impact conception rate (Hess et al., 2008). Providing supplemental fat to beef cows prior to breeding is not a recommended management practice to improve

reproductive performance, however moderate levels of fat may be beneficial in developing replacement heifers (Hess et al., 2008).

Summary and Conclusions

Feeding supplemental fat increases dietary energy density which is important in many cattle production situations. However, performance responses from the addition of dietary fat may be limited due to the sensitivity of the rumen microbial population. Added fat can have detrimental impacts on forage intake and fiber digestion. Rumen lipid metabolism is a multi-step process. The initial hydrolysis step cleaves fat into free fatty acids and glycerol. The free fatty acids then rapidly undergo biohydrogenation to form saturated fats as unsaturated fats have toxic effects on some ruminal microbes. Ruminal bacterial are capable of *de novo* fatty acid synthesis when dietary fat levels are low. Fat can alter the extent of fiber digestion several ways: by coating the forage particles and inhibiting bacterial attachment, through the formation of insoluble complexes, by altering particle surface properties and by decreasing cation availability. Cellulose digestion can be improved by the addition of divalent cations, yet digestibility responses are dependent upon the nature of the cation. Degree of depression of fiber degradation is dependent on type and amount of fat. Adding supplemental fat at 5% of the diet has proven to be efficacious in increasing dietary energy. Fat supplementation can lower metabolizable protein levels. It is important to understand the mechanisms of lipid metabolism to ensure that lipids are effectively and efficiently administered to ruminant animals.

The multifaceted process of lipid metabolism is impacted by various external and internal factors. Though extensive research has been conducted with fat

supplementation, the impacts that it has in ruminant diets will continue to be scrutinized with the increasing abundance of ethanol co-products. These feedstuffs are high in fat and protein and the effects and interactions of these products in ruminant diets warrants further investigation. Finally, nutritional practices that include supplemental fat can alter animal performance and should be carefully evaluated in order to avoid the negative effects that can arise from adding fat to ruminant diets.

LITERATURE CITED

Bickerstaffe, R., D. E. Noakes, and E. F. Annison. 1972. Quantitative aspects of fatty acid biohydrogenation, absorption, and transfer into milk fat in the lactating goat, with special reverence to the *cis*- and *trans*-isomers of octadecenoate and linoleate. Biochem. J. 130:607.

Bock, B. J., D. L. Harmon, R. T. Brant, and J. E. Schneider. 1991. Fat source and calcium level effects on finishing steer performance, digestion, and metabolism. J. Anim. Sci. 69:2211-2224.

Brokaw, L. B. W. Hess, and D. C. Rule. 2001. Supplemental soybean oil or corn for beef heifers grazing summer pasture: Effects of forage intake, ruminal fermentation, and site and extent of digestion. J. Anim. Sci. 79:2704-2712.

Brooks, C. C., G. B. Garner, C. W. Gehrke, M. E. Muhrer and W. H. Pfander. 1954. The effect of added fat on the digestion of cellulose and protein by ovine rumen microorganisms. J. Anim. Sci. 13:758.

Byers, F. M., and G. T. Schelling. 1988. Lipids in ruminant nutrition. Pages 298-312 in The Ruminant Animal: Digestive Physiology and Nutrition. D. C. Church ed. Waveland Press, Inc., Englewood Cliffs, NJ.

Chalupa, W., B. Vecchiatelli, A. Esler, D. S. Kronfeld, D. Sklan, and D. L. Palmquist. 1986. Ruminal fermentation in vivo as influenced by long-chain fatty acids. J. Dairy Sci. 69:1293-1301.

Devendra, C., and D. Lewis. 1974. The interaction between dietary lipids and fibre in the sheep. Anim. Prod. 19:67.

Garton, G. A., P. N. Hobson, and A. K. Lough. 1958. Lypolysis in the rumen. Nature

182:1511.

Girard, V., and J. C. Hawke. 1978. The role of holotrichs in the metabolism of dietary linoleic acid in the rumen. Biochim. Biophys. Acta. 528:17.

Grainger, R. B., M. C. Bell, J. W. Stroud, and F. H. Baker. 1961. Effect of various cations and corn oil on crude cellulose digestibility by sheep. J. Anim. Sci. 20:319.

Harfoot, C. G., R. C. Noble, and J. H. Moore. 1973. Factors influencing the extent of biohydrogenation of linoleic acid by rumen microorganisms in vitro. J. Sci. Food Agric. 24:961.

Harfoot, C. G. 1978. Lipid metabolism in the rumen. Prog. Lipid Res. 17:21.

Henderson, C. 1973. The effects of fatty acids on pure cultures of rumen bacteria. J. Agr. Sci. (Camb.) 81:107.

Hess, B. W., D. C. Rule, and G. E. Moss. 2002. High fat supplements for reproducing beef cows. Have we discovered the magic bullet? Pages 59-83 in Proc. Pacific Northwest Anim. Nutr. Conf., Vancouver, British Columbia, Canada.

Hess, B. W., G. E. Moss, and D. C. Rule. 2008. A decade of developments in the area of fat supplementation research with beef cattle and sheep. J. Anim. Sci. 86(E. Suppl.):E188-E204.

Jenkins, T. C. 1993. Lipid metabolism in the rumen. J. Dairy Sci. 76:3851-3863.

Jenkins, T. C., D. L. Palmquist. 1982. Effect of added fat and calcium on in vitro Formation of insoluble fatty acid soaps and cell wall digestibility. J. Anim. Sci. 55:957.

Kellens, M. J., H. L . Goderis, and P. P. Tobback. 1986. Biohydrogenation of unsaturated fatty acids by a mixed culture of rumen microorganisms. Biotechnol. Bioeng. 28:1268.

Kepler, C. R., W. P. Tucker, and S. B. Tove. 1970. Biohydrogenation of unsaturated fatty acids. IV. Substrate specificity and inhibition of linoleate Δ^{12}-*cis*, Δ^{11}-*trans* isomerase from *Butyrivibrio fibrisolvens*. J. Biol. Chem. 245:3612.

Kouakou, B., A. L. Goetsch, A. R. Patil, D. L. Galloway, SR., Z. B. Johnson, and K. K. Park. 1994. Voluntary intake and digestibility by mature beef cattle and Holstein steer calves consuming alfalfa or orchardgrass hay supplemented with soybean oil and(or) corn. Arch. Anim. Nutr. 47:131-151.

Krysl, L. J., M. B. Judkins and V. R. Bohman. 1991. Influence of ruminal or duodenal soybean oil infusion on intake, ruminal fermentation, site and extent of digestion, and microbial protein synthesis in beef heifers consuming grass hay. J. Anim. Sci. 69:2585-2590.

Latham, M. J., J. E. Storry, and M. E. Sharpe. 1972. Effect of low-roughage diets on the microflora and lipid metabolism in the rumen. Appl. Microbiol. 24:871.

Moore, J. A., R. S. Swingle, and W. H. Hale. 1986. Effects of whole cottonseed, cottonseed oil or animal fat on digestibility of wheat straw diets by steers. J. Anim. Sci. 63:1267.

NRC. 1996. Nutrient Requirements of Beef Cattle. 7th rev. ed. Natl. Acad. Press, Washington, DC.

Palmquist, D. L., and T. C. Jenkins. 1980. Fat in lactation rations. J. Dairy Sci. 63:1-14.

Scholljegerdes, E. J., S. L. Lake, T. R. Weston, D. C. Rule, G. E. Moss, T. M. Nett, and B. W. Hess. 2007. Fatty acid composition of plasma, medial basal hypothalamus, and uterine tissue in primiparous beef cows fed high-linoleate safflower seeds. J. Anim. Sci. 85:1555-1564.

Thomas, M. G., B. Bao, and G. L. Williams. 1997. Dietary fats varying in their fatty acid composition differentially influence follicular growth in cows fed isoenergetic diets. J. Anim. Sci. 75:2512-2519.

Viviani, R. 1970. Metabolism of long-chain fatty acids in the rumen. Adv. Lipid Res. 8:267.

Whitney, M. B., B. W. Hess, L. A. Burgwald-Balstad, J. L. Sayer, C. M. Tsopito, C. T. Talbott, and D. M. Hallford. 2000. Effects of supplemental soybean oil level on in vitro digestion and performance of prepubertal beef heifers. J. Anim. Sci. 78:504-514.

CHAPTER II

USE OF DRIED DISTILLERS GRAINS IN PRECONDITIONING PROGRAMS FOR WEANED BEEF CALVES AND SUBSEQUENT IMPACT ON WHEAT PASTURE AND FEEDLOT PERFORMANCE AND CARCASS CHARACTERISTICS

ABSTRACT

To evaluate the effects of feeding increasing levels of dried distillers grains with solubles (DDGS) during preconditioning, weaned steer (n = 64) and heifer (n = 64) calves were stratified by BW and allotted to receiving pens for a randomized complete block design. Dietary treatments included 0.30, 0.75, 1.20 or 1.65% mean pen BW DDGS. Throughout 56 d, prairie hay (4.8% CP, 68.8% NDF) was fed *ad libitum*, refusals were measured weekly. After 56-d, steers calves grazed wheat pasture before entering the feedlot; heifers were placed in the feedlot. As DDGS level increased, ADG increased quadratically ($P < 0.01$), hay intake decreased linearly ($P < 0.01$) and G:F improved quadratically ($P < 0.01$). Wheat pasture ADG was greatest for steers fed the lowest DDGS level ($P < 0.01$) and decreased linearly across treatments ($P < 0.01$). For steers, HCW and marbling score increased numerically (linear, $P = 0.13$; linear, $P = 0.12$, respectively) with increasing DDGS during preconditioning. Other measured carcass characteristics were not influenced by DDGS level for steers or heifers ($P > 0.20$). Though outside of our feeding range, the response function suggested preconditioning ADG would be maximized with 2.0% BW DDGS for steers, 1.44% BW DDGS maximized ADG for heifers. Visual symptoms of polioencephalomalacia were not observed; high levels of DDGS during preconditioning did not influence subsequent growth performance or carcass characteristics. Calves readily consumed DDGS and DDGS can be included in preconditioning diets at a level which maximizes, but does not exceed recommended dietary S concentrations.

Key words: Calves, Distillers Grains, Receiving Diets, Stocker and Feedlot Performance

INTRODUCTION

It is a common management practice for calves from spring-calving cowherds to be grown on wheat pasture before feedlot entry in the Southern Great Plains. In many instances, calves are weaned 1-2 mo before wheat pasture turnout, resulting in a 30-60 d preconditioning growing period. With the recent expansion of the ethanol industry, the supply of corn dried distillers grains with solubles (**DDGS**) has been abundant. Dried distillers grains with solubles is a high-protein, low-starch, high-energy feedstuff and can be used in diverse cattle production programs. In this region, low-quality forage is abundant; including DDGS to low-quality forage based diets may maximize ADG and decrease cost of gain during this brief preconditioning period.

Previous studies with DDGS in backgrounding programs that utilized a variety of grazed forages showed increased ADG and decreased forage intake. Supplementation of DDGS, up to 0.95% BW, to calves grazing low or high-quality forage indicated ADG increased linearly and forage intake decreased linearly with increasing DDGS level (Morris et al., 2005). Similar responses were observed in ADG and forage intake in yearling steers grazing native summer range and supplemented with increasing levels, up to 1.03% BW DDGS; subsequent feedlot performance or carcass traits were not influenced by DDGS supplementation (Morris et al., 2006). Gustad et al. (2006) reported ADG increased quadratically for weaned calves grazing corn residue at DDGS supplementation levels up to 1.27% BW.

The concentration of S in DDGS is moderate to high; excessive dietary S can cause S-induced polioencephalomalacia (Niles et al., 2002). A high level of S intake

during the finishing phase can reduce growth and efficiency (Loneragan et al., 2001). There is little data available (Morris et al., 2006) evaluating potential lingering symptoms of polioencephalomalacia during the finishing phase, after cattle have been exposed to relatively high dietary S by feeding DDGS during preconditioning. Objectives of this study were to evaluate feeding increasing levels of DDGS in a preconditioning program for weaned calves fed low-quality prairie hay to determine effects on growth performance and hay intake during preconditioning, and subsequent growth performance and carcass characteristics during stocker and finishing phases.

MATERIALS AND METHODS

Animals

Steers. All procedures for this experiment were conducted with an approved Oklahoma State University Animal Care and Use protocol. Spring-born English x Continental beef steer calves (n = 64; initial BW = 197 ± 25 kg) were weaned at the Oklahoma State Range Cow Research Center, North Range Unit on September 26, 2006 and transported to the Willard Sparks Beef Research Center, Stillwater, OK. At weaning, calves were weighed and vaccinated with Ultra Choice 7 (Pfizer Animal Health, New York, NY) and Bovi-Shield Gold 5 (Pfizer Animal Health).

Upon arrival at the Sparks facility, calves were subject to a 6 d adaptation period. During this period, calves were sorted into two 24 x 30 m pens and were fed 0.68 kg DDGS or approximately 0.30% BW daily and provided prairie hay *ad libitum* (composition provided in Table 1). Following the adaptation period, calves were weighed after 16-hr removal from water and feed and this BW was utilized as the trial allocation weight. Calves were re-vaccinated with Bovi-Shield Gold 5 (Pfizer Animal

Health) and were de-wormed with Ivomec injectable (Merial, Deluth, GA) on d 14. After the 56 d preconditioning period, cattle were fed a receiving diet (15% CP; 81%TDN; DM basis) at 2.0% BW for 7 d to equalize rumen fill. Following this 7 d period, cattle were weighed and this BW was used to calculate final preconditioning BW and performance.

Heifers. All procedures for this experiment were conducted with an approved Oklahoma State University Animal Care and Use protocol. Data for this study were collected over a 2 yr period. In yr 1, spring-born English x Continental beef heifer calves (n = 32; initial BW = 185 ± 20 kg) were weaned at the Oklahoma State Range Cow Research Center, North Range Unit on September 26, 2006 and transported to the Willard Sparks Beef Research Center (Stillwater, OK). In yr 2, fall-born English x Continental beef heifer calves (n = 32; initial BW = 175 ± 24 kg) were weaned at the Oklahoma State Range Cow Research Center, North Range Unit on April 1, 2008 and were transported to the Willard Sparks Beef Research Center. At weaning each year, calves were weighed and vaccinated with Ultra Choice 7 (Pfizer Animal Health, New York, NY) and Bovi-Shield Gold 5 (Pfizer Animal Health).

Upon arrival at the Sparks facility each year, calves were subject to a 6 d adaptation period. During this period, calves were sorted into two 24 x 30 m pens and were fed 0.68 kg DDGS or approximately 0.30% BW daily and provided prairie hay *ad libitum* (composition provided in Table 1). Following the adaptation period, calves were weighed after 16-hr removal from water and feed and this BW was utilized as the trial allocation weight. Calves were re-vaccinated with Bovi-Shield Gold 5 (Pfizer Animal Health) and were de-wormed with Ivomec injectable (Merial, Deluth, GA) on d 14. After the 56 d preconditioning period, cattle were fed a common receiving diet (15% CP;

81%TDN; DM basis) at 2.0% BW for 7 d to equalize rumen fill. Following this 7 d period, cattle were weighed and this BW was used to calculate final preconditioning BW and performance.

Treatments and Diet Delivery

Following the adaptation period, calves were blocked by BW and randomly allotted to receiving pens (4 animals/pen, 4 pens/treatment). Treatments included the following feeding levels of DDGS: 1) 0.30% BW; 2) 0.75% BW; 3) 1.20% BW; 4) 1.65% BW. The upper treatment level was selected to maximize DDGS intake while not exceeding the maximum tolerable dietary S concentration (0.40% of diet DM) recommended by NRC (1996). The remaining three DDGS levels were assigned as equally spaced increments from the upper level of DDGS. Cattle were weighed every 14 d throughout the 56-d period, and amount of DDGS fed was subsequently adjusted according to mean pen BW. A monensin containing vitamin and trace mineral supplement (20% Ca; 3.50% P; 20.5% NaCl; 1.0% Mg; 1,000 ppm Cu; 26 ppm Se; 2,400 ppm Zn; 136,000 IU/kg Vitamin A; 13,600 IU/kg Vitamin D; 45 IU/kg Vitamin E; DM basis; Vigortone Ag Products, Hiawatha, IA) was mixed with DDGS and provided 100 mg/animal/d of monensin. The vitamin and mineral supplement was fed at a rate to meet the NRC (1996) requirements for growing cattle. Calves had *ad libitum* access to prairie hay and water throughout the trial. Average nutrient composition of prairie hay and DDGS for year 1 and year 2 are provided Table 1. Step-up of DDGS feeding consisted of increments of 0.91 kg/d until the appropriate feeding level was achieved. Pens provided 4.6 m of bunk space that was divided in half with concrete bunk dividers. Hay was provided in one-half of the bunk and DDGS was delivered in the remaining portion.

Hay Intake, DDGS Intake and Nutrient Analysis

Distillers grains offered and any refusals were weighed daily to determine DDGS intake. Hay intake was measured directly; unconsumed hay was collected, cleaned out of pens and weighed 1x per wk to estimate hay intake. Sub-samples of dietary treatments, hay and orts were dried at 50°C for 48 hr for determination of DM. Prior to laboratory analysis, hay was ground in a Wiley Mill (Model-4 Thomas Scientific, Sweedesboro, NJ) to pass a 2-mm screen. Hay and DDGS were composited by pen and composite sub-samples were analyzed for ash, crude fat, crude protein, acid detergent fiber and neutral detergent fiber. Neutral detergent fiber and ADF content were determined using an ANKOM Fiber Analyzer (ANKOM Technology, Macedon, NY). Crude protein was determined using a Leco NS-2000 Nitrogen Analyzer (Leco Corporation, St. Joseph, MI), and crude fat was determined by ether extraction (AOAC, 1996).

Cattle Management Following Preconditioning

Steers. Steers were placed on wheat pasture at the Oklahoma State University Wheat Pasture Research Unit near Marshall, OK on December 4, 2006. Prior to wheat pasture turn-out, steers were implanted with Component E-S (VetLife, Des Moines, IA). Steers grazed wheat pasture until April 11, 2007 and were then placed on feed at the Willard Sparks Beef Research Center, Stillwater, OK until July 18, 2007. All wheat pasture BW measurements were obtained following overnight removal of steers from feed and water. Upon arrival at the Sparks facility steers were implanted with Revalor-S (Intervet/Schering-Plough, Millsboro, DE). At the completion of the feeding period, cattle were weighed and a 4% pencil shrink was applied to determine final BW. Steers

were transported 333 km to Tyson Fresh Meats, Emporia, KS for harvest. Carcass data were collected following a 24-h chill and included 12th-rib fat thickness, 12th-rib longissimus muscle area, KPH, marbling score and quality grade. Data were collected by Kansas State University Meat Science personnel.

Heifers. In yr 1, heifers were placed directly on feed at Wheeler Brothers Feedyard in Watonga, OK on December 4, 2006 and were on feed through June 6, 2007. Heifer calves were implanted with Revalor-IH (Intervet/Schering-Plough) upon arrival at the feedyard and were re-implanted 75 d later with Revalor-H (Intervet/Shering-Plough). At the completion of the feeding period, cattle were weighed and a 4% pencil shrink was applied to determine final BW. Heifers were transported 499 km to Tyson Fresh Meats, Emporia, KS for harvest. Carcass data were collected following a 24-h chill and included 12th-rib fat thickness, 12th-rib longissimus muscle area, KPH, marbling score and quality grade. Data were collected by Kansas State University Meat Science personnel.

The data included in this study for heifers in yr 2 is only from the preconditioning phase. Due to uncontrollable circumstances, we were not able to obtain adequate data on finishing performance or carcass characteristics of heifer calves in yr 2.

Statistical Analysis

Steers. All data for this study were analyzed using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) for a randomized complete block design. For preconditioning phase data, treatment and block were included in the model as fixed effects and pen served as the experimental unit. Treatment means were separated using linear and quadratic orthogonal polynomial contrasts across feeding levels of DDGS. To analyze data for growth performance following the preconditioning phase and carcass data,

individual animal was the experimental unit and treatment means were separated using linear and quadratic orthogonal polynomial contrasts with respect to increasing feeding levels of DDGS during the preconditioning phase. For all analysis, differences in treatment means were assessed at $\alpha = 0.05$.

Heifers. Data for this study were analyzed using the MIXED procedure of SAS (SAS Inst. Inc.) for a randomized complete block design. For preconditioning phase data, treatment and block were included in the model as fixed effects and pen served as the experimental unit. Year was included in the model as a random effect. For carcass data analysis, individual animal was the experimental unit and treatment means were separated using linear and quadratic orthogonal polynomial contrasts with respect to increasing feeding levels of DDGS during the preconditioning phase. For all analysis, differences in treatment means were assessed at $\alpha = 0.05$.

RESULTS AND DISCUSSION

Preconditioning Phase

Preconditioning performance for steers is reported in Table 2 and pooled data for heifer performance in yr 1 and yr 2 are provided in Table 3. As level of DDGS increased, ADG improved quadratically ($P < 0.01$). Second derivative calculations of the response function indicated that, although outside of our feeding range for steers, ADG was maximized at 2.0% BW of DDGS and 1.44% of BW for heifers. Similar to our response, ADG was improved quadratically with respect to increasing feeding levels of DDGS for steer calves grazing corn residue (Gustad et al., 2006). In contrast with our findings, the upper feeding level of DDGS in the report by Gustad et al. (2006) was 1.27% BW and

authors indicated that 1.1% of BW of DDGS maximized ADG. In other studies designed similar to ours in which calves consuming high-forage diets were fed increasing levels of DDGS, linear responses in ADG were observed when the maximum feeding level of DDGS was approximately 0.95% or 0.61% (Morris et al., 2005; MacDonald et al., 2007). Compared to our results, the lack of a quadratic effect in each of these two experiments can be contributed to a higher maximum feeding level of DDGS in our study.

A quadratic response in gain efficiency was observed ($P < 0.01$) for both steers and heifers, and gain efficiency was maximized at 1.50% BW of DDGS for steers and 1.36% of BW of DDGS for heifers. Furthermore, when expressed as a percentage of mean trial BW, prairie hay intake decreased linearly ($P < 0.01$). Using regression calculations, for every 1.0 kg of DDGS that was consumed, prairie hay intake decreased 0.34 kg for steers ($R^2 = 0.90$) and 0.29 kg for heifers ($R^2 = 0.96$) (Figures 1 and 2**)**. Total DMI increased linearly ($P < 0.01$) as level of DDGS increased. Similar to our findings, when forage intake was measured directly, Morris et al. (2005) reported that intake of low-quality forage was reduced by 0.32 kg for every kg of DDGS fed, and there was a greater magnitude in reduction of forage intake (0.53 kg per kg of DDGS) for calves consuming high-quality forage. Loy et al. (2007) indicated that supplementation of DDGS at 0.4% BW to medium-quality forage (8.2% CP, 56% in vitro OM disappearance) reduced hay DMI 0.22% of BW compared to no supplementation. Likewise, when forage intake was calculated based on NE equations (NRC, 1996), feeding DDGS at incremental levels up to approximately 0.60% BW, MacDonald et al. (2007) speculated that intake of smooth bromegrass pasture would be decreased by 0.50 kg for every kg of DDGS consumed.

Compared to feedstuffs that are traditionally provided as supplements to forage diets, the fat content of DDGS is high. Previous research has pointed out the negative effects of high fat levels on forage intake and digestibility (Moore et al., 1986; Whitney et al., 2000; Hess et al., 2001). Further, in a recent review, Hess et al. (2008) indicated that in order to optimize forage utilization, supplemental fat intake should not exceed 4.5-5.0% of DM. In our study, when expressed as a percentage of average DMI, fat intake was 2.08%, 4.09%, 5.30%, and 6.21% across increasing levels of DDGS, respectively. Based on these percentages, which represent the average among steers and heifers, the additional fat from DDGS could contribute to the reduction in forage intake that we observed.

Beyond dietary fat levels, forage intake is influenced by energy intake in relation to intake of CP as microbial growth may be limited by N when the concentration of fermentable OM is increased (Horn and McCollum, 1987). In an effort to more clearly define the effects of supplementation on forage intake, Moore et al. (1999) concluded that forage intake was reduced when supplemental TDN intake was > .7% of BW. In our study, when expressed as a percentage of mean feeding BW and mean DDGS intake, the intake of TDN, averaged among steers and heifers corresponded to 0.23, 0.54, 0.83, and 1.11% of BW with respect to increasing level of DDGS. A large contribution of energy in DDGS is from the rapidly fermented, non-structural carbohydrate fraction. It is apparent that both fat intake and energy intake were limiting forage intake in a linear fashion with respect to increasing levels of DDGS. Together, the reduction in forage intake and increase in cattle performance as a result of feeding increasing levels of DDGS

may be an important management practice in a variety of scenarios, when producers wish to increase stocking density, when hay price is high, or when forage availability is low.

Additionally, in comparison to feedstuffs that are traditionally supplemented to cattle consuming low-quality forage such as cottonseed meal, the percentage of degradable intake protein is substantially lower in DDGS (Winterholler et al., 2008). In low-quality forage diets, degradable intake protein is a key component in growth of the rumen microbial population as it relates to increasing digestibility and utilization of the forage (McCollum and Galyean, 1985; Köster et al., 1996; Bandyk et al., 2001). Intuitively, it could be speculated that due to the added energy and low concentration of degradable intake protein in DDGS that metabolizable protein could be limited and detrimental to growth performance and forage utilization. Yet, the addition of urea to DDGS to meet requirements for degradable intake protein for heifers consuming medium quality forage (7.4% CP, 58.1% TDN) did not influence ADG or gain efficiency compared to heifers receiving DDGS only (Stalker et al., 2007). These researchers speculated that ruminal N recycling in heifers consuming DDGS without supplemental degradable intake protein was sufficient to meet microbial demands (Stalker et al., 2007).

Different from this, N recycling was not observed with DDGS supplementation to wether lambs consuming chopped bromegrass hay (8.44% CP) as measured by urea N flux Archibeque et al. (2008), which could be attributed to the stage of production as these lambs were mature and required no additional nutrients above maintenance. However, in the same study, DDGS supplementation to chopped bromegrass hay increased the release of α-amino N by the portal drained viscera; together with other nutrient flux data, evidence was provided that α-amino N utilization was increased by

DDGS compared to corn (Archibeque et al., 2008). Based on our findings as well as data from others, it is evident that DDGS supplementation to low-quality forage is effective, but more research is needed to more clearly understand how the ruminant utilizes this feedstuff when consumed in high-forage diets.

Calculations with the NRC (1996) model using the mean feeding BW for both steers and heifers in the present study, feeding DDGS at 1.65% of BW met requirements for degradable intake protein whereas other levels feeding levels of DDGS were deficient. The ADG for steers consuming 1.65% BW of DDGS was 1.27 kg and was 0.87 for heifers. To evaluate metabolizable protein concentrations of the diets, for steers to gain 1.3 kg/d, and for heifers to gain 1.0 kg/d, both steers and heifers consuming 0.30% BW DDGS were deficient in metabolizable protein but other feeding levels were adequate. It is interesting that ADG was optimized at 1.44% BW of DDGS for heifers and according to the NRC (1996) model, were deficient in degradable intake protein, suggesting N recycling was adequate to meet microbial requirements, but we did not observe a similar response in steers.

Exposure to high levels of S can induce polioencephalomalacia (Jeffrey et al., 1994). In finishing diets, ADG, G:F and some carcass characteristics are negatively impacted by high S intake (Zinn et al., 1997; Loneragan et al., 2001). In our study, by experimental design, S intake did not to exceed 0.40% of diet DM (NRC, 1996). For steers fed DDGS at 1.65% BW, the maximum S intake, calculated from intake of DDGS at the end of the preconditioning period was equal to 0.38% of diet DM. We observed no symptoms of S induced polioencephalomalacia at this level. However, nutrient

composition of DDGS is highly variable and should be closely monitored to avoid potential detrimental effects.

Wheat Pasture Phase

Data for wheat pasture performance is provided in Table 4. For steers that grazed wheat pasture following the preconditioning period, ADG decreased linearly as level of DDGS during preconditioning increased ($P < 0.01$). Average daily gain of steers grazing wheat pasture was reduced by 0.16 kg for each 1 kg/d increase in preconditioning gain. Steers fed 0.30% BW of DDGS during preconditioning exhibited the greatest level of compensatory growth while grazing wheat pasture; however, BW at the end of the 128 d wheat pasture grazing period was 34 kg greater for steers fed 1.65% of BW during preconditioning (Figure 2). Similarly, White et al. (1987) indicated that nutrient restricted calves had greater ADG during a subsequent grazing phase than calves without nutrient restrictions.

Though we were not able to measure gain efficiency during the wheat pasture phase, it has been well documented that following a period of nutrient restriction that rate of gain and gain efficiency are increased by re-feeding (Fox et al., 1972; Phillips et al., 1991). Sainz et al. (1995) indicated that compensatory growth rate is related to several mechanisms, but reported that increased DMI was the most significant variable. The dramatic increase in growth rate of calves fed the lower levels of DDGS during preconditioning while on wheat pasture might be attributed to greater DMI and subsequent increase in protein and energy intake while grazing wheat pasture.

Feedlot Performance and Carcass Characteristics

Data for feedlot performance and carcass characteristics for steers and heifers are provided in Tables 5 and 6, respectively. For steers, initial and final BW linearly increased with respect to feeding level of DDGS during preconditioning ($P < 0.05$) but did not influence ADG ($P = 0.21$). Although final BW of heifers was not impacted by level of DDGS during preconditioning ($P = 0.53$), ADG during the finishing phase decreased linearly with respect to increasing levels of DDGS during preconditioning ($P = 0.05$). The increase in feedlot ADG in heifers can be attributed to compensatory growth (White et al., 1987; Sainz et al., 1995; Choat et al., 2003). Further, it is interesting that despite dramatic increases in BW on wheat pasture by steers fed 0.30% BW DDGS during preconditioning, there was a linear increase in final BW with respect to increasing levels of DDGS during preconditioning. This indicates that the substantial compensatory growth that was exhibited by the steers fed 0.30% BW of DDGS during preconditioning was not great enough to overcome nutrient restriction during the preconditioning growing phase.

Although we were unable to calculate a measurement of gain efficiency during the finishing phase, in some production systems, cattle producers take advantage of nutrient restriction early in the growing phase to obtain more efficient feedlot gain (Drouillard and Kuhl, 1999). Though steers fed 1.65% BW during preconditioning were heavier after the finishing period, steers fed 0.30% BW may have been more efficient in converting feed to gain. Despite the potential for more efficient feedlot gains by steers fed DDGS at levels lower than 1.65% BW, in our study, there was greater profit potential for those steers kept on the high plane of nutrition throughout the growing phase as these

steers were the heaviest at the end of the finishing period, and HCW and marbling score were numerically greater (linear, $P = 0.13$ and $P = 0.12$, respectively) in relation to feeding levels of DDGS.

For steers, other carcass variables were not influenced by feeding level of DDDS during preconditioning ($P > 0.20$). All measured variables for carcass characteristics were similar in heifers ($P > 0.20$). Previous research with feeding increasing levels of DDGS, up to 1.03% of BW as a supplement to yearling cattle grazing native range, indicated that level of DDGS supplementation did not influence feedlot performance or carcass characteristics (Morris et al., 2006). However, we are unaware of other studies that have measured the effects of including DDGS during preconditioning (up to 1.65% BW) on feedlot performance and carcass characteristics. In a recent meta-analysis, Klopfenstein et al. (2008) indicated that some feedlot performance measures and carcass characteristics were decreased by the inclusion of 40% of diet DM of DDGS in finishing diets. We report no potential carryover effect of high levels of DDGS during preconditioning on these variables.

As mentioned earlier, high S concentrations during the finishing phase was detrimental to ADG and G:F (Zinn et al., 1997 and Loneragan et al., 2001). Even though we did not exceed the NRC (1996) recommendations for dietary S concentration during preconditioning, we are aware of no research which has evaluated potential lingering effects of exposure to high S levels during the preconditioning phase on subsequent feedlot performance. For steers, measuring the direct effects of S level during preconditioning on feedlot performance was confounded by the wheat pasture grazing period. However, for heifers fed 1.65% of BW during preconditioning, it was apparent

that an average S consumption of 0.28% of daily DMI did not influence feedlot performance or carcass characteristics.

IMPLICATIONS

Corn dried distillers grains may be incorporated into the rations of weaned calves up to 1.65% of BW with no negative effects on subsequent growth performance or carcass characteristics. Although we indicated that 2.0% of BW maximized ADG for steers, we do not recommend feeding this level due to the potential negative effects of feeding beyond the recommendation for dietary S concentration. To avoid excess S, the nutrient composition of DDGS should be closely monitored, and the S concentration of water and the total diet should be accounted for. Additionally, producers can utilize DDGS to manage forage intake in times when forage availability is low or cost is high, but the economic feasibility of feeding DDGS should be assessed with respect to transportation costs as well as fluctuations in feed prices.

Table 1. Average nutrient composition of dried distiller's grains with solubles and prairie hay

	Year 1		Year 2	
Item (DM basis)	DDGS[1]	Prairie Hay	DDGS[1]	Prairie Hay
Crude protein, %	33.2	5.9	30.6	5.4
ADF, %	17.6	43.9	16.2	46.3
NDF, %	44.8	67.4	35.8	74.8
Crude fat, %	10.6	1.7	13.2	1.9
TDN, %	82.7	55.0	81.0	52.0
Ca, %	0.03	0.63	0.05	0.52
P, %	0.78	0.07	0.86	0.05
S, %	0.52	0.08	0.59	0.08

[1]Dried distillers grains with solubles

Table 2. Effect of level of DDGS during preconditioning on performance and hay intake of beef steers

	Percentage of BW of DDGS[1]					*P*-value	
Item	0.30	0.75	1.20	1.65	SEM	Linear	Quadratic
Initial wt, kg	198	197	198	196	19.94	0.32	0.91
Final wt., kg	229	249	260	267	20.5	<0.01	0.02
Total gain, kg	30	52	62	71	1.33	<0.01	<0.01
56 d ADG, kg	0.54	0.93	1.10	1.27	0.02	<0.01	<0.01
Avg. daily hay intake, kg	4.24	4.19	3.56	3.37	0.17	<0.01	0.69
Hay intake as percent BW[2]	1.97	1.87	1.54	1.44	0.07	<0.01	0.99
Avg. daily DDGS, kg	0.67	1.63	2.61	3.49	0.001	<0.01	<0.01
Total DMI, kg	4.90	5.82	6.17	6.86	0.17	<0.01	0.54
Gain:feed	0.11	0.16	0.18	0.19	0.02	<0.01	<0.01

[1]Dried distillers grains with solubles

[2]Hay intake expressed as percentage of average trial weight

Table 3. Effect of level of DDGS during preconditioning on performance and hay intake of beef heifers

	Percentage of BW of DDGS[1]					*P*-value	
Item	0.30	0.75	1.20	1.65	SEM	Linear	Quadratic
Initial wt., kg	174	175	175	174	9.66	0.98	0.51
Final wt., kg	194	217	231	229	10.67	<0.01	<0.01
Total gain, kg	20	42	56	55	2.47	<0.01	<0.01
56 d ADG, kg	0.32	0.67	0.88	0.87	0.04	<0.01	<0.01
Avg. daily hay intake, kg	4.03	3.81	3.55	3.21	0.20	<0.01	0.47
Hay intake as percent BW[2]	2.12	1.91	1.72	1.57	0.07	<0.01	0.63
Avg. daily DDGS, kg	0.44	1.12	1.76	2.36	0.35	<0.01	0.82
Total DMI, kg	4.47	4.93	5.32	5.56	0.45	<0.01	0.60
Gain:feed	0.08	0.15	0.19	0.18	0.01	<0.01	<0.01

[1]Dried distillers grains with solubles

[2]Hay intake expressed as percentage of average trial weight

Table 4. Effect of level of dried distillers grains with solubles during the preconditioning phase on performance of steers on wheat pasture

	Percentage of BW of DDGS[1]					*P*-value	
Item	0.30	0.75	1.20	1.65	SEM	Linear	Quadratic
Initial BW, kg	221	247	259	266	7.29	<0.01	0.18
Final BW, kg	397	419	418	431	8.91	0.01	0.63
Total gain, kg	176	172	159	165	5.17	<0.01	0.12
128 d ADG, kg	1.38	1.34	1.24	1.29	0.03	<0.01	0.12

[1]Dried distillers grains with solubles

Table 5. Effect of dried distillers grains with solubles during the preconditioning phase on steer feedlot performance and carcass characteristics

	Percentage of BW of DDGS[1]					*P* -value	
Item	0.30	0.75	1.20	1.65	SEM	Linear	Quadratic
n =	16	16	16	15	--	--	--
Initial wt., kg	406	429	429	445	8.78	<0.01	0.69
Final wt., kg	565	585	580	598	9.91	0.04	0.91
Total gain, kg	159	156	151	153	4.05	0.22	0.55
97 d ADG, kg	1.64	1.61	1.55	1.58	0.04	0.21	0.55
Hot carcass	361	377	367	380	6.86	0.13	0.77
Dressing percent	63.86	64.47	63.35	63.55	0.53	0.39	0.60
Marbling score[1]	533	525	535	580	21.4	0.12	0.22
12th rib-fat, cm	1.02	1.12	1.24	1.04	0.08	0.57	0.11
Ribeye area, cm^2	85.94	89.99	87.03	90.97	2.39	0.27	0.96
KPH, %	2.25	2.38	2.34	2.30	0.07	0.72	0.26
USDA yield grade	2.7	2.8	2.9	2.7	0.16	0.91	0.32

[1]Dried distillers grains with solubles
[2]Small (low choice) = 500

Table 6. Effect of dried distillers grains during preconditioning on heifer feedlot performance and carcass characteristics (yr 1)

	Percentage of BW of DDGS[1]					*P*-value	
Item	0.30	0.75	1.20	1.65	SEM	Linear	Quadratic
n =	6	8	8	7	--	--	--
Initial wt., kg	201	231	244	243	8.72	<0.01	0.10
Final wt., kg	496	492	500	507	14.5	0.53	0.69
Total gain, kg	295	261	256	264	10.5	0.05	0.05
ADG, kg	1.57	1.38	1.36	1.40	0.05	0.05	0.05
Hot carcass weight, kg	323	319	320	326	9.99	0.78	0.57
Dressing percent	65.16	64.83	63.95	64.32	0.59	0.22	0.55
Marbling score[2]	653	593	685	633	41.1	0.87	0.92
12th rib-fat, cm	1.50	1.52	1.45	1.45	0.13	0.69	0.99
Ribeye area, cm^2	81.09	78.64	77.74	80.39	3.94	0.87	0.53
KPH, %	2.17	2.31	2.31	2.29	0.17	0.66	0.62
USDA yield grade	3.1	3.2	3.2	3.1	0.24	0.94	0.74

[1]Dried distillers grains with solubles
[2]Small (low choice) = 500

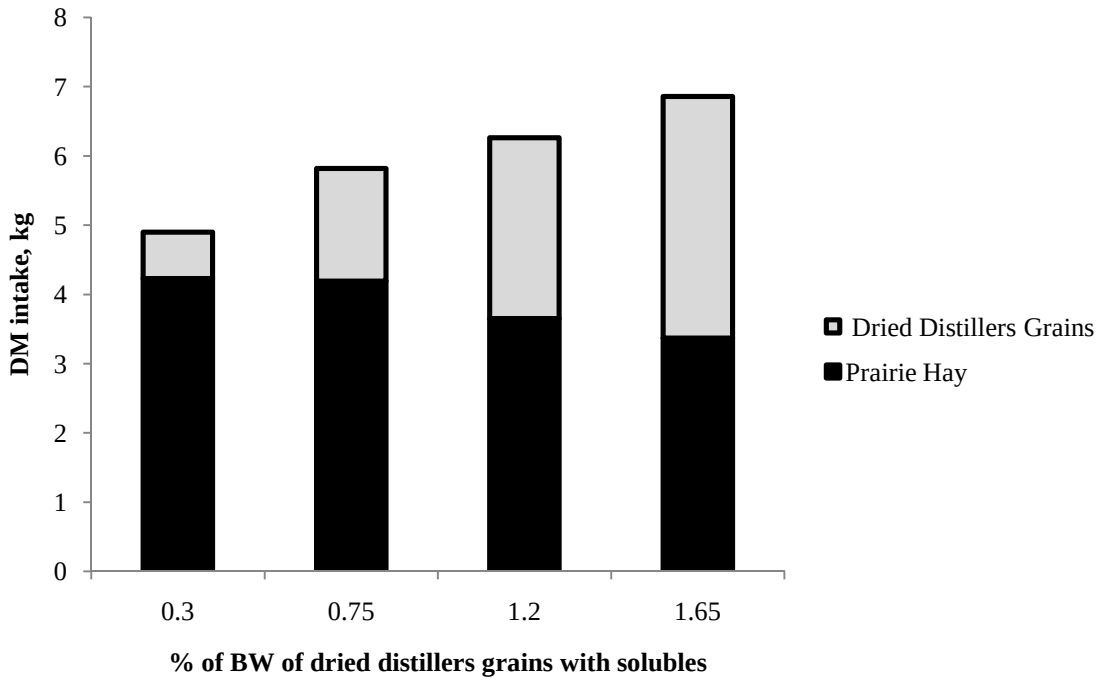

Figure 1. The partitioning of DM intake during preconditioning for steers, measured directly. Prairie hay intake decreased linearly as level of dried distillers grains with solubles increased ($P < 0.01$); the substitution of DDGS for prairie hay was 0.34 kg.

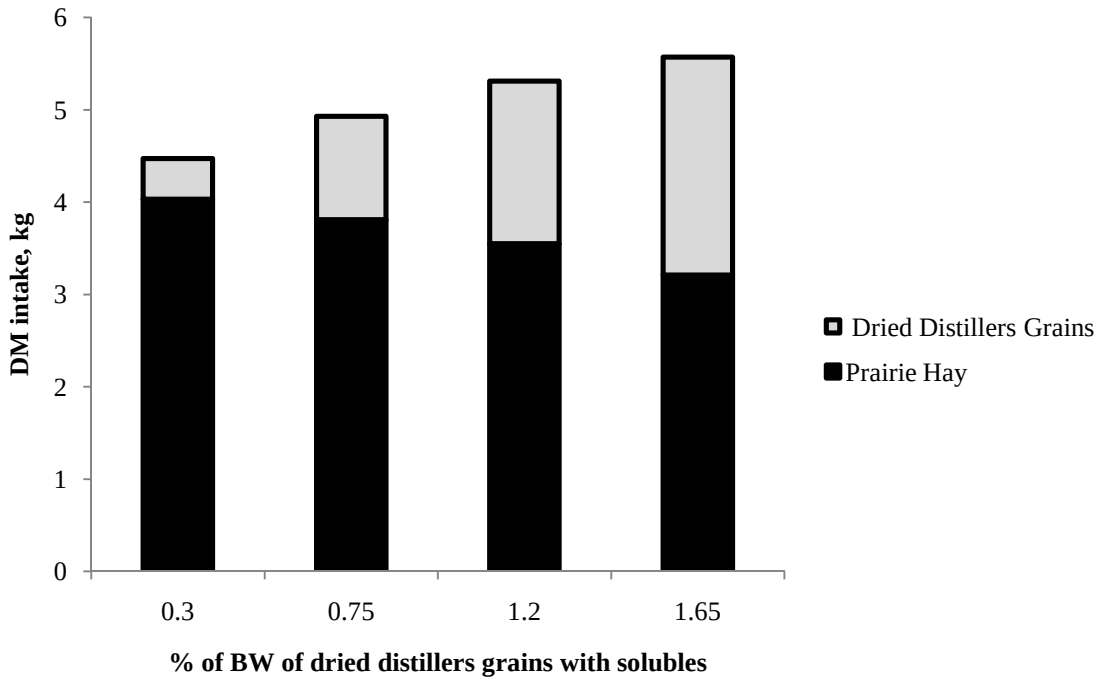

Figure 2. The partitioning of DM intake during preconditioning for heifers, measured directly. Prairie hay intake decreased linearly as level of dried distillers grains with solubles increased ($P < 0.01$); the substitution of DDGS for prairie hay was 0.29 kg.

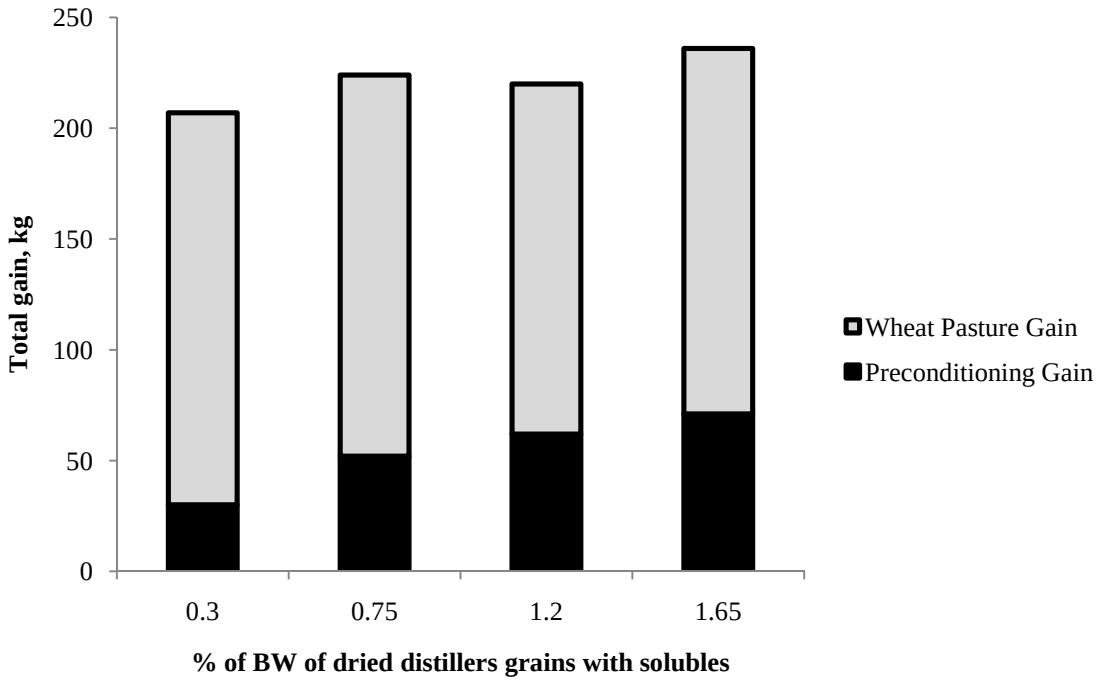

Figure 3. The effect of feeding level of dried distillers grains with solubles on the partitioning of preconditioning and wheat pasture gain. Gray bars represent total gain of steers during the wheat pasture period and black bars represent total gain of steers during the preconditioning period. Total gain for preconditioning increased linearly with respect to increasing level of dried distillers grains with solubles ($P < 0.05$). Total wheat pasture gain linearly decreased as feeding level of distillers during preconditioning increased ($P < 0.05$).

LITERATURE CITED

Technology, A. N. K. O. M. 2009a. Method for Determining Neutral Detergent Fiber (aNDF). http://www.ankom.com/09_procedures/procedures2.shtml Accessed May 19, 2000.

Technology, A. N. K. O. M. 2009b. Method for Determining Acid Detergent Fiber. http://www.ankom.com/09_procedures/procedures1.shtml Accessed May 19, 2000.

AOAC. 1996. Official Methods of Analysis 14th ed. Assoc. Offic. Anal. Chem. Arlington, VA.

Archibeque, S. L., H. C. Freetly, and C. L. Ferrell. 2008. Feeding distillers grains supplements to improve amino acid nutriture of lambs consuming moderate-quality forages. J. Anim. Sci. 86:691-701.

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.

Choat, W. T., C.R. Krehbiel, G. C. Duff, R.E. Kirksey, L. M. Lauriault, J. D. Rivera, B. M. Capitan, D. A. Walker, G. B. Donart, and C. L. Goad. 2003. Influence of grazing dormant native range or winter wheat pasture on subsequent finishing cattle performance, carcass characteristics, and ruminal metabolism. J. Anim. Sci. 81:3191-3201.

Drouillard, J. S., and G. L. Kuhl. 1999. Effects of previous grazing nutrition and management on feedlot performance of cattle. J. Anim. Sci. 77(Suppl. 2):136-146.

Fox, D. G., R. R. Johnson, R. L. Preston, T. R. Dockerty, and E. W. Klosterman. 1972. Protein and energy utilization during compensatory growth in beef cattle. J. Anim. Sci. 34:310-318.

Gustad, K. H., T. J. Klopfenstein, G. E. Erickson, K. J. VanderPol, J. C. MacDonald, and M. A. Greenquist. 2006. Dried distillers grains supplementation of calves grazing corn residue. Nebraska Beef Rep. MP-36:37.

Hess, B. W., G. E. Moss, and D. C. Rule. 2008. A decade of developments in the area of fat supplementation research with beef cattle and sheep. J. Anim. Sci. 86(E. Suppl.):E188-E204.

Hess, B. W., M. B. Whitney, and D. C. Rule. 2001. Site and extent of digestion by beef

Heifers fed medium-quality hay and supplemental corn or soybean oil. Proc. West. Sect. Am. Soc. Anim. Sci. 52:320-324.

Horn, G. W., and F. T. McCollum. 1987. Energy supplementation of grazing ruminants. Pages 125-136 in Proc. Graz. Livest. Nutr. Conf., Jackson Hole, WY.

Jeffrey, M., J. P. Duff, R. J. Higgins, V. R. Simpson, R. Jackman, T. O. Jones, S. C. Mechie, and C. T. Livesey. 1994. Polioencephalomalacia associated with the ingestion of ammonium sulfate by sheep and cattle. Vet. Rec. 134:343-348.

Klopfenstein, T. J., G. E. Erickson, and V. R. Bremer. 2008. BOARD-INVITED REVIEW: Use of distillers by-products in the beef cattle feeding industry. J. Anim. Sci. 86:1223-1231.

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.

Loneragan, G. H., J. J. Wagner, D. H. Gould, F. B. Garry and M. A. Thoren. 2001. Effects of water sulfate concentration on performance, water intake and carcass characteristics of feedlot steers. J. Anim. Sci. 79:2941-2948.

Loy, T. W., J. C. MacDonald, T. J. Klopfenstein, and G. E. Erickson. 2007. Effect of distillers grains or corn supplementation frequency on forage intake and digestibility. 85:2625-2630.

MacDonald, J. C., T. J. Klopfenstein, G. E. Erickson, and W. A. Griffin. 2007. Effects of dried distillers grains and equivalent undegradable intake protein or either extract on performance and forage intake of heifers grazing smooth bromegrass pastures. J. Anim. Sci. 85:2614-2624.

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.

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(Suppl.2):122-135.

Moore, J. A., R. S. Swingle, and W. H. Hale. 1986. Effects of whole cottonseed, cottonseed oil or animal fat on digestibility of wheat straw diets by steers. J. Anim. Sci. 63:1267-1273.

Morris, S. E., J. C. MacDonald, D. C. Adams, T. J. Klopfenstein, R. L. Davis, and J. R.

Teichert. 2006. Effects of supplementing dried distillers grains to steers grazing summer sandhill range. Nebraska Beef Rep. MP-30:32.

Morris, S. E., T. J. Klopfenstein, D. C. Adams, G. E. Erickson, and K. J. VanderPol. 2005. The effects of dried distillers grains on heifers consuming low or high quality forage. Nebraska Beef Rep. MP-18:20.

Niles, G. A., S. Morgan, W. C. Edwards, D. L. Lalman. 2002. Effects of dietary sulfur concentrations on the incidence and pathology of polioencephalomalacia in weaned beef calves. Vet. Human Toxicol. 44:70-72.

NRC. 1996. Nutrient Requirements of Beef Cattle. 7th rev. ed. Natl. Acad. Press, Washington, DC.

Phillips, W. A., J. W. Holloway, and S. W. Coleman. 1991. Effect of pre- and post weaning management system on the performance of Brahman crossbred feeder calves. J. Anim. Sci. 69:3102-3111.

Sainz, R. D., F. De la Torre, and J. W. Oltjen. 1995. Compensatory growth and carcass quality growth-restricted and refed beef steers. J. Anim. Sci. 73:2971-2979.

Stalker, L. A., D. C. Adams, and T. J. Klopfenstein. 2007. Urea inclusion in distillers dried grains supplements. Prof. Anim. Sci. 23:390-394.

White, T. W., F. G. Hembry, P. E. Humes, and A. M. Saxton. 1987. Influence of wintering weight change on subsequent pasture and feedlot performance by steers. J. Anim. Sci. 64:32-35.

Whitney, M. B., B. W. Hess, L. A. Burgwald-Balstad, J. L. Sayer, C. M. Tsopito, C. T. Talbott, and D. M. Hallford. 2000. Effects of supplemental soybean oil level on in vitro digestion and performance of prepubertal beef heifers. J. Anim. Sci. 78:504-514.

Winterholler, S. J., T. K. Dye, C. P. McMurphy, C. J. Richards, and D. L. Lalman. 2008. *In situ* degradation characteristics of extruded-expelled cottonseed meal-based supplements. J. Anim. Sci. 86(Supp. 2):533(Abstr.).

Zinn, R. A., E. Alvarez, M. Mendez, M. Montaño, E. Ramierz, and Y. Shen. 1997. Influence of dietary sulfur level on growth performance and digestive function in feedlot cattle. J. Anim. Sci. 75:1723:1728.

CHAPTER III

IN SITU RUMINAL DEGRADATION CHARACTERISTICS OF BYPRODUCT FEEDSTUFFS FOR BEEF CATTLE CONSUMING LOW-QUALITY FORAGE

ABSTRACT: Eight ruminally cannulated steers (BW = 753 ± 48 kg) were used to evaluate *in situ* N, NDF and DM degradation characteristics of byproduct feeds and their application for beef cows consuming low-quality forage. Experimental feedstuffs included (DM basis) 1) extruded-expelled cottonseed meal (ECSM; 33% CP and 55% NDF), 2) extruded-expelled cottonseed meal with linters (ECSML; 25% CP and 41% NDF), 3) dried distiller's grains with solubles (DGS; 33% CP and 36% NDF), 4) solvent-extracted cottonseed meal (CSM; 43% CP and 29% NDF), and 5) a blend of 76% wheat middlings with 18% CSM (WMCSM; 23% CP and 40% NDF). Steers were fed chopped prairie hay (4.8% CP, 69% NDF; DM basis) *ad libitum* and received 0.38 kg/100kg BW WMCSM daily. *In situ* degradation kinetics of N, NDF and DM components included the following fractions: A (immediately soluble), B (potentially degradable), and C (undegradable). Calculated rumen degradable protein (RDP) for ECSM was the highest among all feedstuffs (83.8%; $P < 0.01$), which was comprised of a large A fraction of N (41%). Similar RDP values were observed for DGS and ECSML (50.7%, and 50.9%, respectively, $P = 0.93$). The B fraction N for ECSML was large (88.9%); however, most of this was unavailable for ruminal degradation. The amount of RDP in CSM and WMCSM was similar (78.2% and 73.5%, respectively; $P = 0.12$) though the A fraction of N was greater for WMCSM compared to CSM ($P < 0.01$). Degradability of NDF was greatest ($P < 0.01$) for DGS (67.4%) and was similar ($P = 0.48$) for WMCSM and CSM (54.5% and 57.0%, respectively). The lowest degradability of NDF was calculated for ECSM (29.3%; $P < 0.01$), attributed to a high lignin value (13.3%, DM). Degradability of DM was greatest ($P < 0.01$) for CSM and WMCSM (63.7 and 59.4%, respectively) and lowest ($P < 0.01$) for ECSM (36.5%) and ECSML (40.6%). Ruminal N degradation

characteristics of ECSM were similar to more traditional supplements containing CSM and WMCSM. The RDP for ECSML and DGS N was low compared to other feedstuffs, indicating these feeds may need to be blended with other ingredients containing greater concentrations of degradable N, particularly in situations where forage RDP is low.

Key Words: *in situ* disappearance kinetics, distiller's grains, extruded cottonseed meal

INTRODUCTION

Recent expansion of the biofuels industry has increased the quantity and accessibility of byproduct feedstuffs. Presently, large quantities of dried distiller's grains with solubles (**DGS;** 33% CP and 10% fat), a byproduct of corn-based ethanol production are available for beef cattle producers for use in a wide variety of production scenarios. In addition, the production of cottonseed oil for use as a biofuel feedstock has increased. Some modern processing plants have adapted mechanical extracting techniques to remove oil from whole cottonseed. Byproducts from this processing technique include: delinted, extruded-expelled cottonseed (**ECSM;** 33% CP and 6.7% fat; DM basis) or extruded-expelled cottonseed meal with linters (**ECSML;** 25% CP and 10.1% fat).

It is widely accepted that supplementing relatively small quantities of rumen degradable protein **(RDP)** is an effective method to increase forage intake and utilization and to maintain BW and condition when forage quality is low (McCollum and Galyean, 1985; DelCurto et al., 1990a; DelCurto et al., 1990b; Marston et al., 1995; Banta et al., 2006; Steele et al., 2007). Cottonseed meal and wheat middlings **(WM)** are commonly supplemented individually or in combination as the primary ingredients in commercial feed formulas throughout the Southern Great Plains. Limited evidence suggests that ECSM and ECSML could be similarly used to supply RDP to forage fed cattle (Meyer et

al., 2001). Conversely, protein from DGS is moderately degradable in the rumen (Waller et al., 1980; Ham et al., 1994; MacDonald et al., 2007).

Knowledge of the relative degradation characteristics of these feeds is critical for the purpose of developing efficacious supplements for cattle fed low-quality forage. Therefore, the objectives of this study were to characterize the N, NDF and DM *in situ* degradation kinetics of commonly used protein sources alongside byproduct feedstuffs derived from the biofuels industry.

MATERIALS AND METHODS

Production of Byproduct Feedstuffs

The ECSM used in this study was produced at Hollybrook Cottonseed Processing in Lake Providence, LA. Whole, raw cottonseed was first mechanically delinted and then passed through the extruder (Insta-Pro, Des Moines, IA) for approximately 30 s, reaching a temperature of 121°C. After exiting the extruder, cottonseed meal was pressed (Insta-Pro) for approximately 30 s and meal temperature upon exiting the press was approximately 104°C. Finally, the meal was ground in a hammer mill to decrease particle size and improve uniformity. Cooling of the meal was achieved by blowing air across the conveyer at room temperature as the meal was transported to storage.

The ECSML used in this study was produced at Motley Mill in Roaring Springs, TX. Whole, raw cottonseed was first extruded (Insta-Pro), reaching a temperature of 121°C and temperature upon exiting the press was approximately 104°C. Cooling of ECSML was by air flow and transport to storage room.

The corn dried distiller's grains with solubles were produced at East Kansas Agri-Energy in Garnett, KS with 100% of solubles added back to the dried distiller's grain. A detailed description of DGS production is provided by Davis (2001).

In situ Experimental Procedures

Animals. This experiment was conducted at the Nutrition and Physiology Barn located on campus at Oklahoma State University in accordance with an approved Oklahoma State University Animal Care and Use Committee protocol. Eight ruminally cannulated crossbred steers (BW = 753 ± 48 kg) were used to evaluate *in situ* degradation properties of supplemental feedstuffs. Steers consumed chopped prairie hay (5 cm; 4.8% CP, 69% NDF; DM basis) *ad libitum* and were individually supplemented once daily with 0.38 kg/100 kg BW of a 76% WM and 18% solvent-extracted cottonseed meal-based supplement (**WMCSM**) to meet the energy requirements for maintenance and degradable intake protein (NRC, 1996). Composition of the experimental dietary components is provided in Table 2. Steers had continuous access to fresh water. Steers were fed once daily at 0800, and were adapted to this diet for 10 d prior to the initiation of the *in situ* experiment.

Feedstuffs. The *in situ* procedures used in this experiment were adapted from Vanzant et al. (1998). Dacron bags (Ankom Technology, Macedon, NY; 10 x 20 cm, 53 ± 15 µm pore size) were labeled with a waterproof permanent marker and bag weight was recorded. All samples were ground in a Wiley Mill (Model-4, Thomas Scientific, Sweedesboro, NJ) to pass a 2-mm screen before being weighed into dacron bags (Ankom Technology). Five grams (as-fed) of WMCSM, solvent-extracted cottonseed meal **(CSM)**, DGS, ECSM and ECSML were weighed in duplicate into dacron bags and were heat sealed.

Prior to ruminal insertion, bags were soaked in tepid water (39°C) for 20 min to remove water soluble fractions and reduce wetting lag time. Following the wetting procedure, all bags (except 0 h) were inserted into the ventral rumen under the ruminal mat in a mesh laundry bag in reverse order. Across the 96 hr incubation period, bags were inserted at 1900 on d 1; 1900 on d 2; 1900 on d 3; 0700 and 1900 on d 4; and 0300, 0700, 1100, 1300, 1500, 1700 on d 5. These times of insertion correspond to incubation times of 96, 72, 46, 36, 24, 16, 12, 8, 6, 4, and 2 h, respectively. After removal from the rumen, bags were rinsed with 39°C water to remove particles adhering to the outside of the bags and the 0-hr sample bags were rinsed immediately after soaking in tepid water. All bags were then washed in a washing machine on the delicate setting for a 1-min rinse and a 2-min spin cycle and this sequence was repeated 10 times with maximum load of 100 bags. Following rinsing, bags were oven dried at 50°C for 72 h. Dried sample bags were allowed to equilibrate with atmospheric conditions for 60 min at room temperature prior to further analysis. Duplicate feed residue samples from each incubation time were composited within individual steer and sub-samples from each composite were analyzed for DM after drying samples at 100°C for 24 h.

Feed samples and feed residue samples were analyzed for N content using a Leco FP-2000 N Analyzer (Leco Corporation, St. Joseph, MI) and NDF content using an ANKOM Fiber Analyzer (ANKOM Technology). Feed sample ADF content was determined using an ANKOM Fiber Analyzer (ANKOM Technology) and feed sample lignin concentration was determined by digesting ADF residue in 72% sulfuric acid for 3 h (AOAC, 1996). Ether extraction (AOAC, 1996) was used to determine crude fat concentration of feed samples. Nonfiber carbohydrate (NFC) concentration was determined by summing DM concentrations

of CP-free NDF, CP, EE and ash, and then subtracting from 100 (NRC, 2001). Correction for microbial contamination of feed residue samples was performed using the procedures described by Mass et al. (1999). Briefly, Mass et al. (1999) indicated that rinsing with NDF solution removed potential N associated with the microbial population. To make this correction, samples were rinsed following the previously described NDF procedure prior to analysis for N using the Leco FP-2000 N Analyzer (Leco Corporation). Nutrient composition of *in situ* feedstuffs is provided in Table 1.

Degradation Kinetics. Total N, NDF, and DM residuals were divided into three fractions according to ruminal degradation susceptibility. The A fraction was equal to the immediately soluble portion, the portion that was washed out at 0 h; the B fraction was comprised of residuals that were degraded at a measurable rate; and the C fraction was the fraction that was still remaining after the 96 h incubation period and was considered to be undegradable. The B fraction was calculated as B = (100% - A - C). Data were fitted to the model described by Mathers and Miller (1981) where extent of rumen degradation was calculated by the following equation:

$$\text{Extent} = \{B[K_d / K_d + K_p]\} + A$$

where K_p is the fractional passage rate (calculated experimentally), and K_d is the slope of the regression of the natural logarithm of the percentage of the chemical component remaining in the rumen versus incubation time.

Passage Rate. Passage rate (K_p) was determined by procedures described by Coblentz et al. (2002). Ruminal contents from four of the eight steers that were used in the *in*

situ study were manually evacuated 2 d following the *in situ* experiment. Ruminal evacuations were performed before feeding (0 h) and 4 h post-feeding. At each evacuation time, total ruminal contents were weighed, mixed, sub-sampled in triplicate, and then returned to the rumen. Ruminal sub-samples were dried at 55^{o}C for 96 h. Hay and ort samples were collected throughout the study and were dried at 55^{o}C for 48 h in forced air oven. All dried samples were ground through a Wiley Mill (Thomas Scientific) to pass through a 1-mm screen. Concentration of acid detergent insoluble ash **(ADIA)** in prairie hay, supplement, orts, and ruminal contents were determined by ashing ADF residues in a muffle furnace at 500^{o}C for 8 h (Van Soest et al., 1991). Fractional passage rate of ADIA (K_p) was determined by dividing the mean ADIA intake (grams per hour) by the mean (from the 0- and 4-h ruminal evacuations) ruminal mass of ADIA (Waldo et al., 1972). The hourly intake of ADIA for each steer was calculated by dividing total daily intake of ADIA by 24 h. Our calculations yielded a mean passage rate of 0.025 ± 0.0055 h^{-1} from four steers.

Statistical Analyses

Means for feedstuff in situ degradation characteristics were analyzed using GLM procedures of SAS (SAS Inst. Inc., Cary, NC) for a randomized complete block design with steers representing the blocking term and feedstuff as the independent treatment variable. When the *P*-value for the F-statistic was ≤ 0.05, least squares means were separated using the LSD procedure of SAS (α = 0.05).

RESULTS AND DISCUSSION

Nitrogen Disappearance

Data for N disappearance are presented in Table 3. Estimated ruminal N degradability of CSM was similar to WMCSM; however, the concentration of N was

partitioned differently among measured fractions. Although residual N in the C fraction was similar among WMCSM and CSM ($P = 0.82$), the A fraction of CSM was lower than that of WMCSM ($P < 0.01$). However, the B fraction of CSM had the most rapid rate of degradation among all feeds tested ($P < 0.01$). Even though we did not evaluate WM alone, these data suggest that WM may have a greater concentration of A fraction N and slightly slower rate of B fraction N degradation relative to CSM. This was demonstrated by Swanek et al. (2001) who evaluated WM and CSM separately and reported a greater amount of A fraction N for WM versus CSM and indicated that rate of B fraction degradation was slower for WM compared to CSM.

When steers were fed a high concentrate diet and particulate passage rate was estimated at 0.05 h^{-1}, Swanek et al. (2001) reported a lower RDP value for CSM (66.6%) than was observed in the present study (78.2%). Similarly, NRC (1996) reports RDP of CSM to be 57% and NRC (2001) reports RDP of CSM to be 52.1% when forage accounts for 50% of DMI. Rate of passage was slower in the present study where steers were fed low-quality prairie hay and this likely increased the extent of ruminal N degradation of CSM compared to other published values.

It is recognized that the rate of passage of the concentrate portion of our diet (approximately 20% of DMI) may have differed substantially from the fractional passage rate measured for the total diet. Therefore, we used the equation provided by NRC (2001) to estimate the passage rate of the concentrate portion alone:

$$K_p = 2.904 + 1.375X_1 - 0.020X_2$$

where K_p is the fractional rate of passage of concentrate particles from the rumen, X_1 is DMI expressed as % of BW, and X_2 is concentrate expressed as percent of diet DM. The predicted fractional passage rate was 0.05 h^{-1}, resulting in a calculated RDP estimate of 64.9% for CSM. Therefore, this 2.5 percentage unit adjustment in passage rate resulted in a 13.3 percentage unit change in calculated RDP. Forage quality in our experiment was likely lower than that used in experiments used to develop the NRC (2001) equations, and therefore, actual concentrate fractional passage rate in our study may have been intermediate to the experimentally measured value (0.025 h^{-1}) and that calculated by the previously described equation, 0.05 h^{-1}. Nevertheless, it appears that NRC (1996, 2001) tabular values underestimate the rumen degradability of CSM protein when used as a supplement to low-quality forage diets.

Extruded, expelled cottonseed meal N was highly degradable predominantly due to the high percentage of A fraction N and moderate rate of B fraction N degradation. Meyer et al. (2001) evaluated the *in situ* degradation characteristics of extruded cottonseed meal (26% CP, 55% NDF and 9% ether extract; DM basis) fed to Holstein steers in a total mixed ration and reported an RDP of 79% when passage rate was estimated at 0.05 h^{-1}. Similarly, when a fractional passage rate of 0.05 h^{-1} was applied to our data, RDP of ECSM was estimated at 76.1%. These N degradation properties indicate ECSM can be substituted for CSM and (or) WM to meet the requirements for degradable intake protein of beef cows when forage N is limited. When beef cows consuming low-quality hay were supplemented with equal amounts of CP from ECSM, WMCSM, or CSM, change in cow BW and BCS was similar among the three experimental supplements (Winterholler et al., 2008). These results indicate that RDP of

ECSM was similar to that of the traditional feedstuffs (WMCSM and CSM) and fulfilled the RDP requirements of the cow, or that the extent of N recycling was great enough to overcome a deficiency in RDP (Krehbiel and Ferrell, 1999).

The N degradation kinetics of DGS most closely followed ECSML as RDP was relatively low for DGS and ECSML although N components were different. Compared to other feedstuffs evaluated, N in the A fraction of ECSML was moderate to low but was greater ($P < 0.01$) for DGS. Additionally, B fraction N was greater for ECSML ($P < 0.01$) than DGS, but rate of B fraction N degradation was similar ($P = 0.38$) and was the slowest ($P < 0.01$) among all feedstuffs. Also, DGS had the greatest percentage of N remaining in the C fraction ($P < 0.01$). The observed RDP for DGS (50.7%) was in agreement with Firkins et al. (1984), Ham et al. (1980), and MacDonald et al. (2007) who reported RDP values of 54%, 47%, and 49%, respectively for DGS. Applying a fractional passage rate of 0.05 h^{-1} to our data resulted in a calculated RDP for DGS of 40.9%. Aside from the potential effects of processing to change the physical properties of DGS, the low RDP of DGS is highly attributable to resistance of the major corn protein source, zein, to rumen degradation (Little et al., 1968). To our knowledge, there is no literature available to compare our *in situ* values to for ECSML. However, chemical analysis of a similar product obtained from The Center for Feed Industry Research and Education; Lubbock, TX indicated a rumen undegradable protein value of 55% or 45% RDP (DM basis), which is similar to our RDP calculation.

Disappearance of NDF and Calculations for TDN

Data for NDF disappearance are presented in Table 4. The NDF degradation properties of WMCSM were similar to CSM as over half of the total NDF disappearance

was represented by the A fraction and NDF degradability among these two feeds was similar ($P = 0.48$) and was intermediate relative to the other feedstuffs evaluated. The concentration of NDF in the B fraction was similar for WMCSM and CSM although B fraction rate of degradation was faster for CSM ($P < 0.01$).

Degradability of NDF was the highest ($P < 0.01$) for DGS, due partially to the most rapidly degraded B fraction ($P < 0.01$). The A fraction of DGS was similar ($P = 0.11$) to CSM, and was also similar ($P = 0.14$) to ECSML. For B fraction NDF, DGS was similar to WMCSM ($P = 0.12$). Like our findings, Varga and Hoover (1983) reported extent of NDF degradation of DGS was 76.6%.

Degradation properties of NDF for ECSML most closely followed WMCSM although NDF degradability was greater ($P < 0.01$) for WMCSM compared to ECSML. This can be partially explained by NDF remaining in the C fraction as it tended ($P = 0.06$; SEM = 0.02) to be greater for ECSML (32.2%) compared to WMCSM (26%). These values indicate that the degradation properties of the fiber portion of the linters associated with ECSML are highly degradable and similar to rapidly degraded fiber portions of WM. Also, it is apparent that, when compared to the fiber portion of the seed coat, the linters are more highly degradable, as evidence by a greater degradability of NDF for ECSML compared to ECSM.

Among the feeds tested, the largest C fraction of NDF was present in ECSM ($P < 0.01$), which resulted in the lowest degradability of NDF ($P < 0.01$). This low value is likely a reflection of the high lignin concentration of the sample (13.3%, DM).

As reported in Table 1, TDN values of each of these feeds were calculated using our values for NDF degradation, chemical compositional data, and the summative

equations of the NRC (2001). The published value for CSM from NRC (1996) is 75% and similar to our calculated value, whereas NRC (2001) reports a TDN value of 66.4%. The TDN of DGS was also similar to the NRC (1996) value of 88%, but greater than the NRC (2001) value of 79.5%. Variability in TDN within these common feedstuffs could be due to a number of factors, including but not limited to, variation in chemical composition among feed samples, variation in the basal diet for which a feed is being evaluated (Swanek et al., 2001), methods used to estimate TDN (Weiss, 1998), variation among laboratories and for byproduct feedstuffs, variability among and within processing plants (Spiehs et al., 2002).

We are not aware of other published values for ECSM and ECSML TDN. An important implication from these calculations was that TDN of ECSM was low due to a high concentration of indigestible fiber and low concentration of NFC. When cattle are fed forage low in CP and TDN, ECSM should be an effective supplemental protein source although its direct contribution to the energy status of the animal will be minimal.

Disappearance of DM

Data for DM disappearance are presented in Table 5. Degradability of DM was similar ($P = 0.11$) for WMCSM and CSM and greater ($P < 0.01$) than the other feeds tested. A greater percentage of DM was found in the A fraction of WMCSM than CSM ($P < 0.01$). Perhaps this is a reflection of the relatively high concentration of NFC in WMCSM, which is assigned a true digestibility value of 98% in the summative equation of the NRC, 2001. However, the greater concentration of A fraction DM in WMCSM was offset by lower concentration of B fraction DM ($P < 0.01$) which was degraded at a slower rate compared to CSM ($P < 0.01$). The unavailable C fraction was similar ($P =$

0.27) among WMCSM, CSM and DGS. *In situ* ruminal DM degradability of DGS was lower than WMCSM and CSM ($P < 0.01$) but greater than ECSM and ECSML ($P < 0.01$). Partitioning of DM in the B fraction of DGS was the greatest among feedstuffs ($P < 0.01$). Rate of degradation of the B fraction of DGS was slower than CSM, but more rapid than the other feeds tested ($P < 0.01$). Perhaps DGS NFC is moderate to low in ruminal degradability considering the moderate DM degradability and relatively high NDF degradability reported here.

Degradability of DM was the lowest ($P < 0.01$) and similar for ECSM and ECSML although the DM degradation characteristics of these feeds were different. Extruded, expelled cottonseed meal had the lowest ($P < 0.01$) concentration of A fraction DM of all feeds tested. It is interesting to note that most of the A fraction DM would have been represented by rapidly degradable CP in ECSM and rapidly degradable NDF in ECSML. There was more DM in the B fraction of ECSM versus ECSML ($P < 0.01$). Rate of degradation of the B fraction was similar among the two feeds ($P = 0.14$). Also, C fraction DM was similar ($P = 0.96$) for ECSM and ECSML, which was greater ($P < 0.01$) than any of the other experimental feedstuffs. Although *in situ* DM disappearance was similar for ECSM and ECSML, TDN was greater for ECSML. This difference is largely attributed to the more highly degradable fiber portion of ECSML.

In summary, N degradation characteristics of ECSM indicate it has value as a complement for low-quality forage as it is a rich source of RDP, but is moderate to low in energy contribution. Low-quality forage supplementation with ECSML and DGS may result in deficiencies in degradable intake protein as RDP was lower for these feeds compared to traditionally used protein supplements. Depending on the potential amount

of N recycling by the ruminant, these feeds may need to be blended with other products high in RDP to meet the RDP requirements of cattle consuming low-quality forage.

Table 1. Nutrient composition of *in situ* feedstuffs

	Feedstuff[1]				
Item	WMCSM	CSM	ECSM	ECSML	DGS
DM, %	92.1	89.5	93.6	93.8	89.3
	----------% of DM ----------				
CP, %	23.3	43.1	32.9	24.5	33.2
NDICP[2]	2.6	5.9	4.0	4.9	12.8
ADF, %	16.2	19.6	41.8	39.3	23.3
NDF, %	39.9	43.9	55.0	59.4	36.5
Lignin, %	4.1	4.3	13.3	8.0	7.3
NFC,[3] %	28.2	13.9	4.1	5.4	28.7
Crude fat, %	3.9	2.5	6.7	10.1	10.3
TDN,[4] %	65.0	73.9	54.4	62.3	87.1

[1]WMCSM = wheat middling and solvent-extracted cottonseed meal, CSM = solvent-extracted cottonseed meal, DGS = dried distillers grains with solubles, ECSM = extruded, expelled cottonseed meal based supplement that has been delinted, ECSML = extruded, expelled cottonseed meal based supplement with linters.
[2]Neutral detergent insoluble crude protein.
[3]NFC = Non-fiber carbohydrate [100-((NDF-NDICP) +CP +EE+ash)].
[4]Calculated using measured chemical composition of feedstuff and the summative equations from NRC (2001). Adjustments were included for *in situ* NDF digestibility and partial fatty acid digestibility coefficient determined in previous experiment.

Table 2. Chemical composition of dietary ingredients fed to steers during the *in situ* experiment

	Feed[1]	
Item, DM basis	Prairie Hay	Supplement[2]
CP, %	4.8	24.5
ADF, %	43.7	12.9
NDF, %	68.8	30.6
Crude fat, %	2.2	4.5
TDN, %	56.0	72.0

[1]Prairie hay was provided for *ad libitum* intake.
[2]Supplement comprised of wheat middlings and cottonseed meal; steers fed 2.7 kg/d.

Table 3. *In situ* ruminal N degradation characteristics of byproduct feedstuffs fed to beef cattle consuming low-quality forage

	Supplement[1]					
Item	WMCSM	CSM	DGS	ECSM	ECSML	SEM
A fraction,[2] %	19.6[b]	5.5[d]	15.0[c]	41.0[a]	6.2[d]	0.02
B fraction,[2] %	79.4[b]	94.0[a]	71.0[c]	56.6[d]	88.9[a]	0.02
C fraction,[2] %	1.0[b,c]	0.50[b]	14.0[a]	2.4[b,c]	4.9[c]	0.02
Rate of B degradation, % h^{-1}	4.02[a]	6.35[b]	2.27[c]	3.67[a]	2.54[c]	0.22
RDP, %[3]	73.5[a]	78.2[a,c]	50.7[b]	83.8[c]	50.9[b]	0.02

[a,b,c,d] Means within a row with different superscripts differ ($P \leq 0.05$).

[1]WMCSM = wheat middling and solvent-extracted cottonseed meal, CSM = solvent-extracted cottonseed meal, DGS = dried distillers grains with solubles, ECSM = extruded, expelled cottonseed meal based supplement that has been delinted, ECSML = extruded, expelled cottonseed meal based supplement with linters.

[2]A = Immediately soluble fraction, B = degradable fraction at a measurable rate, C = undegraded fraction; expressed as percentage of total N.

[3]Rumen degradable protein, calculated as $\{B[K_d/ K_d + K_p]\} + A$ (Mathers and Miller, 1981). Ruminal particulate passage rate, K_p, was 2.5%/hr, determined experimentally.

Table 4. *In situ* ruminal NDF degradation characteristics of byproduct feedstuffs fed to beef cattle consuming low-quality forage

	Supplement[1]					
Item	WMCSM	CSM	DGS	ECSM	ECSML	SEM
A fraction,[2] %	30.0[b]	41.6[a]	35.7[a,b]	17.6[c]	27.6[b]	0.01
B fraction,[2] %	44.0[b,c]	30.8[c]	54.4[a,b]	41.0[c]	40.7[c]	0.02
C fraction,[2] %	26.0[b]	28.0[b]	10.3[c]	41.8[a]	32.2[b]	0.02
Rate of B degradation, % h^{-1}	0.72[a]	1.0[b]	2.39[c]	0.90[a,b]	0.94[a,b]	0.08
NDF degradability,[3] %	54.5[b]	57.0[b]	67.4[a]	29.3[d]	43.1[c]	0.02

[a,b,c,d,e] Means within a row with different superscripts differ ($P \leq 0.05$).

[1]WMCSM = wheat middling and solvent-extracted cottonseed meal, CSM = solvent-extracted cottonseed meal, DGS = dried distillers grains with solubles, ECSM = extruded, expelled cottonseed meal based supplement that has been delinted, ECSML = extruded, expelled cottonseed meal based supplement with linters.

[2]A = Immediately soluble fraction, B = degradable fraction at a measurable rate, C = undegraded fraction; expressed as percentage of total NDF.

[3]Degradability calculated as $\{B[K_d/ K_d + K_p]\} + A$ (Mathers and Miller, 1981). Ruminal particulate passage rate, K_p, was 2.5%/hr, determined experimentally.

Table 5. *In situ* ruminal DM degradation characteristics of byproduct feedstuffs fed to beef cattle consuming low-quality forage

	Supplement[1]					
Item	WMCSM	CSM	DGS	ECSM	ECSML	SEM
A fraction,[2] %	30.7[a]	24.1[b]	17.0[c]	13.3[e]	18.9[d]	0.0002
B fraction,[2] %	57.3[c]	66.5[b]	72.0[a]	64.3[b]	58.5[c]	0.02
C fraction,[2] %	12.0[b]	9.4[b]	11.0[b]	22.4[a]	22.6[a]	0.02
Rate of B degradation, % h^{-1}	1.27[b]	2.79[a]	2.06[c]	1.33[b]	1.11[b]	0.10
Rumen degradable DM,[3] %	59.4[a]	63.7[a]	53.3[b]	36.5[c]	40.6[c]	0.02

[a,b,c,d,e] Means within a row with different superscripts differ ($P \leq 0.05$).

[1]WMCSM = wheat middling and solvent-extracted cottonseed meal, CSM = solvent-extracted cottonseed meal, DGS = dried distillers grains with solubles, ECSM = extruded, expelled cottonseed meal based supplement that has been delinted, ECSML = extruded, expelled cottonseed meal based supplement with linters.

[2]A = Immediately soluble fraction, B = degradable fraction at a measurable rate, C = undegraded fraction; expressed as percentage of total DM.

[3]Degradability calculated as $\{B[K_d/ K_d + K_p]\} + A$ (Mathers and Miller, 1981). Ruminal particulate passage rate, K_p, was 2.5%/hr, determined experimentally.

LITERATURE CITED

AOAC. 1996. Official Methods of Analysis. 14th ed. Assoc. Offic. Anal. Chem., Arlington, VA.

Banta, J. P., D. L. Lalman, F. N. Owens, C. R. Krehbiel, and R. P. Wettemann. 2006. Effects of interval-feeding whole sunflower seeds during mid to late gestation on Performance of beef cows and their progeny. J. Anim. Sci. 84:2410-2417.

Coblentz, W. K., K. P. Coffey, J. E. Turner, D. A. Scarbrough, J. V. Skinner, D. W. Kellogg, and J. B. Humphry. 2002. Comparisons of in situ dry matter disappearance kinetics of wheat forages harvested by various techniques and evaluated in confined and grazing steers. J. Dairy Sci. 85:854-865.

Davis, K. 2001. Corn milling, processing and generation of co-products. In Proc. Minnesota Nutrition Conference. http://www.distillersgrains.org/files/grains/K.Davis--Dry&WetMillProcessing.pdf Accessed August 13, 2008.

DelCurto, T., R. C. Cochran, D. L. Harmon, A. A. Beharka, K. A. Jacques, G. Towne, and E. S. Vanzant. 1990a. 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, L. R. Corah, A. A. Beharka, E. S. Vanzant, and D. E. Johnson. 1990b. 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.

Firkins, J. L., L. L. Berger, G. C. Fahey, Jr., and N. R. Merchen. 1984. Ruminal nitrogen degradability and escape of wet and dry distillers grains and wet and dry corn gluten feeds. J. Dairy Sci. 67:1936-1944.

Ham, G. A., R. A. Stock, T. J. Klopfenstein, E. M . Larson, D. H. Shain, and R. P. Huffan. 1994. Wet corn distillers byproducts compared with dried corn distillers grains with solubles as a source of protein and energy for ruminants. J. Anim. Sci. 72:3246-3257.

Krehbiel, C. R., and C. L. Ferrell. 1999. Effects of increasing ruminally degraded nitrogen and abomasal casein infusion on net portal flux of nutrients in yearling heifers consuming a high-grain diet. J. Anim. Sci. 77:1295-1305.

Little, C. O., G. E. Mitchell, and G. D. Potter. 1968. Nitrogen in the abomasum of wethers fed different protein sources. J. Anim. Sci. 27:1722-1726.

MacDonald, J. C., T. J. Klopfenstein, G. E. Erickson, and W. A. Griffin. 2007. Effects of dried distillers grains and equivalent undegradable intake protein or ether extract on performance and forage intake of heifers grazing smooth bromegrass pastures. J. Anim. Sci. 85:2614-2624.

Marston, T. T., K. S. Lusby, R. P. Wettemann, and H. T. Purvis. 1995. Effects of feeding energy or protein supplements before or after calving on performance of spring-calving cows grazing native range. J. Anim. Sci. 73:657-664.

Mass, R. A., G. P. Lardy, R. J. Grant, and T. J. Klopfenstein. 1999. In situ neutral detergent insoluble nitrogen as a method for measuring forage protein degradability. J. Anim. Sci. 77:1565-1571.

Mathers, J. C., and E. L. Miller. 1981. Quantitative studies of food protein degradation

and the energetic efficiency of microbial protein synthesis in the rumen of sheep given chopped lucerne and rolled barley. Br. J. Nutr. 45:587-604.

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.

Meyer, M. J., J. E. Shirley, E. C. Titgemeyer, A. F. Park, and M. J. VanBaale. 2001. Effect of mechanical processing and fat removal on the nutritive value of cottonseed for lactating dairy cows. J. Dairy Sci. 84:2503-2514.

NRC. 1996. Nutrient Requirements of Beef Cattle. 7th rev. ed. Natl. Acad. Press, Washington, DC.

NRC. 2001. Nutrient Requirements of Dairy Cattle. 7th rev. ed. Natl. Acad. Press, Washington, DC.

Steele, J. D., J. P. Banta, R. P. Wettemann. C. R. Krehbiel, and D. L. Lalman. 2007. Drought-stressed soybean supplementation for beef cows. Prof. Anim. Sci. 23:358-365.

Spiehs, M. J., M. H. Whitney, and G. C. Shurson. 2002. Nutrient database for distiller's dried grains with solubles produced from new ethanol plants in Minnesota and South Dakota. J. Anim. Sci. 80:2639-2645.

Swanek, S. S., C. R. Krehbiel, D. R. Gill, and B. A. Gardner. 2001. Extent and rate of in situ ruminal degradation of protein byproduct feeds on a high concentrate diet. http://www.ansi.okstate.edu/resesarch/2001rr/31/31.htm Accessed Sept. 14, 2006.

Vanzant, E. S., R. C. Cochran, and E. C. Titgemeyer. 1998. Standardization of in situ

techniques for ruminant feedstuff evaluation. J. Anim. Sci. 76:2717-2729.

Van Soest, P. J., J. B. Robertson, and B. A. Lewis. 1991. Symposium: carbohydrate methodology, metabolism, and nutritional implications in dairy cattle. J. Dairy Sci. 74:3583-3597.

Varga, G.A., and W. H. Hoover, 1983. Rate and extent of neutral detergent fiber degradation of feedstuffs in situ. J. Dairy Sci. 66:2109-2115.

Waldo, D. R., L. W. Smith, and E. L. Cox. 1972. Model of cellulose disappearance from the rumen. J. Dairy Sci. 55:125-129.

Waller, J., T. Klopfenstein and M. Poos. 1980. Distillers feeds as protein sources for growing ruminants. J. Anim. Sci. 51:1154-1167.

Weiss, W. P. 1998. Estimating the available energy content of feeds for dairy cattle. J. Dairy Sci. 81:830-839.

Winterholler, S. J., M. D. Hudson, C. L. Goad and D. L. Lalman. 2008. An evaluation of extruded-expelled cottonseed meal as a protein supplement to beef cows consuming low-quality forage. Proc. West. Sect. Amer. Soc. Anim. Sci. 59:7-10.

CHAPTER IV

SUPPLEMENTAL ENERGY AND EXTRUDED-EXPELLED COTTONSEED MEAL AS A SUPPLEMENTAL PROTEIN SOURCE FOR BEEF COWS CONSUMING LOW-QUALITY FORAGE

ABSTRACT: Three experiments were conducted to evaluate the efficacy of supplemental energy and extruded-expelled cottonseed meal (ECSM; 30.6% CP; 44% NDF, 10.2% fat; DM basis) as a protein supplement (SUP) to spring-calving beef cows (n = 96; 535 kg initial BW; 5.4 initial BCS) consuming low-quality forage during late gestation and early lactation. Supplementation of ECSM was compared to two traditional cottonseed meal-based SUP. For all experiments, SUP provided equal CP. On a DM basis, SUP included: 1) a blend of 76% wheat middlings and 18% solvent-extracted cottonseed meal (WMCSM); 2) solvent-extracted cottonseed meal (CSM); and 3) delinted, extruded-expelled cottonseed meal (ECSM). In Exp. 1, cows were individually fed SUP 3 d/wk until calving and 4 d/wk during lactation; total SUP period was 95-d. Tall-grass prairie hay (4.4% CP; 74% NDF; DM basis) was provided *ad libitum* during the SUP period. Change in cow BW during gestation ($P = 0.23$), over the SUP period ($P = 0.27$), and over the 301-d experiment ($P = 0.56$) were similar. Change in BCS was similar during gestation ($P = 0.78$), over the SUP period ($P = 0.95$) and over the 301-d experiment ($P = 0.37$). Calf birth weight ($P = 0.21$) and BW at weaning ($P = 0.76$) were not different. Percentage of cows exhibiting luteal activity at the beginning of breeding season ($P = 0.59$), AI conception rate ($P = 0.71$), and pregnancy rate at weaning ($P = 0.88$) were not different. In Exp. 2, 18 cows in early lactation from Exp. 1 were used to determine the effect of SUP on hay intake and digestion. Hay intake tended ($P = 0.10$) to be greater for CSM than ECSM. Intake of OM and DM was greater for WMCSM ($P \leq 0.02$) compared to CSM and ECSM; likewise, digested DMI and OM intake was greater ($P \leq 0.02$) for WMCSM. Apparent total tract digestibility of crude fat was greater for

ECSM than CSM ($P = 0.03$). In Exp. 3, cows (n = 20/trt) of similar d postpartum were machine-milked to determine SUP effect on milk production and composition. Butterfat, protein, lactose, milk urea N were not different ($P > 0.10$). Similarly, 24-h milk production was not different ($P = 0.25$). Neither greater energy intake of cows consuming WMCSM nor greater fat intake of cows consuming ECSM influenced cow performance measures or calf weaning weight. Cow response to SUP with ECSM compared to traditional cottonseed meal-based SUP indicates that ECSM is a viable source of supplemental protein for beef cows consuming low-quality forage.

Key words: beef cows, extruded expelled cottonseed meal, supplementation, energy

INTRODUCTION

It has been well documented that in the Southern Great Plains, supplementation of protein to spring-calving cowherds consuming low-quality forage is necessary during the winter feeding period to maintain cow BW and BCS (DelCurto et al., 1990b; Vanzant et al., 1991; Steele et al., 2007). Much of this response to CP supplementation is attributed to supplying rumen degradable protein (**RDP**) when cattle consume forage with RDP < 10% of total digestible organic matter intake (Heldt et al., 1999; Mathis et al., 2000). Providing additional supplemental energy, beyond that associated with the supplemental RDP, is costly and may result in only marginal improvements in cow BCS change, calf weaning weight and pregnancy rate (Lusby et al., 1991; Marston et al., 1995b).

Solvent extracted cottonseed meal has been a standard source of RDP for cattle consuming low-quality forage for many years. In response to increasing demand for cottonseed oil as feedstock for biofuel production, some cottonseed oil manufacturing plants have implemented mechanical techniques to extract oil from whole cottonseed. One byproduct of this processing method is extruded-expelled cottonseed meal that has been delinted (**ECSM**). Extruded-expelled cottonseed meal contains a relatively high concentration of CP (30.6%; DM basis) and therefore could be used as a supplemental protein source for beef cattle consuming forage with inadequate CP. However, processing techniques that involve elevated feed temperature may alter rumen degradability of feed components. For example, heat treatment of whole cottonseed reduces rumen degradability of protein and increases protein flow to the small intestine (Plegge et al., 1982; Pena et al., 1986). Cottonseed meal reaches temperatures of around 120°C during

the extrusion process; therefore extrusion may compromise cottonseed meal's effectiveness as a source of RDP. However, in the context of a lactating dairy ration, previous work with ECSM suggested that ruminal degradation and DMI are not affected by the extrusion process (Meyer et al., 2001).

Another potential concern with using ECSM as a supplemental protein source is the relatively high fat concentration (10.2%; DM basis). Previous work at our experiment station has shown that interval feeding of high-fat protein supplements (5.7% or 3.8% diet DM dietary fat) to cows consuming low-quality forage resulted in a reduction in cow performance during the supplementation period (Banta et al., 2006; Steele et al., 2007). Whereas others have reported no depression in cow performance due to supplemental fat under similar conditions (Alexander et al., 2002; Bottger et al., 2002; Martin et al., 2005). We are aware of no previous literature that has evaluated the use of ECSM as a protein and energy source for beef cows consuming low-quality forage.

The objectives of these experiments were to determine the effects of feeding supplemental energy and replacing CSM with ECSM on beef cow performance, intake, digestion and milk yield and composition.

MATERIALS AND METHODS

Production of Delinted, Extruded-Expelled Cottonseed Meal

The delinted, extruded-expelled cottonseed meal used in this study was produced at Hollybrook Cottonseed Processing in Lake Providence, LA. Whole, raw cottonseed (3.4% N, 16.1% fat, 3.8% ash) was mechanically delinted before being passed through an extruder reaching a mean maximum temperature of 121°C for a 30 s period. After exiting the extruder, cottonseed meal was conveyed to presses where mean maximum

temperature was maintained at 104°C for an additional 30 s. Finally, the meal was ground in a hammer mill to decrease particle size and improve uniformity. The meal was cooled with forced air flow as it was conveyed to a storage room prior to shipping to the feed mill at Oklahoma State University. Concentration of free gossypol was 1.26% in whole cottonseed and 0.2% in ECSM.

Experiment 1

Animals. This experiment was conducted at the Range Cow Research Center, North Range Unit located approximately 16 km west of Stillwater, OK, in accordance with an approved Oklahoma State University Animal Care and Use Committee protocol. Spring-calving Angus and Angus x Hereford crossbred beef cows (n = 96; 535 ± 68 kg initial BW; 5.4 ± 0.68 units of initial BCS) were assigned to 1 of 3 dietary supplements in a completely randomized design. Cows were ranked by BW and BCS and randomly allocated so that BW and BCS were similar across all treatments.

Supplements (DM basis) included: 1) 2.45 kg/d during gestation and 3.92 kg/d during lactation of a blend of 76% wheat middlings and 18% solvent-extracted cottonseed meal-based supplement (**WMCSM**); 2) 1.21 kg/d during gestation and 2.03 kg/d during lactation of solvent-extracted cottonseed meal-based supplement (**CSM**); 3) 1.67 kg/d during gestation and 2.75 kg/d during lactation of a delinted, extruded-expelled cottonseed meal based supplement (**ECSM**). All supplements were fed as 0.64-cm diam. pellets and were formulated to provide similar amounts of CP (Table 1). Supplements were balanced for P, Ca and Vitamin A to meet NRC (1996) requirements. Experimental supplementation began on January 2, 2007 and terminated on April 6, 2007 which

encompassed both late gestation and early lactation (average calving d = March 22, 2007); the total supplementation period was 95-d.

A negative control was not included in this experiment as it has been well documented that when forage quality was similar to that in the present study, cows that did not receive supplemental protein during the winter months lost significant BW and BCS compared to those cows receiving supplementation (Schauer et al., 2005; Steele et al., 2007; Clanton and Zimmerman, 1970).

A barn containing 32 individual feeding stalls was used to insure that each cow received the assigned supplement and that cows did not consume more supplement than their assigned amount. Each feeding d, cows were gathered from a pasture adjacent to the feeding barn. Once cows entered the barn, they were allowed to enter a feeding stall and cows were subsequently restrained in the stalls for approximately 30 min while supplements were being fed and consumed by the cows. All supplements were thoroughly consumed throughout the duration of the supplementation period. During late gestation, cows were fed on Monday, Wednesday and Friday mornings. The amount of supplement fed on each of these 3 d was determined by calculating the amount of supplement needed per wk (daily supplement amount x 7 d) and dividing that amount by 3 (i.e., cows receiving WMCSM were fed 5.72 kg/feeding; DM basis). Once cows calved, the supplement frequency was increased to 4 times per week to meet nutrient demands for lactation. During this time, supplements were individually fed on Monday, Wednesday, Friday and Saturday mornings, which resulted in approximately a 65% increase in the amount fed daily. The amount of supplement fed on each of these 4 d was

determined by calculating the amount of supplement needed per wk (daily supplement amount x 7 d) and dividing that amount by 4.

Individual cow BW and BCS were determined at the start of the supplementation period (1/2/07), after the first 30-d of supplementation (2/2/07), before any cows had calved (2/20/07), within 1 wk of calving, at trial termination (4/07/07), prior to breeding (5/17/07) and at weaning (10/30/07). All BW were recorded after 16-h withdrawal from feed and water. Body condition scores (scale 1 through 9; Wagner et al., 1988) were determined by the same two independent evaluators throughout the experiment.

During gestation, cows were managed as a contemporary group in a single pasture (46 hectares) with free choice access to tall-grass prairie hay (4.5% CP, 57% TDN, 74% NDF, 2.2% crude fat; DM basis) and a mineral supplement (28.6% NaCl; 12.8% Ca; 8.5% P; 1.2% Mg; 1044 ppm Cu; 12 ppm Se; 3117 ppm Zn; DM basis). At calving, cow/calf pairs were moved to an adjacent pasture (31 hectares) where they were managed as a contemporary group. Cow/calf pairs had *ad libitum* access to the same prairie hay and mineral supplement as described previously and were provided adequate amounts of experimental supplements to meet the protein and energy requirements for lactation until green forage became available (April 7, 2007). Pastures used during the SUP phase had been previously grazed during spring and summer, and consequently in combination with the heavy stocking rate during SUP, grazed forage contributed minimally to DM intake. Diets were formulated to meet, but not to exceed rumen degradable intake protein and CP requirements (NRC, 1996).

The percentage of cows cycling at the start of the breeding season was determined by quantifying progesterone concentration (Vizcarra et al., 1997) in plasma samples

obtained via tail venipuncture 14 and 7 d prior to breeding and again on the first d of the breeding season. Immediately following blood collection, tubes were placed on ice until analyzed for plasma progesterone concentrations. Cows with one or more plasma samples containing ≥ 0.5 ng/mL progesterone were considered to have ovarian luteal activity. Cows were bred via synchronization with a timed artificial insemination protocol on May 26, and cows were exposed to bulls from June 6 through July 20 resulting in a 55-d breeding season. For estrus synchronization, an EAZI-BREED CIDR device containing 1.38 g of progesterone (Pfizer, Inc., New York, NY) was inserted into the vagina on d 0 of the breeding season and cows were given an i.m. injection of 2-mL GnRH (Cystorelin, Merial LTD, Duluth, GA). On d 7, EAZI-BREED CIDR devices were removed after 7 d. All cows received an i.m. injection of 5-mL Prostaglandin $F_{2\alpha}$ (Lutalyse, Pfizer, Inc., New York, NY) and cows were artificially inseminated approximately 48-h later. At time of artificial insemination, cows were administered an additional i.m. injection of 2-mL GnRH (Cystorelin, Merial LTD, Duluth, GA). First service conception rate was determined by transrectal ultrasonography 30-d following AI and pregnancy rate was determined by rectal palpation at weaning on October 30, 2007.

Birth weight of each calf was determined within 24-h of birth and all male calves were castrated at this time. After withdrawal from feed and water for 16-h, calf weaning BW was obtained on October 30, 2007 and reported as a 205-d weight, adjusted for sex according to the guidelines of the Beef Improvement Federation (2002).

Statistical Analysis. For all statistical analysis, cow was considered to be the experimental unit because supplements were fed individually to each cow. Continuous data were analyzed using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) and

the Satterwaite approximation for degrees of freedom. The model for cow performance included supplement as a fixed effect and cow age and d on supplementation prior to calving as covariates. When the *P*-value for the F-statistic was ≤ 0.05, least squares means were separated and reported using the LSD procedure of SAS ($\alpha = 0.05$). Data for reproductive performance were analyzed using the Glimmix procedure of SAS, assuming a binomial distribution and supplement served as a fixed effect. Least squares means are reported in all tables, except for the percentage of cows exhibiting luteal activity, pregnancy rate, and first service conception rate which are raw means.

For various reasons (calf death, n = 3; failure to calve, n = 3), data from 6 cows was removed from the experiment. No relationship was apparent between any of these factors and the composition of the experimental supplements.

Experiment 2

Animals. This experiment was conducted at the Range Cow Research Center, North Range Unit located approximately 16 km west of Stillwater, Oklahoma in accordance with an approved Oklahoma State University Animal Care and Use Committee protocol. During early lactation, 18 spring-calving beef cows were used to determine the effects of supplement composition on hay intake and apparent total tract digestibility. Based on calving date and treatment, cows were assigned to one of two collection periods in a randomized complete block design. Three cows and their calves from each treatment combination were represented during each period. Cows were given *ad libitum* access to the same prairie hay that was fed in Exp. 1 and were also kept on the same feeding regimen as Exp. 1 (Monday, Wednesday, Friday, and Saturday mornings) prior to and during Exp. 2. Cows were maintained in individual outdoor 3.7-x 9.1-m

pens, so that they would be exposed to the same environmental conditions as their herd mates in Exp. 1.

Each 12-d period consisted of 3 d of adaptation to the pens and hay feeders, and 9 d of data collection. The adaptation period was abbreviated because the cows had been previously exposed to the hay and supplement treatments throughout gestation and early lactation. Hay intake was measured from d 4 through d 10 and fecal grab samples were collected twice daily at 0800 and 1600 from d 6 through d 12 to estimate fecal output from acid detergent insoluble ash concentration. Sub-samples of supplements, hay, and orts were dried at 100ºC to determine DM. Supplement, hay, ort, and fecal samples were dried at 50ºC and ground in a Wiley mill (Model-4, Thomas Scientific, Sweedesboro, NJ) to pass a 2-mm screen before analysis. After grinding, supplement and hay samples were composited within period; ort and fecal samples were composited by cow. All composite samples were analyzed for NDF, ADF, CP, and acid detergent insoluble ash. Neutral detergent fiber and ADF content were determined using an ANKOM Fiber Analyzer (ANKOM Technology, Macedon, NY). Crude protein was determined using a Leco NS-2000 Nitrogen Analyzer (Leco Corporation, St. Joseph, MI). Acid detergent insoluble ash was determined as the residue following complete combustion of the ADF residue (Van Soest et al., 1991). Apparent total tract DM, OM, CP and crude fat digestibility as well as NDF and ADF digestibility were calculated for each cow. Additionally, digested DMI (DMI kg/100kg of BW x DM digestibility) and digested OM intake were calculated for each cow.

Statistical Analysis. Intake and digestibility measurements were analyzed as a randomized complete block design using the MIXED procedure of SAS (SAS Inst. Inc.,

Cary, NC) and the Satterwaite approximation for degrees of freedom. The model included supplement as a fixed effect and collection period as a random variable. When the *P*-value for the F-statistic was ≤ 0.05, least squares means were separated and reported using the LSD procedure of SAS (α = 0.05). One cow was removed from the first period of the digestion experiment due to illness unrelated to supplemental treatment.

Experiment 3

Animals. The objective of this experiment was to determine if winter supplemental protein source affected milk yield or milk composition. A completely randomized design was used with supplemental protein source as the main effect. The milking procedure took place over a 3-d period and included 20 cows from each treatment described in Exp. 1. The experimental methods followed for determining early lactation milk production and composition were adapted from Marston et al. (1992). Prior to milking each d, pairs were gathered at approximately 1600. The calves were then separated from their dams until 2200 when pairs were reunited and calves were allowed to nurse their dams ad libitum, but for < 45 min. Following nursing, cows and calves were separated again until milking was completed. Milking was initiated at 0700 the following morning and was completed by 1300. Cows were provided prairie hay and water free choice during this period.

Before milking, a 1.0-mL injection of oxytocin (20 USP units/mL, i.m.; Phoenix Pharmaceutical Inc., St. Joseph, MO) was administered to each cow to facilitate milk let-down. Cows were then individually milked using a portable milking machine and when milk flow ceased from all quarters, the milking apparatus was removed and each teat was

hand-stripped to ensure complete emptying of each quarter. Milk from milking machine was combined with milk from hand-stripping and weighed immediately following collection. After thorough mixing, a 50 mL sub-sample was obtained and preserved with 2-bromo-2-nitropropane-1,3-diol and shipped to the Heart of America DHIA (Manhattan, KS) for analysis of milk urea N, protein, butterfat, lactose, and solids not fat. Twenty-four hour milk production estimates were obtained by the following equation:

$$P = (MW/MIN)*1440$$

where P = 24 h milk production, MW = weight of milk obtained from milking procedure described above, MIN = minutes from calf-separation to termination of milking procedure and 1440 = minutes in 24 h period.

Statistical Analysis. Cow was considered to be the experimental unit for milk production and milk composition analysis. The model statement for milk production included supplement as a fixed effect and minutes from calf-separation to milking as a covariate. The model for milk composition included supplement as a fixed effect and d postpartum as a covariate. For analyses, when the *P*-value for the F-statistic was ≤ 0.05, least squares means were separated and reported using the LSD procedure of SAS ($\alpha = 0.05$).

RESULTS AND DISCUSSION

Experiment 1

Cow BW and BCS. Data for cow BW, BW change, BCS and BCS change are presented in Table 2. Supplement source did not influence BW, BW change, BCS, or

BCS change at any of the intervals measured. Averaged across treatments, cows lost BCS during late gestation (0.42 units BCS) and during early lactation (0.33 units BCS). However, in previous work at our experiment station, Steele et al. (2007) reported dramatic BCS loss (1.66 units of BCS) when cows did not receive a protein supplement during late gestation. Therefore, even though all treatment groups lost BW and BCS during the experimental supplementation period, we submit that ECSM was as effective in minimizing BW and BCS loss as WMCSM and CSM. As determined by a separate *in situ* analysis (Winterholler et al., 2008), the ECSM used in this study was high in RDP (84% of CP) and similar to RDP of solvent extracted CSM (78% of CP). Together, these studies indicate that ECSM has similar value as CSM when evaluated on an equal CP basis and used as a supplemental protein source for beef cows consuming low-quality forage.

It is widely accepted that protein is the first limiting nutrient for beef cows consuming low-quality forage (Kartchner, 1980; DelCurto et al., 1990a; Freeman et al., 1992; Marston et al., 1995b). However, as shown in the current and in previous experiments under similar conditions where cows consume low-quality hay (Banta et al., 2006) or low-quality stockpiled forage (Lusby et al., 1991; Marston et al., 1995b; Steele et al., 2007), and protein requirements are met with a concentrated CP supplement (38 to 54% CP, DM basis), beef cows continue to experience BCS loss during the winter feeding period. Therefore, producers commonly choose a supplementation program similar to WMCSM, presuming that the additional energy from WMCSM versus CSM is needed during the winter feeding months to minimize BW and BCS loss. However, the additional energy provided by WMCSM (0.75 kg/d more TDN compared to CSM) did

not result in reduced BW or BCS loss during the 60-d prepartum supplementation period in this experiment. In contrast, Marston et al. (1995b) reported increased BW and BCS gain during gestation when beef cows received 0.9 kg additional TDN/d in a high-energy supplement compared to a low-energy supplement containing equal CP. Perhaps the longer prepartum supplementation period of Marston et al. (1995b; approximately 120 d), along with slightly greater difference in energy intake increased the probability of detecting a significant difference due to prepartum energy supplementation.

It has been documented that protein supplements high in fat can be detrimental to cow performance (Banta et al., 2006; Steele et al., 2007; Banta et al., 2008). However, we did not observe any detrimental effects from interval feeding moderate levels of fat through ECSM. Moreover, in a comprehensive review of available literature on fat supplementation, Hess et al. (2008) indicated that in order to avoid a reduction in forage intake and forage digestibility, fat intake should not exceed 4% of daily DMI. In the present experiment, the daily feeding rate of fat in the ECSM treatment was 0.17 kg during gestation and 0.28 kg during lactation, resulting in a diet containing less than 4% fat (DM basis) during each period. We conclude that when fed at a level to meet protein requirements of beef cows during late gestation and early lactation, the additional fat from ECSM was not supplied in a large enough quantity to negatively impact cow performance. However, because ECSM is a byproduct feedstuff, nutrient composition can vary tremendously and should be monitored closely to avoid these potential detrimental effects.

Calf Performance. Calf birth weight was not influenced by dam's winter supplement (Table 3). Likewise, there was no impact of dam's winter supplement on

205-d adjusted weaning weight of calves (Table 3). These results agree with others showing no positive or negative impacts on weaning weights when beef cows are provided supplemental energy in the form of fermentable carbohydrate (Lusby et al., 1991; Marston et al., 1995b) or in the form of fat (Alexander et al., 2002; Banta et al., 2006; Steel et al., 2007).

Reproductive Performance. Data for reproductive performance is presented in Table 4. Supplement type did not influence the percentage of cows exhibiting ovarian luteal activity ($P = 0.59$), AI conception rate ($P = 0.82$), or overall pregnancy rate ($P = 0.88$). However, for non-continuous data, more experimental units would be needed to insure that a type II error was not present. Marston et al. (1995b) found that providing supplemental energy in addition to meeting protein requirements prepartum increased pregnancy rate, although supplemental energy fed only during the postpartum period had no effect on pregnancy rate in spring calving cows.

There is evidence that supplementation with fat sources containing high levels of 18:2n-6 in the early postpartum period may have negative effects on reproductive rates. Postpartum supplementation of high-linoleate safflower seeds (255 g/d of 18:2n-6) increased the concentration of 18:2n-6 in the oviduct (Scholljegerdes et al., 2007), which potentially could negatively impact conception rate (Hess et al., 2008). On average, approximately half of the fat in the residual cottonseed oil is comprised of 18:2n-6 and 18:2n-3 (Sullivan et al., 2004). In the current study, cows supplemented with ECSM consumed 280 g/d crude fat, and accordingly, the contribution of 18:2n-6 and 18:2n-3 to total fatty acid intake from the supplement was approximately 140 g/d from supplement

alone. We can only conclude that this lower level of fat supplementation (relative to Scholljegerdes et al., 2007) did not negatively affect conception rate.

Experiment 2

Data for measurements of intake and digestibility are presented in Table 5. Hay intake did not differ between WMCSM and CSM. This is somewhat surprising because WMCSM-fed cows were provided nearly 2 kg more supplement on a daily basis than CSM-fed cows. Other researchers have indicated that intake of low-quality forage was decreased by energy supplementation when comparing isonitrogenous supplements with varying energy levels (Ovenell et al., 1991; Marston et al., 1995a). For example, Ovenell et al. (1991) evaluated supplementation of low-quality prairie hay fed to beef cows with 1.36 kg soybean meal or 3.41 kg wheat middlings. The higher feeding rate of wheat middlings resulted in 1.1 kg per day decreased hay intake. Similarly, when comparing the effects of supplementation with either 1.36 kg soybean meal or 3.24 kg wheat middlings to beef cows consuming prairie hay, Marston et al. (1995a) reported that hay intake was reduced 0.90 kg per day during gestation and 0.70 kg per day during lactation.

Hay intake tended ($P = 0.10$) to be reduced for ECSM-fed cows compared to CSM-fed cows. Similar daily quantities of CP, RDP and TDN were supplied by CSM and ECSM supplements (Table 1). Therefore, the primary difference in these two supplements was a greater contribution to TDN from fat in ECSM versus a greater contribution to TDN from non fiber carbohydrate and digestible NDF in CSM (Winterholler et al., 2008). In high roughage diets, fat supplementation reduced DMI and fiber digestibility when dietary fat concentration was greater than 5% (DM basis: Coppock and Wilks, 1991; Jenkins, 1993). Moore et al. (1986) indicated that 4%

supplemental fat to steers consuming wheat straw had no negative effects on intake or fiber digestibility, but when fat was added at greater than 6% of DMI, regardless of fat source, intake and fiber digestibility were negatively impacted. In our experiment, feeding d dietary lipid was 2.4% of DMI for CSM and 4.7% of DMI for ECSM; average daily fat intake was 2.3% of DMI for CSM and 3.9% of DMI for ECSM. Therefore, both the feeding d and the average daily dietary fat concentration remained below 5% in the ECSM supplemented cows. Perhaps more research is necessary to determine if an interval feeding strategy for fat-containing protein supplements exacerbates the negative impact that excessive supplemental fat can have on low-quality forage intake.

Apparent digestible DMI and apparent digestible OM intake were not different between CSM and ECSM ($P > 0.10$) but were greater ($P \leq 0.02$) for WMCSM compared to CSM and ECSM. Interestingly, WMCSM supplement supplied 1.12 kg/d more TDN than CSM supplement and apparent digestible OM intake was increased by 1.2 kg/d in WMCSM supplemented cows compared to CSM supplemented cows. Similar calculations for the aforementioned study of Marston et al. (1995a) showed a much lower ratio of DDMI to added TDN (0.34) for gestating cows, reflecting a negative impact of additional supplemental energy on forage DMI.

Apparent total tract digestibility of crude fat was greatest for cows fed ECSM ($P \leq 0.05$) compared to cows fed CSM but was similar for CSM and WMCSM ($P > 0.10$). Fat intake from ECSM was 78% greater than from CSM, and was 39% greater for ECSM compared to WMCSM. Others have shown that supplemental fat increases the apparent digestibility coefficient of ether extract (Palmquist and Conrad 1978; Moore et al., 1986;

Aldrich et al., 1997). The partial digestion coefficient of supplemental fat was estimated from Experiment 2 data according to the equation suggested by Grummer (1988):

> [(extruded, expelled cottonseed meal fat intake – solvent extracted cottonseed meal fat intake) – (extruded, expelled cottonseed meal fat output – solvent extracted cottonseed meal fat output)]/(extruded, expelled cottonseed meal fat intake – solvent extracted cottonseed meal fat intake).

The resulting partial digestibility of supplemental fat from ECSM was 95.2%. Banta et al. (2008) reported a much lower value (66.5%) when cows received 0.29 kg/d supplemental fat from whole soybeans. However, NRC (2001) reports true digestibility of vegetable oils to be 86%. Evidently, supplemental fat from ECSM was highly digestible under the conditions of this experiment.

Apparent total tract digestibility of CP, NDF, DM, and OM, were not influenced by supplemental treatment ($P > 0.10$). Therefore, neither supplemental energy from WMCSM nor added fat from ECSM interfered with apparent total tract digestibility of these dietary components.

Experiment 3

Calculations of 24-h milk production during early lactation were similar among supplement type and averaged 6.33 kg/d ($P = 0.25$; Table 6). In the study of Marston et al. (1995b), beef cows grazing low-quality forage were fed 1.22 kg/d of a 40% CP supplement or 2.44 kg/d of a 20% CP supplement during early lactation. Additional energy from the 20% CP supplement resulted in increased milk yield. In the present study, during early lactation, intake of TDN was 39% and 44% greater for WMCSM compared to CSM and ECSM, respectively. However, we were not able to detect an

increase in milk production with added energy from WMCSM. Lalman et al. (2000) reported a linear relationship between milk yield and increasing levels of energy for heifers fed similar amounts of CP at 60 and 90 d postpartum, but at 30 d postpartum, supplemental energy did not influence milk yield. The average d postpartum of the cows in our study was 21.

Composition of milk constituents, butterfat, protein, lactose, solids not fat, and milk urea N, were not different among supplements (Table 6; $P > 0.10$). These data are consistent with studies evaluating the effects of fat supplementation on milk production and composition for beef cows consuming primarily low-quality forage (Banta et al., 2008; Alexander et al., 2002).

Based on the findings of this study, the additional energy supplied by WMCSM was not great enough to improve beef cow performance or calf weaning weight. Furthermore, ECSM can be effectively utilized as a supplemental protein source for range beef cows consuming low-quality forage. Producers should expect similar production responses when traditional cottonseed meal-based protein and energy sources are replaced with ECSM.

Table 1. Supplement composition and amount of nutrients supplied daily during gestation

Item (DM basis)	Supplement		
	WMCSM	CSM	ECSM
	----------% of DM----------		
Cottonseed meal	18.25	92.34	--
Extruded, expelled cottonseed meal	--	--	93.13
Wheat middlings	76.89	--	--
Calcium carbonate	1.98	3.25	1.45
Dicalcium phosphate	--	1.47	2.58
Molasses	2.78	2.84	2.74
Vitamin A-30,000 IU[1]	0.10	0.10	0.10
CP, %	21.2	43.0	31.1
TDN, %	70.2	80.2	55.0
Crude fat, %	4.48	3.31	10.2
----------Nutrient supplied, gestation----------			
DM, kg/d	2.45	1.21	1.67
CP supplied, kg/d	0.52	0.52	0.52
Degradable intake protein, kg/d[2]	0.38	0.41	0.44
TDN, kg/d[3]	1.72	0.97	0.92
Crude fat, kg/d	0.11	0.04	0.17
----------Nutrient supplied, lactation----------			
DM, kg/d	3.92	2.03	2.75
CP supplied, kg/d	0.86	0.86	0.86
Degradable intake protein, kg/d[2]	0.63	0.67	0.72
TDN, kg/d[3]	2.74	1.62	1.51
Crude fat, kg/d	0.17	0.07	0.28

[1]Provided 12,258 IU of vitamin A per kg of diet DM.

[2]Degradable intake protein determined by separate *in situ* experiment (Winterholler et al., 2008).

[3]Calculated using actual supplement chemical composition and the summative equations from NRC (2001). Adjustments were included for *in situ* true NDF digestibility and the partial fatty acid digestibility coefficient from experiment 3.

Table 2. Effect of winter supplement on cow BW and BCS (Exp. 1)

	Supplement[1]				
Item	WMCSM	CSM	ECSM	SEM	*P*-Value
n =	34	31	31		
Supplementation period, d	95	95	95		
Initial BW (1/2/07), kg	531	536	538	8.00	0.83
BW change before calving, kg[2]	11	2	4	3.64	0.23
BW change after calving, kg[3]	-29	-31	-31	4.17	0.90
BW change 95-d, kg[4]	-64	-71	-72	4.06	0.27
BW at end of supplementation, kg	470	465	466	7.41	0.89
BW change 301-d, kg[5]	-24	-31	-25	4.90	0.56
BW at weaning (10/30/07), kg	507	505	513	7.58	0.77
Initial BCS (1/2/07)	5.46	5.30	5.45	0.13	0.57
BCS change before calving[2]	-0.46	-0.37	-0.42	0.09	0.78
BCS change after calving[3]	-0.27	-0.37	-0.37	0.07	0.49
BCS change 95-d[4]	-0.85	-0.82	-0.87	0.09	0.95
BCS at end of supplementation	4.62	4.48	4.56	0.09	0.50
BCS change 301-d[5]	-1.16	-1.00	-1.04	0.12	0.37
BCS at weaning (10/30/07)	4.30	4.30	4.41	0.07	0.43

[1]Supplements (DM basis) included: 1) 2.45 kg/d during gestation and 3.92 kg/d during lactation of a cottonseed meal and wheat middling based supplement (WMCSM); 2) 1.21 kg/d during gestation and 2.03 kg/d during lactation of a 40% CP cottonseed meal based supplement (CSM); 3) 1.67 kg/d during gestation and 2.75 kg/d during lactation of an extruded, expelled cottonseed meal based supplement that has been delinted (ECSM).
[2]Precalving measurements obtained one week prior to calving.
[3]Change post-calving to end of supplementation period.
[4]Change over supplementation period (1/2/07 to 4/7/07)
[5]Change from beginning of supplementation to weaning (1/2/07 to 10/30/07)

Table 3. Effect of winter supplement on calf performance (Exp. 1)

	Supplement[1]				
Item	WMCSM	CSM	ECSM	SEM	*P*-Value
n =	34	31	31		
Birth weight, kg	34	36	34	0.92	0.21
Calf weaning weight, kg[2]	211	215	212	3.95	0.76

[1]Supplements (DM basis) included: 1) 2.45 kg/d during gestation and 3.92 kg/d during lactation of a cottonseed meal and wheat middling based supplement (WMCSM); 2) 1.21 kg/d during gestation and 2.03 kg/d during lactation of a 40% CP cottonseed meal based supplement (CSM); 3) 1.67 kg/d during gestation and 2.75 kg/d during lactation of an extruded, expelled cottonseed meal based supplement that has been delinted (ECSM).
[2]Weaning weight reported as 205-d weight adjusted for calf sex.

Table 4. Effect of winter supplement on cow reproductive performance (Exp. 1)

	Supplement[1]				
Item	WMCSM	CSM	ECSM	SEM	*P*-Value
n =	34	31	31		
Supplementation period, d	95	95	95		
Pre-breeding wt (5/17/07), kg	483	476	478	8.65	0.83
Pre-breeding BCS (5/17/07)	5.0	4.8	5.0	0.10	0.15
Luteal activity, %[2]	82	74	71	0.08	0.59
AI conception rate, %[3]	30.4	30.4	38.1	0.10	0.82
Pregnancy rate at weaning, %	82	84	87	0.08	0.88

[1]Supplements (DM basis) included: 1) 2.45 kg/d during gestation and 3.92 kg/d during lactation of a cottonseed meal and wheat middling based supplement (WMCSM); 2) 1.21 kg/d during gestation and 2.03 kg/d during lactation of a 40% CP cottonseed meal based supplement (CSM); 3) 1.67 kg/d during gestation and 2.75 kg/d during lactation of an extruded, expelled cottonseed meal based supplement that has been delinted (ECSM).
[2]Percentage of cows exhibiting ovarian luteal activity at the beginning of the breeding season.
[3]N for AI conception rate = 23, 23, and 21 for WMCSM, CSM and ECSM treatments, respectively.

Table 5. Effect of early-lactation supplement on hay intake and apparent total tract digestibility of dietary components (DM basis; Exp. 2)

	Supplement[1]				
Item	WMCSM	CSM	ECSM	SEM	*P*-value
n =	5	6	6		--
Hay intake, kg●100 kg of BW^{-1}●d^{-1}	2.13	2.27	2.03	0.14	0.10
DMI, kg●100 kg of BW^{-1}●d^{-1}	2.79[a]	2.55[b]	2.45[b]	0.16	0.02
OM intake, kg●100 kg of BW^{-1}●d^{-1}	2.60[a]	2.36[b]	2.28[b]	0.14	0.02
Fecal output, kg●100 kg of BW^{-1}●d^{-1}	1.25	1.24	1.19	0.06	0.70
Digestible DMI, kg●100 kg of BW^{-1}●d^{-1}	1.79[a]	1.54[b]	1.53[b]	0.06	0.02
Digestible OM intake, kg●100 kg of BW^{-1}●d^{-1}	1.76[a]	1.52[b]	1.50[b]	0.07	0.01
DM digestibility, %	62.0	58.3	59.6	3.40	0.42
OM digestibility, %	66.7	63.1	63.9	3.50	0.36
NDF digestibility, %	64.5	59.3	62.2	3.55	0.43
ADF digestibility, %	52.2	55.4	55.2	3.70	0.47
CP digestibility, %	57.2	55.9	59.8	2.29	0.51
Crude fat digestibility, %	79.8[a,b]	76.0[a]	84.8[b]	4.29	0.03

[1]Supplements (DM basis) included (during lactation): 1) 3.92 kg/d of a cottonseed meal and wheat middling based supplement (WMCSM); 2) 2.03 kg/d of a 40% CP cottonseed meal based supplement (CSM); 3) 2.75 kg/d of an extruded, expelled cottonseed meal based supplement that has been delinted (ECSM).

[a,b] Means within a row with different superscripts differ ($P \leq 0.05$).

Table 6. Effect of supplement on beef cow milk production and milk composition (Exp. 3)

	Supplement[1]				
Item	WMCSM	CSM	ECSM	SEM	*P*-Value
n =	20	20	20		
Butterfat, %	2.41	2.26	2.55	0.31	0.81
Protein, %	3.09	2.90	2.97	0.08	0.18
Lactose, %	4.98	5.07	5.02	0.06	0.61
Solids not fat, %	9.02	8.93	8.95	0.07	0.64
Milk urea N, mg/dl	4.36	4.35	4.46	0.53	0.48
Milk production, kg[2]	6.65	5.59	6.75	0.51	0.25

[1]Supplements (DM basis) included (during lactation): 1) 3.92 kg/d of a cottonseed meal and wheat middling based supplement (WMCSM); 2) 2.03 kg/d of a 40% CP cottonseed meal based supplement (CSM); 3) 2.75 kg/d of an extruded, expelled cottonseed meal based supplement that has been delinted (ECSM).

[2]Calculated 24-hr milk production from machine milking procedure.

LITERATURE CITED

Aldrich, C. G., N. R. Merchen, J. K. Drackley, G. C. Fahey, Jr., and L. L. Berger. 1997. The effects of chemical treatment of whole canola seed on intake, nutrient digestibilities, milk production, and milk fatty acids of Holstein cows. J. Anim. Sci. 75:512-521.

Alexander, B. M., B. W. Hess, D. L. Hixon, B. L. Garrett, D. C. Rule, M. McFarland, J. D. Bottger, D. D. Simms, and G. E. Moss. 2002. Influence of prepartum fat supplementation on subsequent beef cow reproduction and calf performance. Prof. Anim. Sci. 84:2410-2417.

Banta, J. P., D. L. Lalman, C. R. Krehbiel, and R. P. Wettemann. 2008. Whole soybean supplementation and cow age class: Effects on intake, digestion, performance, and reproduction of beef cows. J. Anim. Sci. 86:1-11.

Banta, J. P., D. L. Lalman, F. N. Owens, C. R. Krehbiel, and R. P. Wettemann. 2006. Effects of interval-feeding whole sunflower seeds during mid to late gestation on performance of beef cows and their progeny. J. Anim. Sci. 84:2410-2417.

Beef Improvement Federation. 2002. Guidelines for Uniform Beef Improvement Programs. 8th ed. Beef Improv. Fed., Athens, GA.

Bottger, J. D., B. W. Hess, B. M. Alexander, D. L. Hixon, L. F Woodard, R. N. Funston, D. M. Hallford, and G. E. Moss. 2002. Effects of supplementation with high linoleic or oleic cracked safflower seeds on postpartum reproduction and calf performance of primiparous beef heifers. J. Anim. Sci. 80:2023-2030.

Clanton, D. C., and D. R. Zimmerman. 1970. Symposium on pasture methods for maximum production in beef cattle: protein and energy requirements for female

beef cattle. J. Anim. Sci. 30:122-132.

Coppock, C. E., and D. L. Wilks. 1991. Supplemental fat in high energy rations for lactating cows: Effects on intake, digestion, milk yield, and composition. J. Anim. Sci. 69:3826-3837.

DelCurto, T., R. C. Cochran, D. L. Harmon, A. A. Beharka, K. A. Jacques, G. Towne, and E. S. Vanzant. 1990a. 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, L. R. Corah, A. A. Beharka, E. S. Vanzant, and D. E. Johnson. 1990b. 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.

Freeman, A. S., M. L. Galyean, and J. S. Canton. 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.

Grummer, R. R. 1988. Influence of prilled fat and calcium salt of palm oil fatty acids on ruminal fermentation and nutrient digestibility. J. Dairy Sci. 71:117-123.

Heldt, J. S., R. C. Cochran, G. L. Stokka, C. G. Farmer, C. P. Mathis, E. C. Titgemeyer, and T. G. Nagaraja. 1999. Effects of different supplemental sugars and starch fed in combination with degradable intake protein on low-quality forage use by beef steers. J. Anim. Sci. 77:2793-2802.

Hess, B. W., G. E. Moss, and D. C. Rule. 2008. A decade of developments in the area of

fat supplementation research with beef cattle and sheep. J. Anim. Sci. 86(E. Suppl.):E188-E204.

Jenkins, T. C. 1993. Lipid metabolism in the rumen. J. Dairy Sci. 76:3851-3863.

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.

Lusby, K. S., R. P. Wettemann, K. H. Ovenell, and D. A. Cox. 1991. Effects of lactation on performance of grazing beef cows wintered with supplements containing soybean meal, wheat middlings, or soybean meal-wheat middlings mixtures. Prof. Anim. Sci. 7:30-34.

Lalman, D. L., J. E. Williams, B. W. Hess, M. G. Thomas, and D. H. Keisler. 2000. Effect of dietary energy on milk production and metabolic hormones in thin, primiparous beef heifers. J. Anim. Sci. 78:530-538.

Marston, T. T., D. D. Simms, R. R. Schalles, K. O. Zoellner, L. C. Martin, and G. M. Fink. 1992. Relationship of milk production, milk expected progeny difference, and calf weaning weight in angus and simmental cow-calf pairs. J. Anim. Sci. 70:3304-3310.

Marston, T. T., and K. S. Lusby. 1995a. Effects of energy or protein supplements and stage of production on intake and digestibility of hay by beef cows. J. Anim. Sci. 73:651-656.

Marston, T. T., K. S. Lusby, R. P. Wettemann, and H. T. Purvis. 1995b. Effects of feeding energy or protein supplements before or after calving on performance of spring-calving cows grazing native range. J. Anim. Sci. 73:657-664.

Martin, J. L., R. J. Rasby, D. R. Brink, R. U. Lindquist, D. H. Keisler, and S. D.

Kachman. 2005. Effects of supplementation of whole corn germ on reproductive performance, calf performance, and leptin concentration in primiparous and mature beef cows. J. Anim. Sci. 83:2663-2670.

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.

Meyer, M. J., J. E. Shirley, E. C. Titgemeyer, A. F. Park, and M. J. VanBalle. 2001. Effect of mechanical processing and fat removal on the nutritive value of cottonseed for lactating dairy cows. J. Dairy Sci. 84:2503-2514.

Moore, J. A., R. S. Swingle, and W. H. Hale. 1986. Effects of whole cottonseed, cottonseed oil or animal fat on digestibility of wheat straw diets by steers. J. Anim. Sci. 63:1267-1273.

NRC. 1996. Nutrient Requirements of Beef Cattle. 7th rev. ed. Natl. Acad. Press, Washington, DC.

NRC. 2001. Nutrient Requirements of Dairy Cattle. 7th rev. ed. Natl. Acad. Press, Washington, DC.

Ovenell, K. H., K. S. Lusby, G. W. Horn, and R. W. McNew. 1991. Effects of lactational status on forage intake, digestibility, and particulate passage rate of beef cows supplemented with soybean meal, wheat middlings, and corn and soybean meal. J. Anim. Sci. 69:2617-2623.

Palmquist, D. L., and H. R. Conrad. 1978. High fat rations for dairy cows, effects on feed intake, milk and fat production, and plasma metabolites. J. Dairy Sci.

61:890-901.

Pena, F., H. Tagari and L. D. Satter. 1986. The effect of heat treatment of whole cottonseed on extent of protein digestion by dairy cows. J. Anim. Sci. 62:1423-1433.

Plegge, S. D., L. L. Berger, and G. C. Fahey, Jr. 1982. Effect of roasting on utilization of soybean meal by ruminants. J. Anim. Sci. 55:395-401.

Schauer, C. S., D. W. Bohnert, D. C. Ganskopp, C. J. Richards, and S. J. Falck. 2005. Influence of protein supplementation frequency on cows consuming low-quality forage: Performance, grazing behavior, and variation in supplement intake. J. Anim. Sci. 83:1715-1725.

Scholljegerdes, E. J., S. L. Lake, T. R. Weston, D. C. Rule, G. E. Moss, T. M. Nett, and B. W. Hess. 2007. Fatty acid composition of plasma, medial basal hypothalamus, and uterine tissue in primiparous beef cows fed high-linoleate safflower seeds. J. Anim. Sci. 85:1555-1564.

Steele, J. D., J. P. Banta, R. P. Wettemann, C. R. Krehbiel, and D. L. Lalman. 2007. Drought-stressed soybean supplementation for beef cows. Prof. Anim. Sci. 23:358-365.

Sullivan, H. M., J. K. Bernard, H. E. Amos, and T. C Jenkins. 2004. Performance of lactating dairy cows fed whole cottonseed with elevated concentrations of free fatty acids in the oil. J. Dairy Sci. 85:665-671.

Vanzant, E. S., R. C. Cochran, and D. E. Johnson. 1991. Pregnancy and lactation in beef heifers grazing tallgrass prairie in the winter: Influence on intake, forage utilization, and grazing behavior. J. Anim. Sci. 69:3027-3038.

Van Soest, P. J., J. B. Robertson, and B. A. Lewis. 1991. Symposium: carbohydrate methodology, metabolism, and nutritional implications in dairy cattle. J. Dairy Sci. 74:3583-3597.

Vizcarra, J. A., R. P. Wettemann, T. D. Braden, A. M. Turzillo, and T. M. Nett. 1997. Effect of gonadotropin-releasing hormone (GnRH) pulse frequency on serum and pituitary concentrations of lutenizing hormone on follicle-stimulating hormone, GnRH receptors, and messenger ribonucleic acid for gonadotropin subunits in cows. Endocrinology. 138:594-601.

Wagner, J. J., K. S. Lusby, J. W. Oltjen, J. Rakestraw, R. P. Wettemann, and L. E. Walters. 1988. Carcass composition in mature Hereford cows: Estimation and effect on daily metabolizable energy requirement during winter. J. Anim. Sci. 66:603-612.

Winterholler, S. J., T. K. Dye, C. P. McMurphy, C. J. Richards, and D. L. Lalman. 2008. *In situ* degradation characteristics of extruded-expelled cottonseed meal-based supplements. J. Anim. Sci. 86(Supp. 2):533(Abstr.).

CHAPTER V

SUPPLEMENTATION OF DRIED DISTILLER'S GRAINS WITH SOLUBLES TO BEEF COWS CONSUMING LOW-QUALITY FORAGE DURING LATE GESTATION AND EARLY LACTATION

ABSTRACT: Three experiments were conducted to evaluate supplementation of dried distiller's grains with solubles (DGS) to spring-calving beef cows (n = 120; 541 kg of initial BW; 5.1 initial BCS) consuming low-quality forage during late gestation and early lactation. Supplemental treatments included (DM basis): 1) 0.77 kg/d DGS (DGSL); 2) 1.54 kg/d DGS (DGSI); 3) 2.31 kg/d DGS (DGSH); 4) 1.54 kg/d of a blend of 49% wheat middlings and 51% cottonseed meal (POS); and 5) 0.23 kg/d of a cottonseed-hull based pellet (NEG). Feeding rate and CP intake were similar for DGSI and POS. In Exp. 1, cows were individually fed 3 d/wk until calving and 4 d/wk during lactation; total SUP period was 119 d. Tall-grass prairie hay (5.6% CP, 50% TDN, 73% NDF; DM basis) was fed *ad libitum* throughout the supplementation period. Change in cow BW and BCS during gestation was similar for DGSI and POS (-4.8 kg, $P = 0.66$ and -0.12, $P = 0.28$, respectively), and linearly increased with increasing DGS level ($P < 0.01$). Likewise, throughout the supplementation period, BW and BCS change were similar for DGSI and POS (-71 kg, $P = 0.51$ and -0.60, $P = 0.08$) and increased linearly with respect to increasing level of DGS ($P < 0.01$). The percentage of cows exhibiting luteal activity at beginning of breeding season (56%; $P = 0.31$), AI conception rate (40% $P = 0.62$), or pregnancy rate at weaning (88%; $P = 0.74$) were not influenced by supplementation. In Exp. 2, 30 cows from a separate herd were used to evaluate the effect of DGS on hay intake and digestion. Supplementation improved all digestibility measures compared to NEG. Hay intake was not influenced by level of DGS ($P > 0.10$); digestibility of NDF, ADF, CP, and fat linearly increased with increasing level of DGS. In Exp. 3, milk production and composition was determined for cows (n = 16/trt) of similar d post-partum from Exp. 1. Daily milk production was not influenced by supplementation (6.34

kg/d; $P = 0.25$). Butterfat (2.1%) and lactose (5.0%) were not different ($P > 0.10$). Milk protein was linearly increased as DGS increased ($P < 0.05$) and was greater for DGSI compared to POS. Similar cow performance was achieved when cows were fed DGS the same rate and level of CP as a traditional cottonseed meal-based supplement. Increasing amounts of DGS did not negatively influence forage intake or diet digestibility.

Key words: beef cow, distiller's grains, supplementation

INTRODUCTION

Supplementation of degradable intake protein (**DIP**) to beef cows is necessary during the winter months in the Southern Great Plains, when forage quality is low, to maintain cow BW and BCS (DelCurto et al., 1990; Lusby et al., 1991; Marston et al., 1995). Protein supplementation programs in this region rely on the use of traditional feeds such as cottonseed meal or soybean meal. However, the corn-based ethanol industry has recently expanded, creating an abundance of dried distiller's grains with solubles (**DGS**). With a few exceptions, the nutrient profile of DGS (33% CP, 10% fat, 87% TDN, 0.87% P; DM basis) indicates that it has potential value as a supplement for beef cattle consuming low-quality forage.

The contribution of DIP from DGS (approximately 50%) is lower than supplied from traditional feeds (Waller et al., 1980; MacDonald et al., 2007; Winterholler et al., 2008). The first-limiting nutrient for beef cattle consuming low-quality forage diets is DIP (Köster et al 1996; Mathis et al., 1999; Bandyk et al., 2001); compared to traditional feeds, feeding a similar level of DGS may result in a deficiency of DIP. Additionally, the fat content of DGS is 10-14%, this is higher than traditionally supplemented feeds (1-3% fat, NRC, 1996). For cattle consuming forage-based diets, high fat concentrations reduce DMI and fiber digestion (Moore et al., 1986; Jenkins, 1993; Hess et al., 2008). Of final concern, the majority of cow/calf operations in the Southern Great Plains have adopted interval-feeding strategies to deliver supplements to reduce labor and fuel cost. We are unaware of studies that have evaluated DGS in an interval feeding scenario.

Previous research using DGS as a supplement in beef cow production systems is limited; yet available literature indicates a favorable response to DGS as a replacement

for traditional supplemental feedstuffs such as cottonseed meal, wheat middlings and soybean meal. At isonitrogenous and isocaloric intake compared to sunflower meal, DGS was an effective supplement for beef cows grazing corn stalks (Doering Resch, 2005). We are aware of no research evaluating supplementation with DGS for beef cows consuming low-quality forage. This study was conducted to determine the efficiency of replacing common supplemental ingredients in an interval feeding system with DGS as a protein and energy source. A second objective was to determine the effects of different DGS feeding amounts.

MATERIALS AND METHODS

Experiment 1

Animals. This experiment was conducted at the Range Cow Research Center, North Range Unit located approximately 16 km west of Stillwater, OK, in accordance with an approved Oklahoma State University Animal Care and Use Committee protocol. Spring-calving Angus and Angus x Hereford crossbred beef cows (n = 120; 541 ± 78 kg of initial BW; 5.1 ± 0.73 initial BCS) were assigned randomly to 1 of 5 dietary supplements for a completely randomized design. Cows were ranked by BW and BCS and randomly allocated so that BW and BCS were similar across all treatments. Experimental supplementation began on December 6, 2007 and terminated on April 3, 2008 which encompassed both late gestation and early lactation (average calving d = March 21); the total supplementation period was 119 d. Because this study encompassed early lactation, once each cow had calved, feeding levels were increased following parturition to meet nutrient demands for lactation.

Supplements (DM basis) included: 1) 0.77 kg/d during gestation and 1.35 kg/d during lactation DGS (**DGSL**); 2) 1.54 kg/d during gestation and 2.68 kg/d during lactation DGS (**DGSI**); 3) 2.31 kg/d during gestation and 4.02 kg/d during lactation DGS (**DGSH**); 4) 1.54 kg/d during gestation and2.68 kg/d during lactation of a blend of 49% wheat middlings and 51% cottonseed meal (**POS**) and 5) 0.23 kg/d during gestation of a cottonseed-hull based pellet and 4.02 kg/d during lactation DGS (**NEG**). All supplements were fed loose, and were formulated so that DGSI and POS provided equal CP and DMI (Table 1).

A barn containing 32 individual feeding stalls was used to insure that each cow received the assigned supplement and that cows did not consume more supplement than their designated amount. During late gestation, cows were fed on Monday, Wednesday and Friday mornings. The amount of supplement fed on each of these 3 d was determined by calculating the amount of supplement needed per wk (daily supplement amount x 7 d) and dividing that amount by 3 (i.e., cows receiving POS were fed 3.59 kg/feeding; DM basis). Once each cow had calved, her supplement frequency was increased to 4 times per week to meet nutrient demands of lactation and during this time, supplements were individually fed on Monday, Wednesday, Friday and Saturday mornings, which resulted in approximately a 57% increase in the amount fed weekly. The amount of supplement fed on each of these 4 d was determined by calculating the amount of supplement needed per wk (daily supplement amount x 7 d) and dividing that amount by 4. To avoid the detrimental effects of no supplementation on reproduction, once NEG cows had calved, they were fed the same diet as DGSH to meet nutrient demands for lactation and help cows achieve adequate BCS at the beginning of the

breeding season. Therefore, all data presented for NEG during lactation and performance measurements obtained beyond lactation represent the effects of nutrient restriction during gestation followed by a brief re-feeding interval from parturition until April 3.

Individual cow BW and BCS were determined at the start of the experimental supplementation period (12/6/2007), after the first 30-d of supplementation (1/10/2008), before any cows had calved (2/28/2008), late-calving cows only (3/30/2007), following parturition, at trial termination (4/03/2008), prior to breeding (5/19/2008) and at weaning (10/15/2008). All BW were recorded after 16-h withdrawal from feed and water. Body condition scores (scale 1 through 9; Wagner et al., 1988) were determined by the same two independent evaluators throughout the experiment.

During gestation, cows were managed as a contemporary group in a single pasture (46 hectares) with free choice access to tall-grass prairie hay (5.6% CP; 50% TDN; 73% NDF; 1.9% crude fat; DM basis) and a high Ca mineral supplement (25.15% NaCl; 19.62% Ca; 5.65% P; 1.08% Mg; 1037 ppm Cu; 12 ppm Se; 3076 ppm Zn; DM basis). At calving, cow/calf pairs were moved to an adjacent pasture (31 hectares) where they were managed as a contemporary group. Cow/calf pairs had *ad libitum* access to the same prairie hay and mineral supplement as described previously and were provided adequate amounts of experimental supplements to meet the protein and energy requirements for lactation until green forage became available (April 3, 2008). Pastures used during the supplemental phase had been previously grazed during spring and summer, and consequently in combination with the heavy stocking rate during the supplemental feeding period, grazed forage contributed minimally to DM intake.

The assessment of N status was estimated during gestation and lactation by measuring serum urea N during each phase. Immediately following blood collection, samples were placed on ice and then allowed to clot for 24 hr at 4^{o} C. After centrifugation (1,500 x g for 20 min), sera were harvested and stored at -20° C for subsequent analysis of serum urea N. Serum urea N concentration was measured using a commercially available kit (Teco Diagnostics, Anaheim, CA) and a microplate reader at 620 nM (96 well plate).

The percentage of cows cycling at the beginning of the breeding season was determined by quantifying progesterone concentration (Vizcarra et al., 1997) in plasma samples obtained via tail venipuncture 14 and 7 d prior to breeding and again on the first d of the breeding season. Immediately following blood collection, tubes were placed on ice until plasma was harvested for analysis of progesterone concentrations. Cows with one or more plasma samples containing $\geq$ 0.5 ng/mL progesterone were considered to have ovarian luteal activity. Cows were artificially inseminated from May 19 through June 14, 2008, followed by natural mating from June 23 through July 21, which resulted in a 63-d breeding season. Cows were observed each morning and evening for 1 h to detect standing estrus; all cows exhibiting standing estrus were artificially inseminated approximately 12 h following observation of estrus. First service conception rate was determined by transrectal ultrasonography approximately 35 d after AI; overall pregnancy rate was determined by rectal palpation at weaning on October 15, 2008.

Birth weight of each calf was determined within 24 h of birth and all male calves were castrated at this time. Calf BW was also obtained on May 5, 2008, June 5, 2008 and

at weaning on October 15, 2008. Weaning weights are reported as a 205-d weight, adjusted for sex according to the guidelines of the Beef Improvement Federation (2002).

Statistical Analysis. For all statistical analysis, cow was considered the experimental unit because supplements were fed individually to each cow. Continuous data were analyzed as a completely randomized design using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) and the Satterwaite approximation for degrees of freedom. The model for cow performance included supplemental treatment as a fixed effect and cow age and d on supplementation prior to calving as covariates. Preplanned contrasts included no supplementation vs. supplementation and DGSI vs. POS. Linear and quadratic orthogonal polynomial contrasts were evaluated for feeding levels of DGS. For lactation, the contrast for no supplementation vs. supplementation was not included in the analysis as the NEG treatment was removed during lactation. For all analysis, differences in treatment means were assessed at $\alpha = 0.05$.

Data for blood urea N were analyzed as a completely randomized design using the MIXED procedure of SAS. Preplanned contrasts included no supplementation vs. supplementation and DGSI vs. POS. Linear and quadratic orthogonal polynomial contrasts were evaluated for feeding levels of DGS. For lactation, the contrast for no supplementation vs. supplementation was not included in the analysis as the NEG treatment was removed during lactation. For all analysis, differences in treatment means were assessed at $\alpha = 0.05$.

Data for reproductive performance were analyzed using the Glimmix procedure of SAS, assuming a binomial distribution and supplement served as a fixed effect. Least

squares means are reported in all tables except for the percentages of cows exhibiting luteal activity, pregnancy rate, and first service conception rate which are raw means.

Experiment 2

Animals. This experiment was conducted at the Range Cow Research Center, North Range Unit located approximately 16 km west of Stillwater, Oklahoma in accordance with an approved Oklahoma State University Animal Care and Use Committee protocol. Thirty cows in mid-gestation from a separate cow herd were used to determine the effects of DGS supplementation on hay intake and apparent total tract digestibility. Cows were randomly assigned to one of two collection periods in a randomized complete block design. Three cows from each treatment combination were represented during each period. Cows were given *ad libitum* access to the same prairie hay that was fed in Exp. 1 and were also kept on the same feeding regimen as gestating cows in Exp. 1 (Monday, Wednesday, and Friday mornings) during Exp. 2. Cows were maintained in individual outdoor 3.7 x 9.1-m pens so that they would be exposed to the same environmental conditions as cows in Exp. 1.

Each 16-d period consisted of 7 d of adaptation to the diet, pens and hay feeders and 9 d of data collection. Hay intake was measured from d 8 through d 14 and fecal grab samples were collected twice daily at 0800 and 1600, from d 10 through d 16 to estimate fecal output from acid detergent insoluble ash concentration. Sub-samples of supplements, hay, and orts were dried at 100^{o}C to determine DM. Supplement, hay, ort, and fecal samples were dried at 50^{o}C and ground in a Wiley mill (Model-4, Thomas Scientific, Sweedesboro, NJ) to pass a 2-mm screen before analysis. After grinding, supplement and hay samples were composited within period; ort and fecal samples were

composited by cow. All composite samples were analyzed for NDF, ADF, CP, crude fat, GE and acid detergent insoluble ash concentration. Neutral detergent fiber and ADF content were determined using an ANKOM Fiber Analyzer (ANKOM Technology, 2009 a, b). Crude protein was determined using a Leco NS-2000 Nitrogen Analyzer (Leco Corporation, St. Joseph, MI) as described by Bilous (1999), crude fat was determined by ether extraction (AOAC, 1996), and acid detergent insoluble was determined as the residue following complete combustion of the ADF residue (Van Soest et al., 1991). The GE of the supplements, hay, orts and feces were determined using an isoperibol bomb calorimeter (model number 1281, Parr Instrument Co., Moline, IL). The P of the supplements, hay, orts and feces were determined by Dairy One Forage Testing Laboratory, Ithaca, NY. Apparent total tract DM, OM, CP, GE, and crude fat digestibility as well as NDF and ADF digestibility were calculated for each cow. Additionally, digested DMI (DMI kg/100kg of BW x DM digestibility), digested OM intake and DE intake were calculated for each cow.

Statistical Analysis. Intake and digestibility measurements were analyzed as a randomized complete block design using the MIXED procedure of SAS (SAS Inst. Inc.) and Satterwaite approximation for degrees of freedom. The model included supplement as a fixed effect and collection period as a random variable. Preplanned contrasts included no supplementation vs. supplementation and DGSI vs. POS. Linear and quadratic orthogonal polynomial contrasts were evaluated for feeding levels of DGS. For all analysis, differences in treatment means were assessed at $\alpha = 0.05$.

Experiment 3

Animals. This experiment was designed to evaluate the effects of supplemental nutrient source on milk yield and composition. Milk production was determined using the weigh-suckle-weigh method. Sixteen cows of similar d post-partum from each treatment described in Exp. 1 were used in the analysis. The evening prior to the experiment, all calves were isolated from their dams at 1800 and the following morning at 0545, calves were reunited with cows and allowed to nurse until the udder was completely empty. Following nursing, calves were again separated from dams and at 1145, calves were weighed and reunited with dams to nurse. Following nursing, calves were weighed again and the difference in BW corresponded to a 6-h estimate of milk production for the cow. After being weighed, calves were again separated from dams and the same procedure was repeated at 1745 to obtain another 6-h estimate of milk production. The two estimates of 6-hr milk production were used to extrapolate a 24-h milk production estimate. Additionally, milk production of the entire cowherd was evaluated by calf BW obtained on May 5, 2008, June 5, 2008 and at weaning on October 15, 2008.

The same cows used in the weigh-suckle-weigh procedure were used to determine the effects of DGS supplementation on milk composition by machine milking. The experimental procedures for evaluating milk composition were adapted from Marston et al. (1992) and took place over a 5-d period. Prior to milking each d, pairs were gathered at approximately 1600. The calves were then separated from their dams until 2200 when pairs were reunited with calves and were allowed to nurse their dams *ad libitum*, but for < 45 min. Following nursing, cows and calves were separated again until milking was

completed. Milking was initiated at 0700 the following morning and was completed by 1300. Cows were provided prairie hay and water free choice during this period.

Before milking, 1.0 mL of oxytocin (20 USP units/mL, i.m.; Phoenix Pharmaceutical Inc., St. Joseph, MO) was administered to each cow to facilitate milk let-down. Cows were then individually milked using a portable milking machine and when milk flow ceased from all quarters, the milking apparatus was removed and each teat was hand-stripped to ensure complete emptying of each quarter. Milk collected from the milking machine was combined with milk from hand-stripping. After thorough mixing, a 50 mL sub-sample was obtained and preserved with 2-bromo-2-nitropropane-1,3-diol and shipped to the Heart of America DHIA (Manhattan, KS) for analysis of milk urea N, protein, butterfat, lactose and solids not fat.

Statistical Analysis. Cow was considered to be the experimental unit for milk production and composition analysis. The model statement for milk production included supplement as a fixed effect and cow age as a covariate. The model for milk composition included supplement as a fixed effect and d post-partum as a covariate. Preplanned contrasts included no supplementation vs. supplementation and DGSI vs. POS. Linear and quadratic orthogonal polynomial contrasts were evaluated for feeding levels of DGS. For lactation, the contrast for no supplementation vs. supplementation was not included in the analysis as the NEG treatment was removed during lactation. For all analysis, differences in treatment means were assessed at $\alpha = 0.05$.

RESULTS AND DISCUSSION

Experiment 1

Cow BW and BCS. Data for cow BW, BW change, BCS and BCS change are presented in Table 2. Feeding increasing amounts of protein and energy from DGS resulted in a linear reduction ($P < 0.01$) in BCS loss over the 119-d supplementation period with respect to feeding level of DGS, and cows fed DGSH maintained the greatest BCS during this period ($P < 0.05$). Change in BCS during gestation and over the 119-d supplementation period was the same for DGSI and POS ($P = 0.22$). There was a greater reduction in BCS for DGSI and POS compared to DGSH, however this decrease (-0.60 units of BCS) left cows in an acceptable BCS (4.54) at the end of the supplementation period.

Using the NRC (1996) model, supplemental DIP differed among DGSI and POS as intake of DIP was greater for POS (Table 1). In the NRC (1996) model, we used actual hay intake data obtained from Exp. 2, and TDN content of each diet to predict microbial efficiency. During gestation, the DIP balance for DGSI was 9 g/d whereas POS was 107 g/d, illustrating that DGSI was marginal in meeting DIP requirements. Despite this, we observed similar performance responses for DGSI and POS suggesting that DGSI cows were able to recycle an adequate amount of N back to the rumen to overcome a potential deficiency (Wickersham et al., 2008 a, b). Beyond this, cows receiving DGSI were fed an additional 0.31 kg/d TDN compared to POS. Thus, we conclude that the ability of the cow to recycle N in a marginally deficient state as well as the additional energy from DGS was enough to achieve similar performance for cows consuming equal amounts of DGS and POS.

Previous work at our research station showed that supplementation with high fat protein feeds reduced cow performance (Banta et al., 2006; Steele et al., 2007; Banta et al., 2008). In a scenario very similar to the present study, when cows were interval fed whole sunflower seeds that supplied 8.0% of dietary lipid (0.94 kg/d; DM basis) on supplementation d, cow BW and BCS were reduced during the supplementation period (Banta et al., 2006). Likewise, cow BW was lower for cows interval fed drought stressed soybeans during gestation; however, BCS was not different compared to a positive control (Steele et al., 2007). In the study of Steele et al. (2007), 0.35 kg/d (DM basis) supplemental fat was supplied on the d of supplementation.

In the present study, we did not observe a deleterious effect of supplying supplemental fat from the interval feeding of DGS. In a recent review, Hess et al. (2008) indicated to avoid the potential negative impacts of fat supplementation; it is recommended that added fat be included at no more than 3% of diet DM for cattle. For our experiment, prairie hay intake for cows during gestation averaged 2.57% of BW for cows fed DGS. Based on this level of hay intake, during gestation, daily fat intake was 3.3% of diet DM with 1.7% added fat from DGS for DGSH cows, and on the d that cows were supplemented, fat intake accounted for 4.7% of diet DM with 3.4% added fat from DGS. For lactation, assuming hay intake was 3.0% of BW, daily fat intake was 4.0% of DM with 2.5% added fat from DGS and was 5.3% of diet DM on the d that cows were supplemented, with 4.3% added fat from DGS for DGSH cows.

As expected, for NEG cows during gestation, BW and BCS loss was substantially greater than supplemented cows. It has been previously documented that cows not receiving a protein supplement during the winter months in similar conditions suffer a

dramatic loss in BCS (1.66 units of BCS; Steel et al., 2007). In the present study, NEG cows lost 0.82 units of BCS during gestation. Once NEG cows had calved, they were fed DGSH to help achieve an adequate BCS prior to breeding. The average calving d for NEG was February 29, 2008 and 5 NEG cows calved after the termination of supplementation on April 3, 2008. The average d on supplementation during lactation for NEG was 34. During this time, BCS loss was similar among treatments (0.34 units of BCS). Although by feeding DGSH, NEG cows received 1.2x maintenance requirements for lactation, this level and duration of feeding was not great enough to overcome nutrient restriction during gestation as BCS for NEG cows was lower than other supplemental treatments after the 119-d supplementation period.

The NRC (1996) recommends that S intake not exceed 0.40% of diet DM as a means to avoid a potential reduction in performance or S induced polioencephalomalacia. If prairie hay intake was 3.0% of BW for DGSH cows during lactation, S intake was approximately 0.25% of diet DM on the d that cows were supplemented. Additional S from DGS was not supplied in a large enough quantity to be detrimental. However, S concentration of DGS can vary substantially (Spiehs et al., 2002), and additional S sources, such as water, should be monitored and accounted for when feeding DGS.

Calf performance. Calf birth weight was influenced by pre-partum supplementation and was linearly increased with respect to increasing levels of DGS (Table 3). The influence of pre-partum supplementation on calf BW has been well researched and results are mixed. Some report that calf BW is related to pre-partum plane of nutrition, (Wiltbank et al., 1962; Houghton et al., 1990; Spitzer et al.,1995), whereas others report no difference (Hough et al., 1990; Wiley et al., 1991; Lake et al.,

2005). Interestingly, in the present study, calf birth weight was similar for POS and NEG ($P = 0.74$), and was lower compared to DGSI ($P < 0.05$). Perhaps the added energy from DGS was partitioned to support fetal growth.

Calf BW increased linearly ($P = 0.06$) with increasing level of DGS at approximately 60 d of age and at approximately 90 d of age ($P = 0.07$). Similarly, Lalman et al. (2000) indicated that 90 d calf ADG was linearly related to supply of post-partum supplemental energy. Also, Perry et al. (1991) indicated that calf BW at 70 d was related to intake of energy post-partum. However, by weaning, 205-d adjusted BW was similar among treatments.

Reproductive Performance. Data for cow performance at the initiation of the breeding season is provided in Table 2 and reproductive data is provided in Table 4. At the beginning of the breeding season, BCS was higher for DGSH compared to other experimental supplements ($P < 0.05$), but had no bearing on reproductive performance. Supplementation of DGS had no influence on the percentage of cows exhibiting ovarian luteal activity ($P = 0.31$), AI conception rate ($P = 0.62$), or overall pregnancy rate ($P = 0.74$), but for non-continuous data, additional experimental units would be necessary to ensure that a type II error was not present.

Previous research with the influence of supplementation with DGS on reproductive performance is favorable. Engle et al. (2008) indicated that supplementation with approximately 40% DGS to ground hay from d 190 of gestation through calving did not influence the percentage of cows in estrus at the beginning of the breeding season but did increase final pregnancy rate compared to a positive control. Likewise, Martin et al. (2007) indicated that supplementation of 0.60% BW of DGS to

prairie hay for developing beef heifers increased AI conception rate as well as pregnancy rate by AI. The authors of these studies speculated that the increased reproductive performance by DGS may be linked to the supply of MP, fat, or the interaction of the two; however, data evaluating the effects of these two variables on reproduction are mixed.

Body condition score at the beginning of the breeding season was lowest for NEG ($P < 0.01$); however, we did not observe a negative effect of pre-partum nutrient restriction on reproductive performance. As mentioned earlier, these cows were not supplemented during gestation but were switched to receive DGSH during lactation. It is apparent that the NEG cows were able to achieve a positive energy balance from the additional MP and energy from DGS as ovarian luteal activity was similar for these cows compared to other supplemental treatments. Houghton et al. (1990) indicated that return to estrus was similar for cows fed a low energy diet during gestation followed by a high energy diet during lactation as compared to supplying moderate to high energy during both periods.

Of additional concern with respect to the influence of DGS on reproductive performance is the potential negative effects caused by feeding excess CP. In dairy rations, feeding high levels of both DIP and undegradable intake protein caused a reduction in uterine pH which could have consequently had detrimental impacts on embryo survival (Elrod and Butler, 1993; Elrod et al., 1993). Despite these previous findings, in the present study, reproductive performance was similar among cows fed increasing levels of DGS compared to a positive control.

Blood Urea Nitrogen

Data for blood urea N (**BUN**) during gestation and lactation are presented in Table 5. To gain a better understanding of how the beef cow uses N from DGS, BUN was measured both during gestation and during lactation. The concentration of BUN was higher during lactation compared to gestation ($P < 0.01$) for all supplemental treatments; we attribute this to increased levels of CP as BUN concentration is related to N intake (Jordan et al., 1983; Rusche et al., 1993; Sletmoen-Olson et al., 2000).

Urea is an indication of N status as urea level is related to concentrations of ruminal ammonia (Hennessy and Nolan, 1988), and is an indicator of N economy as urea is a byproduct of unused ruminal ammonia. Ruminal N is vital for synthesis of microbial cell protein and the use of N for microbial protein synthesis is dependent upon energy intake. If excess N is supplied in relation to energy, ammonia will be lost from the rumen and converted into urea in the liver. Urea has the potential to be recycled back to the rumen through saliva or diffusion across the rumen, or will be excreted. Higher concentrations of BUN and milk urea N are typically related to inefficient use of N (Hammond, 1997). During both gestation and lactation, BUN concentration was greater for POS vs. DGSI ($P < 0.01$).

Sletmoen-Olson (2000) evaluated the influence of N intake on BUN concentrations during gestation and lactation and with respect to increasing time within each period. Findings from their study support our findings of which concentrations of BUN were greater for beef cows during lactation compared to gestation, and this increase was partially related to level of N intake. Interestingly, Sletmoen-Olson (2000) indicated that as time in lactation advanced, up to 3 mo, BUN concentrations were decreased

suggesting that as milk production increased, N recycling to the rumen increased to meet increased nutritional needs during lactation. At the time of BUN sampling in our study, cows were in early lactation (1 mo or less).

Moore et al. (1999) investigated the relationship between supplemental energy and protein and indicated that the optimum ratio of energy to protein (DOM:CP) was 7:1 for cattle on forage-based diets. Based on the data from Exp. 3, during gestation, the DOM:CP ratio was approximately 8 for POS and 9 for DGSI . Blood urea N concentrations for DGSH and POS were similar ($P = 0.66$ and $P = 0.90$ for gestation and lactation, respectively) despite a higher CP intake with DGSH. Perhaps additional energy from DGSH facilitated a greater production of microbial cell protein as evidenced by similar BUN for DGSH and POS ($P > 0.10$) . Data on the effects of ruminal protein degradability on BUN concentrations is mixed. In an N deficient state, Hennessey and Williamson (1990) indicated that BUN was lower for steers and heifers supplemented with ruminally protected casein compared to urea, and the lower BUN for casein translated to an increased ADG. Additionally, Ruche et al. (1993) reported that BUN was increased by a more highly degradable N source. However, when adequate N was supplied, Roseler et al. (1992) demonstrated that BUN was increased to the same magnitude when either DIP or undegradable intake protein was supplied in excess. Many biological factors can influence BUN measurements, however, based on both our cow performance data as well as BUN concentrations, we have evidence that N use from DGS was more efficient compared to a blended cottonseed meal/wheat middlings supplement.

Experiment 2

Data for measurements of hay intake and digestibility are presented in Table 6. Supplementation increased hay intake ($P < 0.01$), but was not different among level of DGS or POS and averaged 2.5% of BW. Previous research with supplementation of DGS in growing cattle has resulted in a linear decrease in forage intake with respect to increasing feeding levels of DGS (Loy et al., 2007; Morris et al., 2007; Winterholler et al., 2007). Intake of chopped grass hay (8.2% CP; 56% in vitro OM disappearance) was reduced by 0.50 kg for each kg of DGS consumed at feeding levels of up to 0.60% BW (Loy et al., 2007). Similarly, Morris et al. (2007) reported that DGS reduced the intake of both low and high-quality bromegrass hay by growing heifer calves supplemented with up to 0.95% of BW with DGS replacing 0.32 kg of low-quality hay and 0.53 kg of high-quality hay. Winterholler et al. (2007) fed increasing levels of DGS, up to 1.65% of BW DGS to weaned calves, and reported that intake of low-quality prairie hay was reduced by 0.34 kg for each kg of supplemental DGS.

According to the aforementioned study of Morris et al. (2007), forage quality influenced the magnitude of the substitution ratio (DGS:forage), with a greater ratio for high-quality forage compared to low. In the study of Winterholler et al. (2007), forage supplied was of similar composition to that used in this study, but the feeding range of DGS was much higher than in this experiment. As a percentage of BW, DGS intake for DGSH corresponded to approximately 0.50% BW. Perhaps we did not observe a reduction in intake of prairie hay by DGS because our feeding range was lower than aforementioned studies with low-quality prairie hay. In addition, animal age and stage of

production could have influenced substitution rate as we are aware of no data that reports of the influence of forage intake by DGS supplementation in mature, gestating beef cows.

Apparent digestible DMI and apparent OM intake were increased by supplementation ($P < 0.01$). Apparent digestible DMI was similar for DGSL and DGSI ($P > 0.10$) and was similar for POS and DGSH ($P > 0.10$). Digestible OM intake was highest for POS, DGSI and DGSH; DGSL was similar to NEG ($P > 0.10$). This is interesting because cow performance was greater for DGSH compared to POS although digestible OM intake was similar among the two. To help explain this, difference in DE intake was not statistically significant, but was numerically greater (1.12 Mcal DE/100 kg BW) for DGSH vs. POS. We suspect this difference would be significant with a more sensitive model and attribute the increase in cow performance of DGSH to greater intake of DE.

Apparent digestibility of crude fat increased with increasing level of DGS and was higher for both DGSI and DGSH compared to POS ($P < 0.05$). Fat intake was 83% greater from DGSH compared to POS and was 63% greater for DGSI than POS. This agrees with other work indicating that apparent digestibility of crude fat is increased with intake of supplemental ether extract (Palmquist and Conrad, 1978; Moore et al., 1986; Winterholler et al., 2008). Also, the partial digestion coefficient of supplemental fat was estimated from Exp. 2 data according to the equation suggested by Grummer (1988):

> [(dried distiller's grains with solubles fat intake – solvent extracted cottonseed meal/wheat middlings blend fat intake) – (dried distiller's grains with solubles fat output – solvent extracted cottonseed meal/wheat middlings blend fat output)]/

(dried distiller's grains with solubles fat intake – solvent extracted cottonseed meal/wheat middlings blend fat intake).

The resulting partial digestibility of supplemental fat from DGSI was 96.7% and for DGSH was 95.7%. We realize that the calculation for DGSH may have been influenced by a greater CP intake of DGSH relative to POS which could potentially influence this comparison. A similar calculation yielded a value of 92.5% when cows were provided 0.11 kg/d supplemental fat from extruded, expelled cottonseed meal (Winterholler et al., 2008). The values we obtained in this experiment indicate that supplemental fat from DGS was highly digestible.

Digestibility of ADF and NDF were increased with increasing supplementation level ($P < 0.05$), and can be attributed to the greater intake of highly degradable ADF and NDF supplied by increasing level of DGS supplement. Others have reported that apparent total tract digestibility of ADF and NDF was increased by increasing levels of highly-fermentable dietary fiber (Tjardes et al., 2002a; Tjardes et al., 2002b). Moreover, methionine is a key amino acid for microbial growth and the optimum fermentation of substrates and requires S for synthesis (Huber, 1988). The addition of various concentrations of supplemental S has either enhanced fiber digestibility (Evans and Davis, 1966; Barton et al., 1971), or has not influenced digestibility of fiber (Momont et al., 1993). In the aforementioned studies, S source, diet and experimental procedures were variable. Aside from additional ADF from additional supplemental DGS, the higher S intake of DGSH may also have had a positive impact on increasing digestibility of ADF. We realize that NDF digestibility was not influenced by DGS, but submit that

additional research evaluating the influence of additional S from DGS on fiber digestibility is warranted.

The digestibility of CP was increased as level of supplemental protein was increased ($P < 0.01$). This finding agrees with others (Guthrie and Wagner, 1988 and Köster et al., 1996). Both DM digestibility and DE were increased ($P < 0.01$) by supplementation but were similar ($P > 0.10$) among supplement type.

Diet intake and digestibility measurements were not different for DGSI and POS. Likewise, cow performance from Exp. 1 was similar among these two supplement types. The composition of these supplements resulted in differences in DIP balance according to the NRC Level 1 model (1996). The POS cows received 110 g DIP above requirements whereas DIP requirements for DGSI were met. Balance of MP was slightly higher for DGSI (370 g/d) compared to POS (330 g/d). The intermediate feeding level of DGS supplied 0.28 kg/d more TDN compared to POS, but was not large enough to influence DE intake. It is apparent that DGSI cows were able to recycle adequate quantities of N to meet microbial requirements as evidence by performance responses from both Exp. 1 and the digestibility measurements calculated in this experiment.

Data for fecal excretion of P are also provided in Table 6 and P excretion was highest for DGSH and POS. Concentration of P in DGS was 0.87% and was 1.05% for POS resulting in a P intake from supplements of 17.14 and 21.43 g/d P from POS and DGSH, respectively. Excretion of P was similar among NEG, POS and DGSH POS ($P = 0.41$). The placebo supplement that NEG cows received contained 5.37% P from dicalcium P, resulting in an intake of 13.18 g/d of P from the supplement. Ruminal solubility of P is dependent on P source, and P will pass to the abomasum for absorption

if not dissolved in the rumen (Witt and Owens, 1983). Though we cannot make a definite conclusion with respect to the availability of P in DGS because the difference in P excretion for DGSH and POS was not significant, it seems as though the processing procedures of DGS could potentially influence the availability of P to the ruminant. With increasing cost of P supplementation, this is an area which merits further investigation.

Experiment 3

Data for milk production are presented in Table 8. Calculations for 24-h milk production were not different ($P = 0.68$) among experimental treatments; however, for increasing levels of DGS, we detected a numerical increase ($P = 0.13$) in milk production with respect to increasing feeding levels of DGS. Others have reported a relationship between energy intake and increased milk production (Wilson et al., 1969; Marston et al., 1995; Lalman et al., 2000). Lalman et al. (2000), milk production increased linearly with increasing energy at 60 d post-partum, but not at 30 d. In our study, the average d post-partum was 29, and may have influenced our ability to detect a statistically significant change in milk production as peak milk production is typically achieved within the range of 50-70 d post-partum (Clutter and Nielsen, 1987; Marston et al., 1992). However, the trend that we observed for increased milk production by increasing level of DGS was supported by calf performance at 60 and 90 d (Table 3).

Results for milk composition are provided in Table 7. Milk fat and lactose were not influenced by supplementation (2.11%, $P = 0.21$; 4.97%, $P = 0.10$, respectively), but both were linearly related to increasing level of DGS ($P < 0.05$). In our study, milk protein was greater for DGSH, DGSI and POS compared to other supplements ($P < 0.01$), and was linearly influenced by level of DGS ($P < 0.05$).

Milk fat linearly decreased as feeding level of DGS increased and milk protein increased. Across a broad range of energy intake levels, Lalman et al. (2000) reported a quadratic response with respect to increasing level of energy on milk fat as well as a linear increase in milk protein with increasing level of dietary energy. This response was similar to ours and supports the theory outlined by Sutton and Morant (1989) that energy intake increases glucogenic precursors due to propionic acid production and consequently, nutrient metabolism shifts from synthesis of milk fat to protein.

Milk energy availability (Mcal/d) is a function of milk fat and milk production (NRC, 1996). In our study, daily milk energy was not influenced by supplement type ($P = 0.97$) and averaged 4.70 Mcal/d, but was linearly related to feeding level of DGS when expressed as Mcal/kg of milk. Sixty d and 90 d calf performance tended ($P = 0.06$ and $P = 0.07$, respectively) to increase linearly with increasing level of DGS; the calculations for milk production together with calf performance support the trend that we observed for increased milk production by feeding higher levels of DGS.

Milk urea N is related to BUN (Roseler et al., 1993; Baker et al., 1995). During lactation BUN concentrations for POS were higher than DGSI at all sampling points (Table 5). Likewise, concentration of milk urea N was higher for DGSI compared to POS while milk protein was greater for DGSI compared to POS (Table 7). Taken together, these data provide further evidence that the beef cow is able to make more efficient use of N from DGS compared to POS.

In summary, feeding the same amount of DGS as a traditional cottonseed meal-based supplement yielded similar responses for the variables evaluated in this study and we provide evidence that beef cows make more efficient use of N from DGS than from a

traditional protein source. Compared to traditional feedstuffs, there are many compositional components that differ. More research is needed to better understand the interactions among compositional differences and the effects of long-term DGS use in range cow settings. We conclude that DGS is a viable supplement option for beef cows consuming low-quality forage and provide a base for future research in understanding how to most effectively use DGS in beef cow/calf production systems.

Table 1. Supplement composition and amount of nutrients supplied daily during gestation and lactation

	Supplement				
Item (DM basis)	DGSL	DGSI	DGSH	POS	NEG
	----------% of DM----------				
Dried distiller's grains with solubles	100	100	100	--	--
Cottonseed meal	--	--	--	51.0	--
Wheat middlings	--	--	--	49.0	13.0
Cottonseed hulls	--	--	--	--	40.0
Molasses	--	--	--	--	3.2
Calcium carbonate	--	--	--	--	18.0
Dicalcium phosphate	--	--	--	--	25.8
----------Nutrients supplied, gestation----------					
DM, kg/d	0.77	1.54	2.31	1.54	0.23
CP supplied, kg,d	0.24	0.47	0.70	0.47	0.02
Degradable intake protein kg/d[1]	0.39	0.77	1.16	1.08	--
TDN, kg/d[2]	0.68	1.35	2.03	1.04	--
Crude fat, kg/d	0.09	0.19	0.28	0.07	0.0006
Phosphorus, g/d	6.70	13.40	20.09	16.17	13.18
Sulfur, g/d	4.35	8.70	13.05	4.77	--
----------Nutrients supplied, lactation[2]----------					
DM, kg/d	1.35	2.68	4.02	2.68	4.02
CP supplied, kg,d	0.42	0.83	1.24	0.83	1.24
Degradable intake protein kg/d[1]	0.68	1.34	2.01	1.88	2.01
TDN, kg/d[2]	1.17	2.33	3.50	1.82	3.50
Crude fat, kg/d	0.16	0.31	0.46	0.12	0.46
Phosphorus, g/d	11.75	23.32	34.97	28.14	34.97
Sulfur, g/d	7.62	15.00	22.51	8.31	22.51

[1]Values for degradable intake protein were obtained using measurements from separate *in situ* experiment (Winterholler et al., 2008).

[2]During lactation, cows receiving NEG supplement were given DGSH upon calving to meet the nutritional demands for lactation and to achieve proper BCS by the beginning of the breeding season.

Table 2. Effect of supplementation with dried distiller's grains with solubles on cow BW and BCS (Exp. 1)

	Supplement[1]						Contrasts[2]			
Item	NEG	POS	DGSL	DGSI	DGSH	SEM	1	2	Linear	Quadratic
n =	24	24	24	24	24	--	--	--	--	--
Supplementation period, d	119	119	119	119	119	--	--	--	--	--
Initial Wt 12/06/07, kg	546	545	545	547	561	12.83	0.88	0.91	0.39	0.70
BW change before calving, kg	-43.7	-6.4	-21.9	-3.7	9.4	3.76	<0.01	0.61	<0.01	0.59
BW change after calving, kg[3]	-49.0	-62.8	-69.5	-72.0	55.7	5.13	--	0.26	0.05	0.14
BW change 119-d, kg[4]	-99.3	-68.3	-89.6	-76.5	-53.5	4.76	--	0.22	<0.01	0.52
BW at end of supplementation, kg	459	487	466	494	518	10.35	--	0.60	<0.01	0.41
Pre-breeding wt (5/19/2008), kg	462[b]	442[b]	492[a]	463[b]	445[b]	9.18	--	0.86	<0.01	0.64
BW change 313-d, kg[5]	27.0	27.9	21.7	-37.1	22.7	5.69	--	0.22	0.90	0.03
BW at weaning 10/15/2008, kg	520	522	520	510	535	9.08	--	0.35	0.24	0.13
Initial BCS 12/06/07	5.02	4.98	5.01	5.02	5.18	0.12	0.76	0.80	0.30	0.60
BCS change before calving	-0.82	-0.20	-0.48	-0.06	0.02	0.08	<0.01	0.25	<0.01	0.13
BCS change after calving[3]	-0.43	-0.35	-0.48	-0.39	-0.03	0.11	--	0.85	<0.01	0.40
BCS change 119-d, kg[4]	-1.14	-0.49	-0.95	-0.70	-0.21	0.09	--	0.10	<0.01	0.17
BCS at end of supplementation	3.87	4.50	4.26	4.58	5.10	0.13	--	0.68	<0.01	0.28
Pre-breeding BCS (5/19/2008)	4.91	4.65	5.31	4.84	4.29	0.13	--	0.68	<0.01	0.68
BCS change 313-d[5]	-0.31	-0.30	-0.11	-0.33	-0.22	0.11	--	0.83	0.52	0.26
BCS at weaning 10/15/2008	4.71	4.67	4.90	4.69	4.96	0.14	--	0.96	0.74	0.15

[1]Supplements (DM basis) included: 1) 0.77 kg/d during gestation and 1.35 kg/d during gestation of dried distiller's grains with solubles (DGSL); 1.54 kg/d during gestation and 2.68 kg/d during lactation of dried distiller's grains with solubles (DGSI); 2.31 kg/d during gestation and 4.02 kg/d during lactation of dried distiller's grains with solubles (DGSH); 1.54 kg/d during gestation 2.68 kg/d during lactation of a blend of 49% wheat middlings and 51% cottonseed meal (POS) and 0.23 kg/d during gestation of a cottonseed-hull based pellet and 4.02 kg/d during lactation of dried distiller's grains with solubles (NEG).

[2]Contrast *P*-value for treatment effect; 1 = no supplementation vs. supplementation; 2 = DGSI vs. POS. Linear and quadratic contrasts performed with respect to increasing level of dried distiller's grains with solubles.

[3]Change post-calving to end of supplementation period.

[4]Change over supplementation period (12/06/07 to 4/03/08)

[5]Change from beginning of supplementation to weaning (12/06/07 to 10/15/08)

Table 3. Effect of supplementation with dried distiller's grains with solubles on calf performance (Exp. 1)

	Supplement[1]						Contrasts[2]			
Item	NEG	POS	DGSL	DGSI	DGSH	SEM	1	2	Linear	Quadratic
n =	23	24	24	23	24	--	--	--	--	--
Birth weight, kg	34.9	35.3	36.1	37.8	39.5	0.89	<0.01	0.05	<0.01	0.99
BW 5/5/08, kg	80.2	84.3	72.8	78.8	84.1	4.13	0.28	0.34	0.06	0.95
BW 6/5/08, kg	114.7	122.6	110.5	114.9	122.9	4.78	0.27	0.24	0.07	0.75
Calf weaning weight, kg[3]	224.2	235.1	221.8	232.4	239.4	7.67	0.41	0.79	0.10	0.84

[1]Supplements (DM basis) included: 1) 0.77 kg/d during gestation and 1.35 kg/d during gestation of dried distiller's grains with solubles (DGSL); 1.54 kg/d during gestation and 2.68 kg/d during lactation of dried distiller's grains with solubles (DGSI); 2.31 kg/d during gestation and 4.02 kg/d during lactation of dried distiller's grains with solubles (DGSH); 1.54 kg/d during gestation 2.68 kg/d during lactation of a blend of 49% wheat middlings and 51% cottonseed meal (POS) and 0.23 kg/d during gestation of a cottonseed-hull based pellet and 4.02 kg/d during lactation of dried distiller's grains with solubles (NEG).

[2]Contrast *P*-value for treatment effect; 1 = no supplementation vs. supplementation; 2 = DGSI vs. POS. Linear and quadratic contrasts performed with respect to increasing level of dried distiller's grains with solubles.

[3]Weaning weight reported as 205-d weight adjusted for calf sex

Table 4. Effect of supplementation with dried distiller's grains with solubles on cow reproductive performance (Exp. 1)

	Supplement[1]						
Item	NEG	POS	DGSL	DGSI	DGSH	SEM	*P*-Value
n =	24	24	24	24	24	--	--
Supplementation period, d	119	119	119	119	119	--	--
Luteal activity, %[2]	50.2	63.0	36.4	68.2	62.3	0.11	0.31
AI conception rate, %	40.0	36.0	29.2	43.5	52.2	0.09	0.62
Overall pregnancy rate, %	84.8	100.0	76.3	87.8	89.7	0.08	0.74

[1]Supplements (DM basis) included: 1) 0.77 kg/d during gestation and 1.35 kg/d during gestation of dried distiller's grains with solubles (DGSL); 1.54 kg/d during gestation and 2.68 kg/d during lactation of dried distiller's grains with solubles (DGSI); 2.31 kg/d during gestation and 4.02 kg/d during lactation of dried distiller's grains with solubles (DGSH); 1.54 kg/d during gestation 2.68 kg/d during lactation of a blend of 49% wheat middlings and 51% cottonseed meal (POS) and 0.23 kg/d during gestation of a cottonseed-hull based pellet and 4.02 kg/d during lactation of dried distiller's grains with solubles (NEG).

[2]Percentage of cows exhibiting ovarian luteal activity at the beginning of the breeding season.

Table 5. Effect of supplementation with dried distiller's grains on blood urea N concentration of beef cows during gestation and lactation (Exp. 1).

	Supplement[1]						Contrasts[2]		
Item[3]	NEG	POS	DGSL	DGSI	DGSH	SEM	1	2	Linear	Quadratic
Gestation										
n =	24	24	24	24	24	--	--	--	--	--
Urea N, mg/dL,	3.76	6.66	4.36	5.07	6.90	0.39	<0.01	<0.01	<0.01	0.23
Lactation										
n =	19	23	19	17	18	--	--	--	--	--
Urea N, mg/dL	14.29	17.79	11.46	14.06	17.64	0.96	--	<0.01	<0.01	0.67

[1]Supplements (DM basis) included: 1) 0.77 kg/d during gestation and 1.35 kg/d during gestation of dried distiller's grains with solubles (DGSL); 1.54 kg/d during gestation and 2.68 kg/d during lactation of dried distiller's grains with solubles (DGSI); 2.31 kg/d during gestation and 4.02 kg/d during lactation of dried distiller's grains with solubles (DGSH); 1.54 kg/d during gestation 2.68 kg/d during lactation of a blend of 49% wheat middlings and 51% cottonseed meal (POS) and 0.23 kg/d during gestation of a cottonseed-hull based pellet and 4.02 kg/d during lactation of dried distiller's grains with solubles (NEG).

[2]Contrast *P*-value for treatment effect; 1 = no supplementation vs. supplementation; 2 = DGSI vs. POS. Linear and quadratic contrasts performed with respect to increasing level of dried distiller's grains with solubles.

[3]Gestation vs. lactation ($P < 0.01$)

Table 6. Effects of supplementation with dried distiller's grains with solubles on prairie hay intake and apparent digestibility of dietary components

	Supplment[1]						Contrasts[2]			
Item	NEG	POS	DGSL	DGSI	DGSH	SEM	1	2	Linear	Quadratic
n =	6	6	6	6	6	--	--	--	--	--
Hay intake, kg•100 kg of BW^{-1}•d^{-1}	2.01	2.64	2.38	2.43	2.60	0.11	0.03	0.20	0.16	0.68
DMI, kg•100 kg of BW^{-1}•d^{-1}	2.06	2.99	2.55	2.79	3.14	0.11	<0.01	0.22	<0.01	0.70
OM intake, kg•100 kg of BW^{-1}•d^{-1}	2.09	2.92	2.44	2.79	3.03	0.18	0.04	0.43	<0.01	0.72
Fecal output, kg•100 kg of BW^{-1}•d^{-1}	1.20	1.39	1.16	1.25	1.29	0.11	0.28	0.18	0.24	0.82
Digestible DMI, kg•100 kg of BW^{-1}•d^{-1}	0.92	1.64	1.44	1.59	1.89	0.09	<0.01	0.25	<0.01	0.75
Digestible OM intake, kg•100 kg of BW^{-}	0.93	1.55	1.36	1.57	1.83	0.07	<0.01	0.91	<0.01	0.79
DE intake, Mcal•100 kg of BW^{-1}•d^{-1}	12.11	15.14	14.33	14.94	16.26	1.05	0.02	0.83	0.04	0.66
P excretion, g/d	163.2	192.5	127.1	152.3	176.2	16.9	<0.01	0.02	<0.01	0.96
Digestibility, %										
DM	40.1	50.9	52.3	53.6	56.2	3.2	<0.01	0.38	0.20	0.81
OM	45.5	53.8	57.1	57.5	61.1	2.6	<0.01	0.14	0.11	0.46
NDF	43.5	51.3	56.1	55.1	58.4	3.2	0.01	0.21	0.43	0.41
ADF	41.7	48.5	52.3	51.8	58.7	3.3	0.03	0.28	0.04	0.17
CP	15.1	46.2	35.7	55.5	51.9	4.3	<0.01	0.14	0.01	0.04
Crude fat	39.4	59.3	69.3	71.2	76.6	2.5	<0.01	<0.01	0.03	0.54
DE	41.2	54.6	58.4	58.1	59.7	1.9	<0.01	0.20	0.62	0.67

[1]Supplements (DM basis) included: 1) 0.77 kg/d dried distiller's grains with solubles (DGSL); 1.54 kg/d dried distiller's grains with solubles (DGSI); 2.31 kg/d dried distiller's grains with solubles (DGSH); 1.54 kg/d of a blend of 49% wheat middlings and 51% cottonseed meal (POS) and 0.23 kg/d during gestation of a cottonseed-hull based pellet (NEG).

[2]Contrast *P*-value for treatment effect; 1 = no supplementation vs. supplementation; 2 = DGSI vs. POS. Linear and quadratic contrasts performed with respect to increasing level of dried distiller's grains with solubles.

Table 7. Effect of supplementation with dried distiller's grains with solubles on milk production and composition of beef cows (Exp. 3)

	Supplement[1]						Contrasts[2]			
Item	NEG	POS	DGSL	DGSI	DGSH	SEM	1	2	Linear	Quadratic
n =	16	16	16	16	16					
Milk yield, kg/d	8.34	8.45	7.43	8.46	8.74	0.61	--	0.99	0.14	0.63
Fat, g/d	189.7	164.3	190.0	183.8	150.9	24.4	--	0.57	0.26	0.66
Protein, g/d	258.6	243.4	218.3	266.9	277.1	18.2	--	0.36	0.03	0.39
Lactose, g/d	412.9	431.1	363.6	418.5	437.0	31.1	--	0.77	0.11	0.64
Milk composition										
Butterfat, %	2.14	2.06	2.45	2.18	1.71	0.22	--	0.71	0.02	0.71
Protein, %	3.13	2.90	2.92	3.16	3.15	0.05	--	<0.01	<0.01	0.04
Lactose, %	4.95	5.08	4.88	4.95	5.00	0.05	--	0.08	0.10	0.86
Solids not fat, %	8.97	8.92	8.71	9.02	9.08	0.06	--	0.23	<0.01	0.09
Milk urea N, mg/dL	5.78	6.35	2.57	3.98	4.61	0.54	--	<0.01	<0.01	0.55
Milk energy[3]										
Mcal/d	4.85	4.65	4.52	4.84	4.62	0.41	--	0.75	0.87	0.60
Mcal/kg	0.57	0.58	0.60	0.57	0.53	0.02	--	0.71	0.02	0.69

[1]Supplements (DM basis) included: 1) 0.77 kg/d during gestation and 1.35 kg/d during gestation of dried distiller's grains with solubles (DGSL); 1.54 kg/d during gestation and 2.68 kg/d during lactation of dried distiller's grains with solubles (DGSI); 2.31 kg/d during gestation and 4.02 kg/d during lactation of dried distiller's grains with solubles (DGSH); 1.54 kg/d during gestation 2.68 kg/d during lactation of a blend of 49% wheat middlings and 51% cottonseed meal (POS) and 0.23 kg/d during gestation of a cottonseed-hull based pellet and 4.02 kg/d during lactation of dried distiller's grains with solubles (NEG).

[2] Contrast *P*-value for treatment effect; 1 = no supplementation vs. supplementation; 2 = DGSI vs POS. Linear and quadratic contrasts performed with respect to increasing level of dried distiller's grains with solubles.

[3]Milk energy (Mcal/kg) = 0.097 x (milk fat percentage) + 0.361 (NRC, 1996)

LITERATURE CITED

Technology, A. N. K. O. M. 2009a. Method for Determining Neutral Detergent Fiber (aNDF). http://www.ankom.com/09_procedures/procedures2.shtml Accessed May 19, 2000.

Technology, A. N. K. O. M. 2009b. Method for Determining Acid Detergent Fiber. http://www.ankom.com/09_procedures/procedures1.shtml Accessed May 19, 2000.

AOAC. 1996. Official Methods of Analysis 14th ed. Assoc. Offic. Anal. Chem. Arlington, VA.

Archibeque, S. L., H. C. Freetly, and C. L. Ferrell. 2008. Feeding distillers grains supplements to improve amino acid nutriture of lambs consuming moderate-quality forages. J. Anim. Sci. 86:691-701.

Baker, L. D., J. D. Fergusion, and W. Chalupa. 1995. Responses in urea and true protein of milk to different protein feeding schemes for dairy cows. J. Dairy Sci. 78:2424-2434.

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.

Barton, J. S., L. S. Bull, and R. W. Hemken. 1971. Effects of various levels of sulfur upon cellulose digestion in purified diets and lignocelluloses digestion in corn fodder pellets *in vitro*. J. Anim. Sci. 33:682-685.

Banta, J. P., D. L. Lalman, C. R. Krehbiel, and R. P. Wettemann. 2008. Whole soybean

supplementation and cow age class: Effects on intake, digestion, performance, and reproduction of beef cows. J. Anim. Sci. 86:1-11.

Banta, J. P., D. L. Lalman, F. N. Owens, C. R. Krehbiel, and R. P. Wettemann. 2006. Effects of interval-feeding whole sunflower seeds during mid to late gestation on performance of beef cows and their progeny. J. Anim. Sci. 84:2410-2417.

Beef Improvement Federation. 2002. Guidelines for Uniform Beef Improvement Programs. 8th ed. Beef Improv. Fed., Athens, GA.

Bilous, M. 1999. Total nitrogen and total sulfur (LECO combustion) in feed. Method LECO 001 (1). Leco Corp. St. Joseph, MI.

Clutter, A. C., and M. K. Nielsen. 1987. Effect of level of beef cow milk production on pre- and postweaning calf growth. J. Anim. Sci. 1313-1322.

DelCurto, T., R. C. Cochran, D. L. Harmon, A. A. Beharka, K. A. Jacques, G. Towne, and E. S. Vanzant. 1990. 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.

Doering-Resch, H. C. Wright, K . Tjardes, G. Perry, K. Bruns, and B. Rops. 2005. Effectiveness of dried distiller's grain with solubles as a replacement for oilseed meal in supplements for cattle consuming poor quality forage. South Dakota Agric. Exp. Sta. Research Report. 14:68-72.

Elrod, C. C., M. Van Amburgh, and W. R. Butler. 1993. Alterations of pH in response to increased dietary protein in cattle are unique to the uterus. J. Anim. Sci. 71:702-706.

Elrod, C. C., and W. R. Butler. 1993. Reduction of fertility and alteration of uterine pH in heifers fed excess ruminally degradable protein. J. Anim. Sci. 71:694-701.

Engel, C. L., H. H. Patterson, and G. A. Perry. 2008. Effect of dried corn distillers grains plus solubles compared with soybean hulls, in late gestation heifer diets, on animal and reproductive performance. J. Anim. Sci. 86:1697-1708.

Evans, J. L., and G. K. Davis. 1966. Dietary phosphorus, sulfur and molybdenum and mineral composition of rumen fluid. J. Anim. Sci. 25:1010-1013.

Grummer, R. R., 1988. Influence of prilled fat and calcium salt of palm oil fatty acids on ruminal fermentation and nutrient digestibility. J. Dairy Sci. 71:117-123.

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.

Hammond, A. C. 1997. Update on BUN and MUN as a guide for protein supplementation in cattle. Pages 43-52 in Proc. Florida Ruminant Nutr. Symp., Univ. Florida, Gainesville.

Hennessy, D. W., and J. V. Nolan. 1988. Nitrogen kinetics in cattle fed a mature subtropical grass hay with and without protein meal supplementation. Aust. J. Agric. Res. 39:1135-1150.

Hennessey, D. W., and P. J. Williamson. 1990. Feed intake and liveweight of cattle on subtropical native pasture hays. II. The effect of urea and maize flour, or protected-casein. Aust. J. Agric. Res. 41:1179-1185.

Hess, B. W., G. E. Moss, and D. C. Rule. 2008. A decade of developmens in the area of

fat supplementation research with beef cattle and sheep. J. Anim. Sci. 86(E. Suppl.):E188-E204.

Hough, R. L., F. D. McCarthy, H. D. Kent, D. E. Eversole, and M. L. Wahlberg. 1990. Influence of nutritional restriction during late gestation on production measures and passive immunity in beef cattle. J. Anim. Sci. 68:2622-2627.

Houghton, P. L., R. P. Lemenager, L. A. Horstman, K. S. Hendrix and G. E. Moss. 1990. Effects of body composition, pre- and postpartum energy level and early weaning on reproductive performance of beef cows and preweaning calf gain. J. Anim. Sci. 68:1438-1446.

Huber, J. T. 1988. Vitamins in ruminant nutrition. Pages 336-338 in The Ruminant Animal Digestive Physiology and Nutrition. D. C. Church, ed. Prentice-Hall, Inc, Englewood Cliffs, NJ.

Jenkins, T. C. 1993. Lipid metabolism in the rumen. J. Dairy Sci. 76:3851-3863.

Jordan, E. R., T. E. Chapman, D. W. Holtan, and L. V. Swanson. 1983. Relationship of dietary crude protein to composition of uterine secretions and blood in high-producing dairy cows. J. Dairy Sci. 66:1854.

Köster, H. H., R. C. Cochran, E. C. Titgemeyer, E. S. Vanzant, I. Abdelgair, and G. St-Jean. 1996. The 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.

Lake, S. L., E. J. Schollegerdes, R. L. Atkinson, V. Nayigihugu, S. I. Paisley, D. C. Rule,

G. E. Moss, T. J. Robinson, and B. W. Hess. 2005. Body condition score at parturition and postpartum supplemental fat effects on cow and calf performance. J. Anim. Sci. 83:2908-2917.

Lalman, D. L., J. E. Williams, B. W. Hess, M. G. Thomas, and D. H. Keisler. 2000. Effect of dietary energy on milk production and metabolic hormones in thin, primiparous beef heifers. J. Anim. Sci. 78:530-538.

Loy, T. W., J. C. MacDonald, T. J. Klopfenstein, and G. E. Erickson. 2007. Effect of distillers grains or corn supplementation frequency on forage intake and digestibility. J. Anim. Sci. 85:2624-2630.

Lusby, K. S., R. P. Wettemann, K. H. Ovenell, and D. A. Cox. 1991. Effects of lactation on performance of grazing beef cows wintered with supplements containing soybean meal, wheat middlings, or soybean meal-wheat middlings mixtures. Prof. Anim. Sci. 7:30-34.

MacDonald, J. C., T. J. Klopfenstein, G. E. Erickson, and W. A. Griffin. 2007. Effects of dried distillers grains and equivalent undegradable intake protein or ether extract on performance and forage intake of heifers grazing smooth bromegrass pastures. J. Anim. Sci. 85:5614-2624.

Marston, T. T., D. D. Simms, R. R. Schalles, K. O. Zoellner, L. C. Martin, and G. M. Fink. 1992. Relationship of milk production, milk expected progeny difference, and calf weaning weight in angus and simmental cow-calf pairs. J. Anim. Sci. 70:3304-3310.

Marston, T. T., and K. S. Lusby. 1995. Effects of energy or protein supplements and

stage of production on intake and digestibility of hay by beef cows. J. Anim. Sci. 73:651-656.

Martin, J. L., A. S. Cupp, R. J. Rasby, Z. C. Hall, and R. N. Funston. 2007. Utilization of dried distillers grains for developing beef heifers. J. Anim. Sci. 85:2298-2303.

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.

Momont, P. A., R. J. Pruitt, and P. S. Johnson. 1993. Effect of methionine addition to urea-grain supplement on intake and digestibility of mature, dormant grasses and performance of cows grazing winter range. J. Anim. Sci. 71:515-521.

Moore, J. A., R. S. Swingle, and W. H. Hale. 1986. Effects of whole cottonseed, cottonseed oil or animal fat on digestibility of wheat straw diets by steers. J. Anim. Sci. 63:1267-1273.

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.

Morris, S. E., J. C. MacDonald, D. C. Adams, T. J. Klopfenstein, R. L. Davis, and J. R. Teichert. 2006. Effects of supplementing dried distillers grains to steers grazing summer sandhill range. Nebraska Beef Rep. MP-30:32.

NRC. 1996. Nutrient Requirements of Beef Cattle. 7th rev. ed. Natl. Acad. Press, Washington, DC.

Perry, R. C., L. R. Corah, R. C. Cochran, W. E. Beal, J. S. Stevenson, J. E. Minton, D. D.

Simms, and J. R. Brethour. 1991. Influence of dietary energy on follicular development, serum gonadotropins and first postpartum ovulation in suckled beef cows. J. Anim. Sci. 69:3762-3773.

Rosler, D. K., J. D. Ferguson, C. J. Sniffen, and J. Herrema. 1993. Dietary protein degradability effects on plasma and milk urea nitrogen and milk nonprotein nitrogen in Holstein cows. J. Dairy Sci. 76:525-534.

Rusche, W. C., R. C. Cochran, L. R. Corah, J. S. Stevenson, D. L. Harmon, R. T. Brant, Jr., and J. E. Minton. 1993. Influence of source and amount of dietary protein on performance, blood metabolites, and reproductive function of primiparous beef cows. J. Anim. Sci. 71:557-563.

Sletmoen-Olson, K. E., J. S. Canton, K. C. Olson, D. A. Redmer, J. D. Kirsch, and L. P. Reynolds. 2000. Undegraded intake protein supplementation: II: Effects on plasoma hormone and metabolite concentrations in periparturient beef cows fed low-quality hay during gestation and lactation. J. Anim. Sci. 78:456-463.

Spiehs, M. J., M. H. Whitney, and G. C. Shurson. 2002. Nutrient databse for distiller's dried grains with solubles produced from new ethanol plants in Minnesota and South Dakota. J. Anim. Sci. 80:2639-2645.

Spitzer, J. C., D. G. Morrison, R. P. Wettemann, and L. C. Faulkner. 1995. Reproductive responses at calf birth and weaning weights as affected by body condition at parturition and postpartum weight gain in primiparous beef cows. J. Anim. Sci. 73:1251-1257.

Steele, J. D., J. P. Banta, R. P. Wettemann, C. R. Krehbiel, and D. L. Lalman. 2007.

Drought- stressed soybean supplementation for beef cows. Prof. Anim. Sci. 23:358-365.

Sutton, J. D., and S. V. Morant. 1989. A review of the potential of nutrition to modify milk fat and protein. Livest. Prod. Sci. 23:219-237.

Tjardes, K. E., D. D. Buskirk, M. S. Allen, N. K. Ames, L. D. Bourquin, and S. R. Rust. 2002. Neutral detergent fiber concentration of corn silage and rumen inert bulk influences dry matter intake and ruminal digesta kinetics of growing steers. J. Anim. Sci. 82:833-840.

Tjardes, K. E., D. D. Buskirk, M. S. Allen, R. J. Tempelman, L. D. Bourquin, and S. R. Rust. 2002. Neutral detergent fiber concentration in corn silage influences dry matter intake, diet digestibility, and performance of Angus and Holstein steers. J. Anim. Sci. 80:841-846.

Van Soest, P. J., J. B. Robertson, and B. A. Lewis. 1991. Symposium: carbohydrate methodology, metabolism, and nutritional implications in dairy cattle. J. Dairy Sci. 74:3583:3597.

Vizcarra, J. A., R. P. Wettemann, T. D. Braden, A. M. Turzillo, and T. M. Nett. 1997. Effect of gonadotropin-releasing hormone (GnRH) pulse frequency on serum and pituitary concentrations of lutenizing hormone on follicle-stimulating hormone, GnRH receptors, and messenger ribonucleic acid for gonadotropin subunits in Cows. Endocrinology. 138:594-601.

Waller, J., T. Klopfenstein and M. Poos. 1980. Distillers feeds as protein sources for growing ruminants. J. Anim. Sci. 51:1154-1167.

Wagner, J. J., K. S. Lusby, J. W. Oltjen, J. Rakestraw, R. P. Wettemann, and L. E. Walters. 1988. Carcass composition in mature Hereford cows: estimation and effect on daily metabolizable energy requirement during winter. J. Anim. Sci. 66:603-612.

Wickersham, T. A., E. C. Titgemeyer, R. C. Cochran, E. E. Wickersham, and D. P. Gnad. 2008. Effect of rumen degradable intake protein supplementation on urea kinetics and microbial use of recycled urea in steers consuming low-quality forage. J. Anim. Sci. 86:3079-3088.

Wickersham, T. A., E. C. Titgemeyer, R. C. Cochran, E. E. Wickersham, and E. S. Moore. 2008. Effect of frequency and amount of rumen degradable intake protein supplementation on urea kinetics and microbial use of recycled urea in steers consuming low-quality forage. J. Anim. Sci. 86:3089-3099.

Wiley, J. S., M. K. Peterson, R. P. Ansotegui, and R. A. Bellows. 1991. Production from first-calf beef heifers fed a maintenance or low level of prepartum nutrition and ruminally undegradable or degradable protein postpartum. J. Anim. Sci. 69:4279:4293.

Wilson, L. L., J. E. Gillooly, M. C. Rugh, C. E. Thompson, and H. R. Purdy. 1969. Effects of energy intake, cow body size and calf sex on composition and yield of milk by Angus-Holstein cows and preweaning growth rate of progeny. J. Anim. Sci. 28:789-795.

Wiltbank, J. N., W. W. Rowden, J. E. Ingalls, K. E. Gregory, and R. M. Koch. 1962. Effect of energy level on reproductive phenomena of mature Hereford cows. J. Anim. Sci. 21:219-225.

Winterholler, S. J., T. K. Dye, C. P. McMurphy. C. J. Richards, and D. L. Lalman. 2008. *In situ* degradation characteristics of extruded-expelled cottonseed meal-based supplements. J. Anim. Sci. 86(Supp. 2):533(Abstr.).

Winterholler, S. J., B. P. Holland, T. K. Dye, C. R. Krehbiel, G. W. Horn, and D.L. Lalman. 2008. Effects of dried distiller's grains during preconditioning on subsequent wheat pasture and finishing performance of fall-weaned beef steers. Page 9 in Proc 2008 American Society of Animal Science, Southern Section, Dallas, TX.