INFLUENCE OF HIGH-STARCH VERSUS HIGH-FIBER ENERGY SUPPLEMENTS ON PERFORMANCE AND FORAGE INTAKE AND UTILIZATION BY STOCKER CATTLE GRAZING WHEAT PASTURE

By

MATTHEW DAVID CRAVEY

Bachelor of Science
Texas A&M University
College Station, Texas
1982

Master of Science
Texas A&M University
College Station, Texas
1989

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
May, 1993

OKLAHOMA STATE UNIVERSITY

INFLUENCE OF HIGH-STARCH VERSUS HIGH-FIBER ENERGY SUPPLEMENTS ON PERFORMANCE AND FORAGE INTAKE AND UTILIZATION BY STOCKER CATTLE GRAZING WHEAT PASTURE

Thesis Approved:

Gerald W. Horn
Thesis Advisor

Robert L. Dillon

Fred McCollum

Charles A. Gilliland

Leach A. Lusby

Thomas C. Collins
Dean of the Graduate College

ACKNOWLEDGMENTS

First and foremost, I must thank my wife Sandra for her contributions towards my goal. I am thankful for the many nights of drafting you put in to help us pay the bills. I also am very proud of the efforts you have invested in our two children, Sarah and Logan. They could not have a better mother and I could not have found a better wife.

Secondly, I must express extreme gratitude to Dr. Gerald Horn, my advisor, for providing me the excellent opportunity of conducting this research. His guidance has been invaluable and his professionalism is unparalleled. Dr. Horn and his family have been very observant to the special needs a graduate student's family may have. Their kindness towards my family has not gone unnoticed and they could not have done any greater thing for me, than this.

Special appreciation and thanks goes to the members of my committee, Dr. Ted McCollum (despite his Aggie jokes), Dr. Chuck Hibberd, Dr. Keith Lusby and Dr. Bob Gillen for the many hours of consultation and guidance they have contributed. These men have treated me with respect and as a friend. For this I am truly grateful.

Without the support of my parents this task would have been much harder to complete. Sandra and I truely appreciate all you have done for us. I am proud to have been raised by such good people. Also, special appreciation must be expressed to Bruce and Dora Hobbs for their support. You are some of the most giving people I have ever known.

I would like to thank Bobby McDaniel, Ken Poling, Donna Perry, Carolyn Gray, Carolyn Bowen and Mirta Donnelly for their friendship and assistance in accomplishing this effort. I would also like to thank my fellow graduate students. I appreciate your help in collecting data and samples, especially on those days when the only tree between us and the North Pole had blown down. Thanks to those few I had time to spend with the most, namely, Paul Beck, Troy

Miller, Todd Thrift, Gary Ziehe, Mike Van Koevering, Chester Wiernusz, and Twig "The Steer Jock" Marston. To Paul Beck, I leave this one question for pondering; "What will they gain"?

TABLE OF CONTENTS

Chapter — Page

I. INTRODUCTION ... 1
Literature Cited ... 4

II. REVIEW OF LITERATURE ... 5

Composition of Wheat and Other High Quality Forages ... 5
Regulation of Forage Intake ... 6
Quantity of Forage ... 7
Physical and Chemical Composition of Forage ... 8
Effects of Energy Supplementation on Forage Intake and Utilization ... 10
Mechanisms of Effects of Energy Supplements on Forage Intake and Utilization ... 11
Osmolality ... 11
Ruminal pH ... 13
VFA Concentrations ... 15
Blood Acid-Base Status ... 16
Bacterial Competition ... 18
Digestion Lag Time ... 18
Associative Effects ... 19
Substitution of Energy Supplements for Forages ... 20
High-Fiber Energy Supplements ... 22
Effects of Energy Supplementation on Performance of Cattle Grazing High-Quality Pastures ... 24
Use of Controlled-Release Chromium Capsules for Estimating Fecal Output of Grazing Ruminants ... 27
Summary of Review of Literature ... 29
Literature Cited ... 30

III. INFLUENCE OF HIGH-STARCH VERSUS HIGH-FIBER ENERGY SUPPLEMENTS ON PERFORMANCE OF STOCKER CATTLE GRAZING WHEAT PASTURE, SUBSEQUENT FEEDLOT PERFORMANCE AND CARCASS CHARACTERISTICS ... 37

Abstract ... 37
Introduction ... 38
Experimental Procedure ... 39
Study Site ... 39
Cattle ... 40
Experiment 1 ... 40
Experiment 2 ... 41
Experiment 3 ... 43
Three Year Study - Pooled ... 43
Results ... 44
Experiment 1 ... 44
Experiment 2 ... 45

Chapter Page

Experiment 3 46
Three Year Study - Pooled 47
Discussion 47
Implications 50
Literature Cited 51

IV. EFFECT OF HIGH-STARCH VERSUS HIGH-FIBER ENERGY SUPPLEMENTS ON FORAGE INTAKE AND UTILIZATION BY STEERS GRAZING WHEAT PASTURE 62

Abstract 62
Introduction 63
Materials and Methods 64
Experiment 1 64
Pasture and Cattle Management 64
Effects of Energy Supplementation on Forage Intake 64
Prediction of Chromium Release Rate and Fecal Output 66
Statistical Analysis 67
Experiment 2 68
Pasture and Cattle Management 68
Effects of Energy Supplementation on Forage Intake 68
In Situ Procedure 69
Statistical Analysis 70
Results and Discussion 70
Experiment 1 70
Effects of Energy Supplementation on Forage Intake 70
Prediction of Chromium Release Rate and Fecal Output 71
Experiment 2 72
In Situ Procedure 72
Effects of Energy Supplementation on Forage Intake 73
Implications 75
Literature Cited 76

V. EFFECT OF HIGH-STARCH VERSUS HIGH-FIBER ENERGY SUPPLEMENTS ON RUMEN AND BLOOD ACID-BASE PARAMETERS OF STOCKER CATTLE GRAZING WHEAT PASTURE 88

Abstract 88
Introduction 89
Materials and Methods 90
Results and Discussion 93
Ruminal Parameters 93
Blood Parameters 95
Implications 96
Literature Cited 97

APPENDIX 111

CLIPPING DATA AND FORAGE ESTIMATES AT THE MARSHALL WHEAT PASTURE RESEARCH UNIT, 1989 - 1992 112

LIST OF TABLES

Table		Page
3-1.	Forage Available for Grazing by Steers on Wheat Pasture	53
3-2.	Composition (% as-fed) of Energy Supplements	54
3-3.	Effect of Type of Energy Supplement and Method of Feeding on Performance of Steers Grazing Wheat Pasture, Experiment 1.	55
3-4.	Effect of Type of Energy Supplement and Stocking Density on Performance of Steers Grazing Wheat Pasture, Experiment 2.	56
3-5.	Feedlot Performance of Steers, Experiment 2	58
3-6.	Effect of Type of Energy Supplement on Performance of Steers Grazing Wheat Pasture, Experiment 3	59
3-7.	Feedlot Performance of Steers, Experiment 3	60
4-1.	Composition (% as-fed) and Digestibility of Energy Supplements	78
4-2.	Chemical Composition and Digestibility of Wheat Forage Masticate in Experiments 1 and 2	79
4-3.	Means of Ruminal Fermentation Data of Steers Grazing Wheat Pasture (Experiment 1) and Grazing Wheat Pasture and Supplemented With High-Starch or High-Fiber Energy Supplements (Experiment 2)	82
4-4.	Means for Actual and Predicted Fecal Outputs (FO) by Steers Grazing Wheat Pasture 10 to 12 Days After Administration of Controlled-Release Cr Capsules (Experiment 1)	84
4-5.	Means of Rate and Extent of In Situ Wheat Forage OM Digestion by Steers Grazing Wheat Pasture and Supplemented With High-Starch or High-Fiber Energy Supplements (Experiment 2)	85
5-1.	Chemical Composition and Digestibility of Wheat Forage Grazed by Steers	99
5-2.	Composition (% as-fed) and Digestibility of Energy Supplements	100
5-3.	Ruminal Fermentation Parameters and Forage Intake of Steers	101
5-4.	Four-Hour Post-Feeding Ruminal Fluid Volatile Fatty Acid Concentrations of Steers Grazing Wheat Pasture	102

Table Page

5-5. Blood Acid-Base Parameters of Steers..... 103

LIST OF FIGURES

Figure — Page

3-1. Influence of Supplementation and Stocking Density on Average Daily Gain of Steers Grazing Wheat Pasture 61

4-1. Predicted Release of Cr by the Controlled-Release Cr Capsule in Steers Grazing Wheat Pasture From d 6 to 15 80

4-2. Substitution of Energy Supplement for Wheat Forage by Steers Grazing Wheat Pasture, Experiment 1 81

4-3. Actual (Collected) and Predicted (Controlled-Release Cr Capsules; Experimentally Derived and Company Specified Release Rate) Fecal Output by Steers Grazing Wheat Pasture from d 10 to 12 After Dosing 83

4-4. Effects of Consumption of a High-Starch Energy Supplement on Wheat Forage Intake by Steers Grazing Wheat Pasture, Experiment 2 86

4-5. Forage Intake Versus Supplement Intake fof Steers Supplemented With Increasing Amounts of a High-Fiber Energy Supplement and Grazing Wheat Pasture, Experiment 2 87

5-1. Time-Course Changes in Ruminal pH. 104

5-2. Time-Course Changes in Ruminal Ammonia N 105

5-3. Time-Course Changes in Ruminal Osmolality 106

5-4. Time-Course Changes in Blood pH 107

5-5. Time-Course Changes in Blood pCO_2 108

5-6. Time-Course Changes in Blood HCO_3 109

5-7. Time-Course Changes in Blood Base Excess 110

CHAPTER I

INTRODUCTION

Rate of weight gain (ADG) is a key variable influencing profitability of stocker cattle enterprises. Daily gains of stocker cattle can vary from year to year because of fluctuations in weather, forage availability and cattle types (i.e., breed, sex and body composition differences). In times of low forage availability, supplementation programs can be implemented to enhance performance. In addition to improved weight gains, supplementation of stocker cattle on pasture has several advantages (Wagner et al., 1984). These include 1) increased stocking rates or carrying capacity, 2) extending available forage supplies during periods of adverse weather, 3) inclusion of feed additives such as ionophores and poloxalene to improve gains and reduce health and disease problems, and 4) improving the overall nutrient balance to improve ADG or feed utilization. The combination of these advantages may allow the producer to more accurately predict wheat pasture stocker cattle performance. This is particularly challenging because of the potentially large variation in weather and amounts of available forage. If cattle performance cannot be predicted, breakeven selling prices cannot be calculated and strategies for managing market risk become more uncertain. The ability to predict cattle performance will become more important as the feedlot and stocker segments of the industry compete for supplies of stocker/feeder cattle.

The supplements of choice for stocker cattle grazing wheat pasture have typically contained high-energy, grain-based products. Weight gains have been improved by approximately .1 to .15 kg/d when 2.27 to 4.83 $kg \cdot head^{-1}d^{-1}$ of high energy, grain-based supplements are fed. However, the efficiency of supplement use is often quite low. Elder

(1967) and Gulbransen (1976) reported that efficiency of grain use was approximately 9.4 and 10.3 kg of grain per kg of increased weight gain per acre.

The use of high-fiber, by-product feedstuffs for supplementation of livestock is becoming increasingly popular because they can be an economical source of energy and protein. Additionally, many of these feedstuffs are relatively low in starch content (as compared to a grain such as corn) which may minimize potential negative associative affects and improve efficiency of use of these supplements. Examples of these feedstuffs are wheat middlings, soybean hulls, corn bran and corn gluten feed. One objective of this research was to determine the effects of feeding moderate levels of high-starch versus high-fiber energy supplements on performance of stocker cattle grazing wheat pasture. Additionally, the influence of this supplementation strategy on subsequent feedlot performance and carcass characteristics was evaluated.

Substitution ratios (units change in forage intake per unit increase in concentrate intake) vary depending on quality of forage, the amount and type of supplement consumed and species of livestock. Moore (1992), in a review paper, reported negative substitution ratios for grain supplements on a variety of forages. Work by Coleman (1977), Jarrige et al. (1986) and a review by Horn and McCollum (1987) suggests that substitution of energy supplements for forage becomes more negative with increasing forage digestibility. Effects of high-starch and high-fiber energy supplements on forage intake and utilization have not been quantified for steers grazing wheat pasture. Therefore, the second objective of this research was to determine the influence of the two types of energy supplements on wheat forage intake and utilization by stocker cattle.

Numerous mechanisms have been suggested for the adverse effects of energy supplements on forage intake and/or fiber digestion, including decreased ruminal pH (Mould et al., 1983), a decline in numbers of cellulolytic bacteria (Henning et al., 1980), elevated ruminal osmolality (Carter and Grovum, 1990) and altered blood acid-base status (Horn and McCollum, 1987; Uhart and Carrol, 1967; Huber, 1976). However, energy supplements may have very different effects on ruminal pH and forage intake and utilization depending on the feedstuff

composition of the supplement, the form and type of roughage and resulting rates of particle fragmentation (and therefore, chewing and rumination times and salivation). To prevent the adverse effects of starch on ruminal fermentation, high-fiber by-product feeds, such as wheat middlings, soybean hulls and corn gluten feed, offer opportunities to formulate energy supplements with fairly high energy densities. The potential for use of these by-product feeds in supplementing growing cattle on wheat pasture is particularly good because of the rapid rate of ruminal degradation of wheat forage and the relative low ruminal pH values of these cattle (Andersen and Horn, 1987). Therefore, the final objective of this study was to investigate the effects of the high-starch, corn-based and high-fiber, soybean hull and wheat middling-based energy supplements on ruminal and blood acid-base parameters in relation to their affect on wheat forage intake and utilization by steers.

Literature Cited

Andersen, M. A. and G. W. Horn. 1987. Effect of lasalocid on weight gains, ruminal fermentation and forage intake of stocker cattle grazing winter wheat pasture. J. Anim. Sci. 65:865.

Carter, R. and W. L. Grovum. 1990. A review of the physiological significance of hypertonic body fluids on feed intake and ruminal function: Salivation, motility and microbes. J. Anim. Sci. 68:2811.

Coleman, S. W. 1977. Energy supplementation of grazing cattle. Proc. of Amer. Forage and Grassland Council Rep. EC 80-218, p 9.

Elder, W. C. 1967. Winter grazing small grains in Oklahoma. Okla. Agr. Exp. Sta. Bull. B-654.

Gulbransen, B. 1976. Response to supplementary sorghum grain by cattle grazing oats. Aust. J. Exp. Agr. & Anim. Husb. 16:646.

Henning, P. A., Y. Van der Linden, M. E. Mattheyse, W. K. Nauhaus and H. M. Schwartz. 1980. Factors affecting the intake and digestion of roughage by sheep fed maize straw supplemented with maize grain. J. Agric. Sci., Camb. 94:565.

Horn, G. W. and F. T. McCollum. 1987. Energy supplementation of grazing ruminants. pp. 125-137. Proc. of the Grazing Livestock Nutr. Conf. Univ. of Wyoming, Laramie.

Huber, T. L. 1976. Physiological effects of acidosis on feedlot cattle. J. Anim. Sci. 43:902.

Jarrige, R., C. Demarquilly, J. P. Dulphy, A. Holden, J. Robelin, C. Beranger, Y. Geay, M. Journet, C. Malterre, D. Micol and M. Petit. 1986. The INRA "Fill Unit" system for predicting the voluntary intake of forage-based diets in ruminants: A review. J. Anim. Sci. 63:1737.

Moore, J. E. 1992. Matching protein and energy supplements to forage quality. Proc. Third Florida Ruminant Nutrition Symposium. Gainesville, FL. p 31.

Mould, F. L., E. R. Ørskov and S. O. Mann. 1983. Associative effects of mixed feeds. I. Effects of type and level of supplementation and the influence of the rumen fluid pH on cellulolysis in vivo and dry matter digestion of various roughages. Anim. Feed Sci. Tech. 10:15.

Uhart, B. A. and F. D. Carrol. 1967. Acidosis in beef steers. J. Anim. Sci. 26:1195.

Wagner, D., R. Lowrey and M. Grigsby. 1984. Supplemental feeding of grain and protein for stocker cattle on small grain pastures. In : G. W. Horn (Ed.). Proc. Natl. Wheat Pasture Symp. Okla. Agr. Exp. Sta. Pub. MP-115:327.

CHAPTER II

REVIEW OF LITERATURE

Composition of Wheat and Other High-Quality Forages

Cool season forages (i.e., wheat, oats, rye, ryegrass and barley) have unique characteristics which impact forage utilization and performance of growing ruminants. In general, these small grain forages are characterized by high DM digestibility and crude protein (CP) content and commonly contain 75% digestible DM and 25 to 30% CP during the fall and early spring grazing periods. Stewart et al. (1981) reported the chemical characteristics of wheat pasture over a 4-year period. Dry matter content ranged from 20 to 45% and crude protein concentrations were greater than 20% (DM basis) during the fall, winter and early spring. Johnson et al. (1974) reported CP values of wheat forage of 25 to 31% of DM during the months of January to April. Horn (1984) and Vogel (1988) reported in vitro dry matter digestibility (IVDMD) values ranging from 70 to 80% and 70 to 84%, respectively.

Forage CP is commonly characterized as either true protein or non-protein-nitrogen (NPN). Wheat pasture usually contains large quantities of soluble N and soluble NPN in the CP fraction (Johnson et al., 1974; Horn et al., 1977). The primary components of the NPN fraction of forages include amino acids, amides, nitrates, alkaloids, purines and pyrimidines (McDonald et al., 1988). The soluble N and NPN content of forages can have a great impact on the amount of N reaching the small intestine. Beever et al. (1976) found a significant negative relationship ($r=-.98$; $P<.001$) between the amount of N flowing to the small intestine and the solubility of N of perennial ryegrass conserved by different methods. Vogel (1988) observed significant

correlations between the size of a highly soluble rapidly disappearing N pool in the rumen and soluble N ($r=.69$; $P<.05$) and NPN ($r=.67$; $P<.05$) content of wheat forage.

The carbohydrates present in forages are diverse and can include sucrose, fructosan, starch (the main storage carbohydrate), cellulose (the major structural carbohydrate), pectin and hemicellulose. The fiber content of wheat forage is low with most acid detergent fiber (ADF) values being less than 30% of DM and neutral detergent fiber (NDF) values falling below 50% of DM. Lignin content will range between 2.5 and 5% of DM for most of the grazing season. The water soluble carbohydrates (primarily sucroses) and pectin represent the more rapidly digestible carbohydrates while cellulose and hemicellulose digestion is influenced by the extent of lignification (Van Soest, 1982). Small grain forages typically contain significant amounts of water soluble carbohydrates. Johnson et al. (1974) reported that soluble carbohydrates in wheat forage increased from 20% (DM basis) in January to over 30% in late February. Beever et al. (1986) indicated that the soluble carbohydrate content of ryegrass ranged from 14.5 to 17.9% of DM depending on stage of forage maturity.

Forage maturity is the primary factor influencing forage quality. Vogel (1988) reported that with advancing wheat forage maturity, CP content decreased from about 24.7% to 12.8% of DM, and IVOMD decreased from 76.6 to 69.4%. These results are similar to conclusions of Horn (1984) and are most likely attributable to the decreased proportion of leaf to stem and the increased structural carbohydrate content observed with advancing forage maturity.

Regulation of Forage Intake

Minson (1982) indicated that the quantity of forage consumed by grazing ruminants depends on three factors: (1) the availability (i.e., quantity) of suitable forage, (2) the physical and chemical composition of the forage and (3) the nutrient requirements of the animal. An understanding of the determinants influencing these factors is important in establishing means of controlling forage intake. The following discussion will focus on the first two factors.

Quantity of Forage

Restricted nutrient intake is probably the major factor limiting performance of grazing animals. Small grain species offer the advantage of providing fresh forage at a time when native grasses are dormant. However, growth of cereal forages is heavily dependent on environmental factors which can lead to inadequate availability of nutrients for optimum livestock performance. These factors include precipitation, soil moisture, ambient and soil temperature, soil fertility, variety and others. Carver et al. (1991) reported significant variations in hard red winter wheat forage production in the fall, winter and over the entire growing season. These variations were attributed to variety differences and resiliency or regrowth potential after clipping. Soft red wheat varieties produced 30% more winter forage than the hard red cultivars, but the hard red cultivars produced 26% more regrowth after clipping, than the soft red cultivars. Beever et al. (1986) indicated peak ryegrass yields in May and late June.

Ellis et al. (1984a) reported that dry matter digestibility and daily intake of steers grazing annual ryegrass were significantly and progressively decreased when daily herbage allowance was reduced below 30 kg/100 kg BW. However, fecal output was not influenced by a progressive decline in daily forage allowance (i.e., from 70 to 10 kg/100 kg BW), suggesting that quantity of prehensible forage was not limiting in the study and that quality effects were responsible for determining intake of grazed ryegrass. Ellis et al. (1984a) also found that selective grazing resulted in depressed digestibility of the subsequent diet when daily herbage allowance was reduced to less than 20-30 kg DM/100 kg BW.

McCollum et al. (1992) reported on a preliminary study where forage intake was estimated while beef steers grazed paddocks with varied levels of standing wheat forage. Standing forage ranged from 754 to 1452 kg/ha at the start of the trial. Forage allownace varied from 4.7 to 36.2 kg•100 kg BW^{-1}•$day^{-1}$for the 7-day trial. The highest intakes were observed when daily herbage DM allowance exceeded 14.3 kg DM•100 kg BW^{-1}•day^{-1}. The authors concluded that intake was limited when herbage allowance was less than 15 kg DM•100 kg BW^{-1}•day^{-1}. Preliminary results from a second trial (McCollum., 1993) indicate a depression in intake occurred at a

herbage allowance higher than that indicated in the first trial and possibly similar to that reported by Ellis et al. (1984a) of about 20 to 30 kg DM•100 kg BW^{-1}•day^{-1}.

The literature indicates that intake of high-quality forages may be depressed when herbage allowance falls below 20 to 30 kg DM•100 kg BW^{-1}•day^{-1}, but may be more of a function of forage quality which is accenuated by reduced opportunities for selective grazing by cattle. Furthermore, it is not uncommon for winter forages to incur freeze damage at times when ambient temperatures are sufficiently low and when no protection (i.e., snow or ice cover) is available. Substantial browning, reduced growth and decreased digestibility of the forage can result. Producers must be prepared to supplement nutrients such as energy in times of low forage availability.

Physical and Chemical Composition of Forage

Several physical characteristics of forage are known to influence intake. The primary plant factor that influences intake is the rate at which it is broken down to particles small enough to leave the rumen (Minson, 1982). Ground and pelleted forages usually correspond with increased intakes. Campling and Freer (1966) reported that pelleted forages have a faster passage rate through the rumen which leads to increased intakes. Generally, feed particles greater than 1 mm (sieve hole size) are prevented from leaving the rumen and are regurgitated and reduced in size by rumination (Poppi et al., 1980). Balch (1971) reported that finely ground forages contain few particles greater than 1 mm in size and therefore, are ruminated very little. Thus, the relationship between chopped and pelleted forages, in terms of intake and digestibility, seems to be associated with the reduction in need for the forage to be broken down by rumination and in consequence the faster passage of forage through the rumen.

Physical differences also exist between different parts of the same plant. Laredo and Minson (1975, as cited in Minson, 1982) found that sheep consumed higher quantities of leaf of a temperate grass than stem. Minson (1982) summarized 30 comparisons of forages and found that the mean difference in intake between leaf and stem was 42% with a difference of only one

percent in DM digestibility between the two fractions. Minson concluded that the mechanism controlling the difference in intake between leaf and stem fraction was similar to that operating with pelleted and chopped forages, i.e., the rate at which particles were broken down to small enough size to exit the rumen.

A primary chemical factor of a plant affecting intake is fiber content. As forage matures there is usually an increase in fiber content and a decrease in the protein and non-structural carbohydrates of the cell contents. With these changes, digestibility and intake by livestock are generally reduced. Donefer et al. (1963) confirmed, for 14 grass and legume species, a positive relationship between DMD and forage intake.

Other chemical constituents of pastures that may an influence on animal intake are essential nutrients such as protein and minerals. Grasses that are low in protein content (i.e., less than 6-8 %) may not provide the rumen microbial population with adequate nitrogen and result in depressed intake (Minson, 1982). Blaxter and Wilson (1963) indicated that 8.5% was a critical value for temperate forages. Cool season grasses typically have crude protein contents in excess of 20% and therefore, CP is not usually of concern.

Minerals known to cause a reduction in intake when they are deficient in forages include sulfur, sodium, phosphorus and other trace elements such as cobalt (Minson, 1982). The primary nutrients of concern in small grain forages are Ca and Mg. The National Research Council (1984) indicates that fresh, early vegetative wheat contains .42% Ca, .21% Mg, .40% P and 3.5% K. For perspective, the NRC recommends the following mineral requirements for a 136 kg medium-frame steer to gain .91 kg/d: .72% Ca, .05% to .25% Mg, .32% P, and .65% K. In small grain forages, Ca levels are often low, Mg and P levels are often marginal and K is high. The ratio of K/(Ca + Mg) is often used as an indicator of tetany hazard for forages. Increased levels of K have been reported to inhibit both Ca and Mg absorption in the gastro-intestinal tract (Bohman et al., 1984). Wheat pasture poisoning seems to be triggered by sudden changes of Ca availability of the diet, or by a sudden increase in Ca demand by the animal (Bohman et al., 1984).

This author is not aware of any research indicating a reduction in intake by ruminants when calcium is deficient in cool season forages. However, low levels of calcium in the diet may lead to incidence of tetany (Bohman et al., 1983). Clay (1973) reported on the causes of death of stocker cattle grazing small grain pastures. In these forages, Ca, P and Mg were generally deficient and blood serum Ca concentrations dropped as grazing progressed in the spring.

Magnesium, Ca and K are known to be involved in muscle activity (Breazile, 1984). Magnesium is necessary for the activity of kinase enzymes which regulate the transfer of energy between metabolic molecules and eventually to muscle contraction and relaxation. Potassium plays a key role in maintaining and regulating nerve and muscle excitation. Calcium, which regulates muscle contraction and relaxation, is also necessary for regulation of enzymatic reactions, which regulate the energy available for, and intensity of, muscle contraction. Since wheat forage is typically low in Ca and Ca is important in muscular activity, including ruminal and gut motility, it has been proposed that there may be a relationship between Ca and the incidence of bloat in stocker cattle (Horn, 1992). Further research is needed to resolve the specific mechanisms involved in wheat pasture bloat. However, the research cited supports the need for Ca and probably Mg and P supplementation of ruminants grazing small grain pastures.

Effects of Energy Supplementaiton on Forage Intake and Utilization

Supplementation of grazing ruminants is often necessary to augment inadequate or low quantities of existing forage and (or) to provide additional nutrients to animals grazing low-quality forage. Feeding relatively small amounts of natural protein supplements to ruminants consuming low-quality forage increases forage intake and utilization (Arelovich, 1983; Guthrie, 1984; McCollum and Galyean, 1985; Caton et al., 1988; and DelCurto et al., 1990). Energy supplements (depending on the level of feeding) generally decrease forage intake. This reduction in forage intake can be desirable or undesirable. If forage supplies are limited, the provision of energy supplements can help "stretch" available forage by reducing intake. Conversely, if the desired animal performance is high, energy supplements are needed (versus

protein supplements) to meet nutrient requirements of the animal. The "optimum" level of supplemental feed substitution for forage is dependent not only on existing forage supplies but also the limits of intake and the ability of the diet to meet nutrient requirements of the animal. Energy supplements may also be necessary to counter environmental conditions which increase maintenance requirements.

Mechanisms of Effects of Energy Supplements on Forage Intake and Utilization

There are a number of mechanisms that have been suggested to explain the effects of energy supplements on intake and utilization of forage. The following discussion is included to summarize these theories. It must be kept in mind that many of these mechanisms are interrelated and the dietary influence of one mechanism may affect another.

Osmolality. It is generally believed that osmotic pressure of rumen fluid, and particularly hypertonicity, has important physiological influences on rumen function and feed intake. Osmotic pressure is measured in osmoles. A 1-Osmol (1,000 mOsmol) solution contains 6×10^{23} dissolved particles per liter of solution (Carter and Grovum, 1990). Osmotic pressure arises from dissolved particles attracting water across a membrane, such as the rumen epithelium. Tonicity of body fluids, reported as osmolality, infers that solutes occupy negligible space because they are so dilute (i.e., 1 Osmol of solute diluted in 1 kg of water = 1 Osmol/kg). The term osmolarity is sometimes used, indicating the osmolar concentration expressed as osmoles per liter of solution. Guyton (1986, as cited in Carver and Grovum, 1990) reports the quantitative difference between osmolarity and osmolality to be less than 1% for the dilute solutions found in the body.

Carter and Grovum (1990) indicated the tonicity of blood and interstitial fluids are maintained at approximately 300 mOsmol/kg. However, large deviations from this figure are found in the gut and are a result of diet and rumen fermentation. Owens and Goetsch (1988) report that normal fermentation occurs at osmolarities between 260 and 340 mOsm in ruminants.

Engelhardt and Hauffe (1975, as cited in Carter and Grovum, 1990) report rumino-reticular fluid to be hypotonic to plasma (247 ± 18 mOsmol/kg) prior to feeding sheep. Bergen (1972) reported maximal values in the range of 310 to 370 mOsmol/kg (2 hr post-feeding) in the rumen of sheep fed silage or one of three dry rations composed of various levels of ground corn cobs, alfalfa meal, rolled oats, ground corn and ground hay (trial 1). In an in vitro trial (trial 2) the author found a decrease in cellulose digestion when either NaCl or Na-acetate was added to ruminal contents to elevate tonicity above 400 mOsmol/kg. However, he concluded that ruminal fluid tonicity was not important in controlling intake because ruminal fluid tonicities did not reach 400 mOsmol/kg on the diets used in trial 1 and only tonicities greater than 400 mOsmol/kg inhibited in vitro cellulose digestion. Horn et al. (1979) reported on a study involving rumen cannulated steers fed ground, ensiled high-moisture corn diets with or without various buffers. In all steers, tonicity of rumen contents was increased by over 50% by 1 h post-feeding. The rate of decline of osmolality in all steers was similar; a rapid decline from 1 to 4 h post-feeding followed by a slower decline during the 4- to 24 h period. All rumen osmolalities returned to the normal range by 8 h post-feeding, indicating a short term influence of the diet. Phillip et al. (1981) found an inverse linear relationship between intake in sheep and ruminal fluid tonicity over the range of 200 to 500 mOsmol/kg after infusions of hypertonic extracts of fresh and ensiled whole corn plant and NaCl solutions into the rumen. They concluded that osmolality was a major factor limiting the short-term intake of corn silage. Ternouth (1967, as cited by Carter and Grovum, 1990) reported an inverse linear depression in voluntary feed intake and the tonicity of ruminal fluid over the entire range of 250 to 400 mOsmol. In the studies of Ternouth (1967, as cited by Carter and Grovum), Bergen (1972) and Phillip et al. (1981), feed intakes were measured 1, 2 and 3 h post-feeding. These intervals preclude identification of the organ or site responsible for sensing the increase in tonicity. Since absorption and possibly passage of digesta could have occurred in the 1, 2 and 3 h intervals, tonicity changes may have been registered beyond the rumen. However, Carter and Grovum (1990) concluded that the wall of the rumino-reticulum was the site mediating the inhibitory effect of hypertonicity on feed intake. Intake depression

observed after salt loading was not mediated by an effect on motility of the rumen-reticulum (Phillip et al., 1981).

Lactic acid has been associated with increased rumen osmolality. Huber (1971 as cited by Huber, 1976) reported that with a reduction in total body water to 8% of body weight, due to diarrhea enduced dehydration, ruminal ingesta became hypotonic to plasma and a significant portion of the lost body water entered the rumen. Osmolar concentrations of lactic acid increased from .08 to 89.2 mOsm and rumen osmolality increased from 255 to 401 mOsm. The author concluded that lactic acid accounted for the majority of the increased rumen osmolality.

Further studies involving ad libitum access to feed are needed to evaluate whether meals are initiated or cease when tonicity is high or low, or whether eating rate decreases during meals as the tonicity increases.

Ruminal pH. The effect of rumen pH on fiber digestion is a topic that has received extensive study over the years. The abrupt consumption of energy supplements with readily fermentable carbohydrate (RFC) is generally believed to impact fiber digestion in the rumen. Carbohydrate is fermented to volatile fatty acids (VFA) which can reduce rumen pH. Mould et al. (1983) reported on the effect of level of whole, pelleted and pelleted ground barley on rumen pH of steers fed increasing amounts of hay. In general, all levels of barley supplementation up to and including the 50% level reduced rumen pH to an equal extent, and the pH fell from 6.6 on all hay diets to 6.2 for the 50% barley diet. When barley composed 100% of the diet, rumen pH fell to 5.8, 5.4 and 5.3 for the whole barley, pelleted and ground barley, and pelleted whole barley, respectively. In another study, Mould and Ørskov (1983) reported that in situ ruminal degradation of grass hay at 24 h of incubation in the rumen of sheep was decreased from about 30 to 9% when rumen pH was reduced from 6.6 to below 6.0 by continuous infusion of an acid solution. The depression of roughage digestion when RFC were fed was of a "composite nature", due in part to the decreased rumen pH and also to the amount of readily degradable substrate associated with supplementation (Mould et al., 1983). The effect due to readily

degradable substrate was termed a "carbohydrate effect". The authors also found a substantial reduction in cellulolytic bacteria when diets were changed from all hay to all barley and the pH subsequently depressed. Stewart (1977) reported similar results when cellulolysis was inhibited after pH dropped from 6.9 to 6.0 and total cellulolytic microorganisms declined from 10^6 to 10^3/ml. Based on the conclusions of Mould et al. (1983), efforts to maintain pH may or may not improve fiber digestion. The composition and level of supplement and roughage fed interact to complicate matters.

Horn and McCollum (1987) report that decreased microbial attachment and washout may play an important role in the mechanism by which low rumen pH decreases digestion of roughages in the rumen. The authors cite research by Mould and Ørskov (1983), Russell and Dombrowski (1980) and Shriver et al. (1986) to support their conclusions.

Huber (1976) showed the relationship between ruminal pH and endotoxins released from dead gram negative bacteria may be a contributing factor in lactic acid acidosis syndrome in ruminants. When sheep were dosed with 20 g glucose/kg BW intraruminally, rumen pH dropped from 6.90 (h 0) to 4.75 (h 72). No endotoxin was detected until pH fell below 5.4. Huber (1976) related his findings to those of Mullinax et al. (1966 as cited by Huber, 1976) that showed rumen stasis in both cattle and sheep injected intravenously with endotoxin extracted from rumen bacteria. Endotoxins were also suspected to indirectly inhibit motility by releasing endogenous histamine from body cells. Hence, it is feasible that grazing animals that consume sufficient quantities of a high-starch energy supplement would experience a reduction in rumen pH and therefore, motility. A decrease in rumen motility would result in reduced digestion, passage rate and therefore, reduced forage intake.

Branine and Galyean (1990) conducted a study to determine the effects of grain and monensin supplementation on ruminal fermentation, intake, digesta kinetics and incidence and severity of bloat in steers grazing wheat pasture. Twelve ruminally cannulated steers (three/treatment) were fed individually with 1) no grain (C), 2) .5 kg•hd^{-1}•d^{-1} steam-flaked milo (G), or 3) G plus 170 mg monensin•hd^{-1}•d^{-1}. Ruminal fluid samples were collected during three

10-d periods (i.e., early April, late May and mid-May). Ruminal pH was determined to be greater for M than C or G in early April (6.3 vs 6.0) but not in late April or mid-May. Horn (1981) also reported higher ruminal pH for steers grazing wheat pasture and fed supplement providing 200 mg•hd-1•d-1 of monensin, as compared to non-supplemented steers. These studies illustrate the potential for monensin to increase ruminal pH when cattle are consuming highly degradable energy supplements.

VFA Concentrations. Ruminal volatile fatty acid concentrations are fairly stable with roughage diets usually exhibiting molar ratios (moles of acetate:propionate:butyrate) of about 65:25:10 and concentrate ration near 50:40:10 (Owens and Goetsch, 1988). However, VFA concentrations are usually more variable for concentrate diets, and depend on pH. Volatile fatty acids are a major end product of microbial fermentation and are readily absorbed from the rumen. Horn et al. (1979) reported that total VFA (mmoles/liter) were highest 1 to 2 h post-feeding in steers fed ground, ensiled high-moisture corn diets with or without various buffers. Control steers (no buffer) exhibited total VFA concentrations from a low of 91.2 (h 0) to a high of 170.2 mmoles/liter (h 2). Total VFA returned to the normal range by 24 h post-feeding.

In the study of Branine and Galyean (1990) discussed above, total concentration of ruminal VFA and proportions of ruminal acetate were not influenced by dietary treatments (i.e., no grain, grain supplement or grain plus monensin) of steers grazing wheat pasture. However, monensin supplemented cattle had higher molar proportions of propionate and less butyrate. Horn et al. (1981) also reported increased propionate and improved gains in steers supplemented with monensin while grazing wheat pasture, suggesting improvements in efficiency of energy metabolism.

With low-fiber diets, rumen pH often falls below 6, at least intermittently (Owens and Goetsch, 1988). Consequently, microbial diversity is limited and, due to pH or substrate supply, amylolytic species thrive. Cellulolytic species are generally able to shift from fiber digestion to fermentation of sugars (an alternative energy source). Relative to these cellulolytic bacteria,

amylolytic species are less adaptable to changes in substrate (source or supply). High VFA concentrations occur in animals grazing lush forage such as wheat pasture, probably due to the readily available carbohydrate fraction of the forage and lower amounts of saliva produced relative to forages with higher fiber content. Therefore, low ruminal pH, as a result of accumulation of VFA, can inhibit certain fermentation processes and likely alter forage intake.

Blood Acid-Base Status. Research indicates that blood-acid base status in addition to or in lieu of rumen parameters can affect animal performance (Uhart and Carrol, 1967; Horn et al., 1979; Huber, 1976). Huber (1976) discussed the significance of the bicarbonate buffering system in blood as an assessment of acid-base status. He used the Henderson-Hasselbalch equation to illustrate the desired blood pH to bicarbonate (HCO_3) ratio of 20:1 (i.e., pH=pKa + log HCO_3/CO_2 or 7.4 = 6.10 +log HCO_3/CO_2). As lactic acid enters the blood, it dissociates and the anion ($CH_3CHOHCOO^-$) combines with cations such as sodium (Na). The hydrogen ion combines with HCO_3 forming carbonic acid (H_2CO_3) which dissociates to CO_2 and H_2O. The resulting effect is a decrease in HCO_3 and an increase in CO_2 concentration. Huber (1976) stated that according to the Henderson-Hasselbalch equation, a reduction in blood pH should result in a decrease in the HCO_3:CO_2 ratio. However, the increased CO_2 tension of blood and decrease in blood pH stimulates respiration and restores the desired HCO_3:CO_2 ratio to near 20:1. Huber (1976) suggests that long term compensation of this ratio would involve removal of H^+ by the kidney. Norwegian researchers (Juhász and Szegedi, 1968 as cited by Huber, 1976) reported on the changes in mean blood pressure, respiration rate and bicarbonate buffering system in a sheep following the administration of 16.2 g of glucose/kg BW into the rumen. At 16 h, blood pH had fallen from 7.52 to 7.31 and respiration had accelerated from 26 to 86 per minute. Although pulse rate had accelerated from 65 to 130 beats per minute, blood pressure was maintained relatively well. However, as more lactate entered the system (i.e., 22 mg/100 ml at h 0 to 168 mg/100 ml at h 23), respiration slowed to 20-60 per minute and blood pressure and pH decreased rapidly. The rapid rise in blood lactic acid between 16 and 23 h was attributed to a

failure in aerobic metabolism and was not necessarily of gastrointestinal origin. Apparently, in cases of acute acidosis, the systemic blood pressure begins to decline, causing a decrease in perfusion pressure and oxygen supply to peripheral tissues. Thus, lactic acid accumulates due to a failure in aerobic metabolism. Although these extreme responses were experimentally produced they do give insight into the relationship of lactic acidosis with blood acid-base status.

Horn et al. (1979) reported on the effect of dietary buffers and ruminal blood parameters of subclinical lactic acidosis in steers. In this study, steers were slowly adapted to a high-concentrate diet by decreasing the proportion of cottonseed hulls in the diet (controls) or were abruptly changed to a high-concentrate diet (acidotic steers). Jugular blood samples were taken to determine pH, pCO_2 and HCO_3. Blood pH, pCo_2 (mmHg) and HCO_3 means (± SEM) for control and acidotic steers were 7.44 ± .01, 36.6 ± 2.1, 24.2 ± 2.1 and 7.32 ± .03, 33.5 ± 3.8, 17.0 ± 2.8, respectively. The acidotic steers exhibited signs of marked dehydration, muscle tremors and laminitis. In steers consuming an 85% ground, ensiled high-moisture corn diet and various buffers, jugular pCO_2 and HCO_3 all tended to drop to a 2 h post-feeding time and then begin to rise until 12 to 24 h post-feeding and then level off to point similar to time zero (Hom et al., 1979). However, blood pH values of steers on all diets changed very little with time and never decreased below 7.37. It was reported that restoration of acid-base balance may have encouraged renewed feeding by steers fed certain buffers (bentonite plus either dolomite or $KHCO_3$)

In another acidosis study, Uhart and Carroll (1967) changed eight calves from an alfalfa hay diet to an ad libitum 90% grain diet without adaptation. Reportedly, seven steers went off feed for 2 to 6 days. When the steers stopped eating the HCO_3:CO_2 ratio had fallen from 18.9 to 15.3 and blood pH had decreased from 7.37 to 7.29. Additionally, rumen lactic acid levels had increased considerably and urine pH had fallen from 8.23 to 5.89. The steers resumed eating when HCO_3:CO_2 levels reached 16.1 and stabilized at 18.2, similar to the initial ratio of 18.9.

Baker et al. (1991) reported significantly lower blood pH, pCO_2 and HCO_3 values for geldings fed low vs high dietary cation-anion balanced (DCAB) diets. It was further concluded

that horses consuming low DCAB diets may experience metabolic acidosis. Conversely, Tucker et al. (1992) indicated that blood pH and pCO_2 were not affected by dietary cation-anion balance of the diet in dairy cattle. Blood HCO_3 was reduced by a low DCAB diet. In a similar study (Tucker et al., 1988), daily DM intake of dairy cows decreased as DCAB of the diet decreased.

The literature indicates that blood acid-base status can have a role in reducing intake of domestic livestock. Further research is needed to document blood acid-base status of cattle consuming energy supplements while grazing high-quality pastures, and its possible role in regulation of forage intake.

Bacterial Competition. Bryant (1973, as cited by Horn and McCollum, 1987) discussed the probable symbiotic relationship between cellulolytic and noncellulolytic bacteria. He concluded that cellulolytic bacteria represent only 25% of the total viable population of bacteria in the rumen, even when cellulose is the only source of energy in the diet. Ammonia is the preferred N source for many bacteria (e.g., cellulolytics). These bacteria must depend on cross-feeding with either ureolytic or proteolytic species which produce ammonia (Yokoyama and Johnson, 1988). Accordingly, provision of RFC to low-quality roughage diets increases substrate availability and rate of fermentation, and may cause shortages of ruminal ammonia.

Digestion Lag Time. Mertens and Loften (1980) reported on the effects of the addition of purified wheat or corn starch to alfalfa, Coastal bermudagrass, fescue and orchardgrass hays on fiber digestion in vitro (pH maintained at 6.8). The addition of starch linearly increased lag time of fiber digestion, but digestion rate was not affected. A prediction equation for fiber digestibility using rate of passage has been reported (Mertens, 1977, as cited in Horn and McCollum, 1987). Horn and McCollum (1987) used this equation to try and account for the large depression in ruminal cellulose digestion noted by MacRae and Armstrong (1969) when starch was added to the diet. They could not account for the depression with this technique, but concluded that differences between in vitro and in vivo fiber digestibility when starch was added was due to differences in pH between the two systems. Teller et al. (1990) used Holstein-Friesian cows with

ruminal and duodenal cannulas to examine voluntary intake of direct cut or wilted perennial ryegrass. The authors concluded that particle size reduction was not the only factor limiting intake and that time lag for functional density of feed particles to increase was probably involved.

Associative Effects

Feeding different proportions of two or more feedstuffs together seldom results in a linear response in digestibility and net energy values. This deviation from linearity is referred to as an associative effect. Rust (1983) suggested that the presence of associative effects depends on the level of intake, physical and chemical composition of the diet, the proportion of concentrate to roughage, the source of N and (or) the presence of feed additives. Numerous studies have been reported in the literature concerning the effect of providing protein or energy supplements on forage digestion by grazing ruminants. Branine and Galyean (1990) reported that extent of in vitro wheat forage DM disappearance was increased by a corn grain plus monensin supplement relative to controls (no supplement) during the initial 30 h of ruminal incubation in early April. Steers fed the corn grain supplement without monensin also exhibited a greater extent of forage disappearance at 4 and 8 h of incubation than did control steers. Disappearance of forage was greater at 12 and 30 h with the monensin diet than with the grain diet, indicating an additive effect of monensin on wheat forage DM disappearance. However, by 48 h, extent of forage digestibility was equal across all treatments. Branine and Galyean (1990) concluded that since extent of digestion was generally greater for the monensin supplemented steers than for the steers fed grain without monensin during early incubation times, increased DM disappearance was probably more attributable to monensin than supplemental grain. Ellis et al. (1984b) suggested that monensin improves forage digestibility by increasing cell wall degradation by decreasing ruminal turnover time. In the Branine and Galyean (1990) study, rate of digestion (%/h) ranged from 6.2 to 7.3 in early April, 5.4 to 6.3 in late April and 6.7 to 7.6 in mid-May, but did not differ between treatments within sampling periods.

Rittenhouse et al. (1970) provided various levels (from 6.1 to 24.5 g/kg $BW^{.75}$) of supplement containing 4.7 to 45% protein to cattle grazing native range. Amount of supplemental energy had no effect on digestibility of the forage. Horn and McCollum (1987) concluded from several studies (Lamb and Eadie, 1979; Mould et al., 1983, as cited by Horn and McCollum, 1987) that effects of added concentrate on total tract digestion of roughages generally appear minor unless extremely large amounts are fed. In these studies, regression techniques were used to determine associative effects of grain (barley) supplementation on DM or OM digestibility of the roughage component of the diets. Data of Lamb and Eadie (1979) suggest that at levels up to 33 g DM/kg $BW^{.75}$, barley did not reduce OMD of the roughages. In the other study (Mould et al., 1983, as cited by Horn and McCollum, 1987) lambs were fed either chopped or ground and pelleted hay with various amounts of whole or rolled and pelleted barley (0, 30, 45, 60 or 75 g DM/kg $BW^{.75}$) with or without bicarbonate salts. Digestibility of the chopped hay was decreased by only 5.4% at the highest level of barley fed. However, digestibility of the ground and pelleted hay was decreased from 23 to 37% by 45 or 60 g barley DM/kg $BW^{.75}$. Bicarbonate prevented a reduction of hay degradation when it was included at a level of 3.5% of DM. Horn and McCollum (1987) concluded that form and type of roughage probably alter chewing and rumination time so that salivation varies, and that salivation is necessary to maintain rumen pH in a range conducive to cellulolysis when large amounts of supplemental concentrates are fed.

Substitution of Energy Supplements for Forages

The units change in forage intake per unit increase in concentrate intake is termed a substitution ratio. Substitution ratios vary depending on the quality of forage, the amount of supplement consumed and the species of livestock involved. Mieres and McCollum (1992) supplemented stocker cattle grazing tallgrass prairie in June and August with either 0, .2, .4, .6 or .8 g of an 84% corn supplement•100 g BW^{-1}•d^{-1}. The authors reported that compared to the forage OM intake and total OM intake of calves receiving no supplement, forage OM intake was

not depressed unless supplement intake exceeded .55 g/100g BW, which equates to about 21 g/kg $BW^{.75}$ for this study. Chase and Hibberd (1987) fed increasing amounts (0, 1, 2 or 3 kg/d) of corn grain to cows (mean weight, 328 kg) consuming low-quality native grass hay to determine effects on forage utilization. Hay intake decreased linearly with increasing amounts of corn intake and was most notable when 2 and 3 kg/d of corn was consumed. Therefore, a significant decrease in low-quality hay intake ocured when corn intake exceeded about 22.6 g/kg $BW^{.75}$. In and excellent review, Horn and McCollum (1987) summarized findings from several studies on the effects of increasing amounts of high-starch supplements on voluntary intake by cattle and sheep consuming forages of various DM and digestibilities. The authors found that the substitution ratio becomes more negative with increasing forage digestibility ($r = -.93$, cattle; $r = -.87$, sheep). Conclusions by Coleman (1977) and Jarrige et al. (1986) support the results discussed by Horn and McCollum (1987) that greater substitution ratios are associated with high-quality forages. Horn and McCollum (1987) observed that at concentrate intakes of 30 g/kg $BW^{.75}$, predicted forage intakes for cattle and sheep were 55 and 39 g/kg $BW^{.75}$, respectively. In most of the studies reviewed, the highest amount of concentrate fed did not exceed 35 g/kg $BW^{.75}$, yet conclusions are often found in the literature implying large substitution ratios of concentrate for forage. Accordingly, feeding concentrates at amounts of 30 g/kg $BW^{.75}$ or less may not result in large decreases in intake of high-quality forages.

A decrease in forage intake may be desirable when forage supplies are limited so energy supplements are often fed to substitute grain for forage intake. Cravey et al. (1992) reported a substitution ratio of -.86 for steers grazing wheat pasture and supplemented with increasing amounts (i.e., .4 to 1.2% BW) of energy supplements. Vogel et al. (1989) reported a substitution ratio of .66 in studies of effects of increasing amounts of supplemental silage on voluntary intake of wheat forage by steers. Lake et al. (1974) conducted a study to determine the influence of energy supplementation on performance of steers grazing irrigated pastures (i.e., orchardgrass, smooth bromegrass and alfalfa mixtures). Steers were fed increasing amounts of corn (i.e., from 0 to 2.7 kg/d). Forages reportedly contained about 20% CP on a DM basis. The authors

suggested that feeding energy supplements on high-quality pastures could decrease intake of forage and improve N utilization by reducing the N to energy ratio. Moore (1992) summarized 40 studies involving supplementation of non-lactating cattle and sheep consuming various forages. Change in voluntary forage DM intake (% of BW) due to feeding concentrate (substitution) ranged from +.21 (protein supplement) to -1.48 (barley). Level of concentrate fed ranged from .17 to 1.74% of BW. In all cases, when concentrate was fed, substitution was observed. Horn and McCollum (1987) concluded in their review, that it appears concentrates can be fed in amounts up to about 30 g/kg $BW^{.75}$ without effecting large decreases in forage intake. Pordomingo et al. (1991) reported corn grain supplemented at .2% BW to steers grazing summer blue grama rangeland in New Mexico, had no detrimental effects and tended to increase forage OM intake. However, supplement provided at .4 or .6% of BW decreased forage OM intake compared with 0 or .2% BW.

From the literature cited above, it appears that relatively small amounts of energy supplement (about 30 g/kg $BW^{.75}$, or less) can be fed to grazing ruminants without decreasing forage intake. Conversely, higher amounts can be fed to reduce intake in times of limited forage supplies ("stretch" forage). Horn (1992) advised caution in feeding high-starch energy supplements. The potential for lactic acid acidosis in cattle that consume these supplements abruptly warrants careful bunk management.

High-Fiber Energy Supplements

Interest in utilizing low-starch byproduct feeds in supplements for grazing ruminants has received considerable interest. Because of their low-starch content, these products are fairly safe to use yet still provide an excellent source of digestible energy. Examples of these feedstuffs include wheat middlings, corn gluten feed, soybean hulls and rice bran. Researchers in Missouri (Paterson et al., 1988) compared ground and pelleted corn to corn gluten feed as supplements fed to yearling cattle grazing fescue. When fed at 1% of BW whole corn and pelleted corn reduced forage intake (-19%) but a reduction in intake was not observed when corn

gluten feed was fed. Nebraska workers have reported on several studies with soybean hulls used as an energy source for ruminants (Anderson et al., 1988a; Anderson et al., 1988b; McDonnell et al., 1982; McDonnell et al. 1983; Merrill and Klopfenstein, 1984). Anderson et al. (1988a) conducted five trials utilizing beef calves grazing smooth brome or corn residue pastures, to compare soybean hulls with corn as an energy supplement. In general, soybean hulls were at least equal to corn in energy value as a supplement. The authors reported the advantage of soybean hulls was their high amount of digestible fiber vs starch of corn, therefore minimizing changes in ruminal fermentation and reducing the possibility of acidosis. McDonnell et al. (1982) reported that steers consuming corn stalks were supplemented with 0, 12.5, 25 or 50% of either soybean hulls or corn. Within levels of energy supplement consumed, steers had similar daily gains, whether consuming corn or soybean hulls. However, steers consuming soybean hulls tended to have a larger dry matter intake and thus, had a poorer feed efficiency. The Nebraska authors reported that soybean hulls contained about 74% NDF but that the NDF was 93-95% digestible.

Hibberd et al. (1986) suggested that soybean hull supplements may be a more efficient method of supplying energy to wintering beef cows than corn-based supplements. In this study, Hereford X Angus fall-calving beef cows were supplemented with either .59 kg cottonseed meal (CSM), 1.50 kg CSM, 2.81 kg corn-CSM blend or 3.5 kg soybean hulls per day while grazing dormant native grass. During the 117-d study, cows supplemented with soybean hulls lost less weight than corn supplemented cattle. The authors suggested that the corn supplement may have had a slight detrimental effect on forage utilization by decreasing forage digestibility and intake and that the soybean hulls may have truly supplemented consumed forage without decreasing forage digestibility.

High-fiber feedstuffs appear to be a good, and relatively safe source of supplemental energy for cattle grazing high-quality forages.

Effects of Energy Supplementation on Performance of Cattle Grazing High-Quality Pastures

Average daily gains on small grain pastures are potentially excellent because of the high-quality of the forage. Since forage availability can be extremely variable with cool season pastures, provisions of moderate to high levels of energy supplements can be used to "stretch" forage supplies, as previously discussed. Despite the high-quality of these forages, evidence exists to support additional gains by providing energy supplements to the grazing ruminant. The ratio of N/digestible organic matter (DOM) of forages in relation to the amount of non-ammonia nitrogen (NAN) digested in the intestine of sheep was examined by Hogan and Weston (1970). The authors report that when N/DOM was below about 3 the NAN digested in the intestine exceeded N intake. High-quality pastures such as wheat reflect N/DOM ratios of about 6 (i.e., 4.48/.75). Vogel et al. (1987) and Zorrilla-Rios et al. (1985) report that CP of wheat forage of two stages of maturity exist kinetically as two distinct pools in the rumen. Fifty to 75% of the forage N disappeared from a "very rapid disappearance" pool at rates of 13 to 28% per h. Thus, relatively small amounts of energy supplements provided to ruminants grazing high-quality pastures, such as wheat, may improve performance by reducing the N/DOM of the diet and increasing microbial protein synthesis in the rumen.

In the study by Branine and Galyean (1990), involving steers grazing wheat pasture and supplemented with 1) no grain (C), 2) .5 $kg \cdot hd^{-1} \cdot d^{-1}$ steam flaked milo (G) or 3) G plus 170 mg $monensin \cdot hd^{-1} \cdot d^{-1}$ it was reported that ruminal NH_3 was decreased by G and M in early April, decreased by G and increased by M in late April, and decreased by G in mid-May. The authors concluded that supplemental energy and not monensin was responsible for the decreased ruminal NH_3 concentrations. Dietary carbohydrate apparently reduced ruminal NH^3 concentration by facilitating the incorporation of ammonia N into microbial protein, subsequently increasing ammonia N flow to the small intestine. These results support the concept of improving performance of cattle on high-quality pastures by reducing the dietary N/DOM with

supplemental energy. Evidence by Hogan (1982) would suggest that a DOM:CP ratio between 4 and 10 would be optimum for animal performance.

Elder (1967) reported that gains of steers grazing wheat pasture, without supplement, ranged from .60 to .68 kg/d and when steers consumed between 2.27 to 2.72 kg/d of corn or grain sorghum supplement, gains ranged from .73 to .81 kg/d. This shows a supplementation response of .05 to .21 kg/d. Wagner et al. (1984) reported increased daily gains, averaged over a four year study, of .14 kg (.78 vs .64 kg) for steers supplemented with about 2.5 kg of grain/d. When steers grazing rye, wheat and ryegrass mixed pastures were supplemented with grain at a level of about 1.1% of BW, daily gains were increased by only .05 kg (Lowrey et al., 1976a; Lowrey 1976b). However stocking density was doubled where supplements were fed. Several studies reported by Utley and McCormick (1975 and 1976) indicate positive responses in ADG from grain supplementation. Daily gains of steers consuming corn at a level of about 1.5% of BW and grazing rye pastures were increased about .30 kg. Grigsby et al. (1991) and Rouquette et al. (1990) report supplementation responses in ADG between .15 and .57 kg when steers grazing rye-ryegrass pastures were supplemented with a corn ration at a level of about .15 to .2% of BW. Daily gains of cattle on rye-ryegrass pastures and supplemented with a corn ration at a level of about .4% of BW were reported to be .11 kg greater than controls (Rouquette et al., 1990).

When moderate levels of grain supplements were fed to cattle grazing winter annuals, supplement conversion (kg•kg increased gain^{-1}•HA^{-1}) ranged from 6.7 to 10.3, stocking density was increased by 21 to 100% (Elder, 1967; Gulbransen, 1976; Utley and McCormick, 1976; Lowrey et al., 1976a; Lowrey et al., 1976b). Work by Grigsby et al. (1991) showed supplement conversions of about 3 when supplements were fed at a level of about .2% BW to steers grazing cool season annuals. One would expect more efficient conversions with smaller amounts of supplement consumed (Horn and McCollum, 1987). Furthermore, in the studies of Grigsby et al. (1991) and Rouquette et al. (1990) the supplements contained the ionophore monensin which

improves feed efficiency and has been reported to reduce incidence of bloat (Branine and Galyean, 1990).

Concerns relative to the practice of energy supplementation programs on high-quality pastures on subsequent feedlot performance have been expressed by feedlot managers. Do supplemented calves exhibit reduced gains and intakes in the feedlot and do controls (no supplement) reflect compensatory gains? Bryant et al. (1965) fed ground shelled corn to steer calves (about 8 mo) and yearlings (about 16 mo) grazed continuously or rotationally on bluegrass, orchardgrass and white clover mixed pastures for 123 to 184 days. Previous grazing management (i.e., continuous vs rotational) had no significant effect on daily gains and carcass grades of the steers in drylot. Carcass grade of yearlings were not improved by feeding of corn on pasture. However, carcass grades of calves fed corn on pasture were subsequently one-half grade higher than those not fed corn. Calves, but not yearlings, fed corn on pasture gained more in drylot than calves and yearlings not fed corn on pasture. The steers previously fed corn on pasture ate .59 kg more corn and .64 kg less hay per day during the drylot period. Steers supplemented with corn at a level of 1% of BW during grazing reached full feed more quickly in the feedlot than control steers.

Lake et al. (1974) reported on the supplementation of energy (ground corn) to yearling steers grazing irrigated pastures (i.e., orchardgrass, smooth bromegrass and alfalfa mixtures) and their subsequent feedlot performance in two trials. The corn was fed at 0, .23, .45, .91 or 1.82 kg/d. The steers grazed pasture for 119 to 122 days and were on feed for 89 to 144 days, depending on treatment. In the first trial, steers that received .91 kg corn daily while grazing gained faster in the feedlot than the other treatments. No explanation was offered for this. In the second trial daily gains in the feedlot were not affected by previous energy supplementation. Feed intake and conversion could not be analyzed because of lack of replication but it was stated that only small differences were noted among treatments. None of the carcass characteristics were affected by energy fed on pasture, in the second trial, but in the first trial, carcass weights and grades were different among pasture treatments for which no explanation

was known. Energy supplementation did appear to decrease the number of days required in the feedlot.

Coleman and Evans (1982) conducted a study to determine the effect of a low vs moderate rate of gain during the growing phase (two diets: control = dehydrated alfalfa pellets; restricted = cubed grass-alfalfa hay, cottonseed hulls and soybean meal) of two breeds of steers (Angus and Charolais) and two ages (i.e., spring-born, older vs fall-born, younger) on performance during the subsequent finishing phase. Older, restricted steers exhibited compensatory gains from 30 to 120 days after the beginning of the feedlot phase, while older, control steers did not. Rates of gain of younger, restricted steers was intermediate to those of the older steers throughout the finishing phase and were not influenced by growing diet. During the initial growing phase control steers averaged .72 kg/d gain while restricted steers averaged .25 kg/d and rate of gain during the finishing phase was negatively correlated to the rate of gain during the growing phase. Feedlot feed/gain for restricted steers was slightly lower ($P < .05$) than control steers.

Results from the literature indicate that steers supplemented with grain on pasture may have slightly lower daily gains in the feedlot than control steers. However, the magnitude of these effects appears to be dependent on numerous factors such as age, level and type of supplement fed, and length of the grazing and feeding periods.

Use of Controlled Release Chromium Capsules For Estimating Fecal Output Of Grazing Ruminants

Quantifying forage intake of grazing animals requires knowledge of digestibility of the forage and fecal output of the animal. Use of external markers such as chromium has been of interest to researchers for many years (Smith and Reid, 1955; Pigden and Brisson, 1956). A controlled-release chromic oxide (Cr_2O_3) device has been recently developed to potentially reduce the labor and adverse effects of repeated dosing, or from the presence of fecal bags during total fecal collection of ruminants. Buntinx et al. (1992) reported on the efficacy of this device in estimating fecal output of lambs. Three trials were conducted. In trial 1, 14 crossbred

wethers were dosed with the capsule and rotationally grazed for 18 days on alfalfa paddocks. Daily total fecal collections (actual fecal output) and grab samples (predicted fecal output) were taken. In trial 2, bermudagrass was strip-grazed for 30 days by the same wethers used in trial 1. In trial 3, 72 crossbred lambs were assigned to six groups of eight wethers (four with fecal bags) and four ewes, and allotted to three stocking rates (74, 99 and 148 sheep/ha). Sampling was conducted from day 6 to 10 (period 1) after dosing and day 20 to 24 (period 2) after dosing. In trial 1, the correlation between actual and predicted fecal output was r = .59. The data were averaged by day and the correlation increased to r = .82. In trial 2 mean actual fecal output differed ($P < .0001$) from predicted fecal output, with a correlation of .60. In trial 3 there was a correlation of r = .63 and r = .46 between actual and predicted fecal output, for periods 1 and 2, respectively. The capsule underestimated fecal output (80 to 87% of actual fecal output) in trial 1. In trials 2 and 3, actual fecal output was overestimated (104 to 164% of actual output). Hatfield et al. (1990) reported similar results. Buntnix et al. (1992) concluded that the controlled-release Cr_2O_3 device did not adequately predict total fecal output by wether lambs. It was suggested by Hatfield et al. (1990) that the capsule did a better job of estimating fecal output of grazing sheep than of confined sheep, but these results disagree with those of Pond et al. (1987) and Buntinx et al. (1992).

Parker et al. (1989, 1990) reported on the lack of consistency of the controlled-release device to predict fecal output. First, they noted that plunger travel was related linearly to time, but there was significant variation about the regression line, which increased with time. Secondly, plunger travel tended to increase with decreasing DM digestibility and interacted with feed type. Thirdly, release rates of the capsule were 8 to 12% slower in ruminally fistulated sheep with the capsule attached to the cannula than intact sheep.

Pond et al. (1990, as cited in Buntnix et al., 1992) noted that animal variation was involved in the use of the capsules. The authors dosed four capsules each to steers consuming alfalfa hay or a pelleted diet at two levels of intake and found minimal variation in the release of Cr_2O_3 within an animal but considerable difference between animals on the same diet. Diurnal

variation in release rate of Cr_2O_3 due to grazing patterns has also been of concern (Parker et al., 1989; Buntnix et al. 1992). Parker et al. (1989) advocate the use of the controlled-release device for estimating mean animal intake in grazing situations, however the work of Buntnix et al. (1992) disagrees with this.

The previous findings indicate that at the current stage of development the controlled-release capsule does not provide enough accuracy to be used in experimental situations.

Summary of Review of Literature

The high-quality of cool season annuals such as wheat forage provide the potential for excellent weight gains by grazing animals. However, provision of energy supplements to ruminants grazing these forages has been shown to increase animal performance and can be used to stretch inadequate forage supplies. Development of energy supplementation programs is limited by a lack of understanding of the interacting factors that affect forage utilization and cause substitution of supplement for forage. Current relationships do not permit accurate prediction of effects of supplementation on forage intake and utilization.

Ruminal mechanisms (i.e., osmolality and pH) and blood acid/base status are believed to be involved in the mechanisms by which energy supplements affect intake and utilization of high-quality forages, but concrete evidence is lacking. In these situations, ruminal pH is often lower and may play a role in depressing rate of fiber digestion and (or) wahout of cellulolytic bacteria. Fluctuations of rumen osmolality and blood acid/base status on these diets is probable but its their role in affecting forage intake needs documentation.

Highly digestible fiber sources such as wheat middlings and soybean hulls offer opportunities to formulate energy supplements with fairly high energy densities. The reduced potential for lactic acid acidosis from these byproduct feedstuffs, as compared to high-starch energy supplements, warrants further investigation of their use as supplements to ruminants grazing high-quality forages.

Literature Cited

Anderson, S. J., J. K. Merrill and T. J. Klopfenstein. 1988a. Soybean hulls an energy supplement for the grazing ruminant. J. Anim. Sci. 66:2959.

Anderson, S. J., J. K. Merrill, M. L. McDonnell and T. J. Klopfenstein. 1988b. Digestibility and utilization of mechanically processed soybean hulls. J. Anim. Sci. 66:2965.

Arelovich, H. M. 1983. Effect of protein and starch supplementation on the utilization of low-quality roughages. M.S. Thesis. Oklahoma State University.

Baker, L. A., D. R. Topliff, S. W. Freeman, R. G. Teeter, and J. W. Breazile. 1991. Effect of dietary cation-anion balance on acid-base status in horses. Okla. Agr. Exp. Sta. Res. Rep. MP-134.

Balch, C. C. 1971. Proposal to use time spent chewing as an index of the extent to which diets for ruminants posses the physical property of fibrousness characteristics of roughages. Br. J. Nutr. 26:383.

Beever, D. E., D. J. Thompson and S. B. Cammell. 1976. The digestion of frozen and dried grass by sheep. J. Agric. Sci. Camb. 86:443.

Beever, D. E., M.S. Dhonoa, H. R. Losada, R. T. Evans, S. B. Cammell and J. France. 1986. The effect of forage species and stage of harvest on the processes of digestion occurring in the rumen of cattle. Br. J. Nutr. 56:209.

Bergen, W. G. 1972. Rumen osmolality and feed intake. J. Anim. Sci. 34:1054.

Blaxter, K. L. and R. S. Wilson. 1963. The assessment of a crop husbandry technique in terms of animal production. Anim. Prod. 5:27.

Bohman, V. R., F. P. Horn, E. T. Littledike, J. G. Hurst and D. Griffin. 1984. Mechanisms of tetany in cows grazed on wheat pastures. In: G. W. Horn (ed.). Natl. Wheat Pasture Symp. Proc. Okla. Agr. Exp. Sta. Pub. MP-115.

Bohman, V. R., F. P. Horn, B. A. Stewart, A. C. Mathers, and D. L. Grunes. 1983. Wheat pasture poisoning. I. An evaluation of cereal pastures as related to tetany in beef cows. J. Anim. Sci. 57:1352.

Branine, M. E. and M. L. Galyean. 1990. Influence of grain and monensin supplementation on ruminal fermentation, intake, digesta kinetics and incidence and severity of frothy bloat in steers grazing winter wheat pasture. J. Anim. Sci. 68:1139.

Breazile, J. E. 1984. Role of magnesium, potassium and calcium in normal neuromuscular functions in ruminants. In: G. W. Horn (Ed.). Proc. Natl. Wheat Pasture Symp. Okla. Agr. Exp. Sta. Pub. MP-115.

Bryant, H. T., R. C. Hammes, Jr., R. E. Blaser and J. P. Fontenot. 1965. Effects of feeding grain to grazing steers to be fed fattened in drylot. J. Anim. Sci. 24:676.

Buntinx, S. E., K. R. Pond, D. S. Fisher and J. C. Burns. 1992. Evaluation of the Captec Chrome controlled release device for the estimation of fecal output by grazing sheep. J. Anim. Sci. 70:2243.

Campling, R. R. and M. Freer. 1966. Factors affecting the voluntary intake of food by cows. 6. A preliminary experiment with ground, pelleted hay. Br. J. Nutr. 17:263.

Carter, R. and W. L. Grovum. 1990. A review of the physiological significance of hypertonic body fluids on feed intake and ruminal function: Salivation, motility and microbes. J. Anim. Sci. 68:2811.

Carver, B. F., E. G. Krenzer, Jr. and W. E. Whitmore. 1991. Seasonal forage production and regrowth of hard red winter wheat. Agron. J. 83:553.

Caton, J. S., A. S. Freeman and M. L. Galyean. 1988. Influence of protein supplementation on forage intake, in situ forage disappearance, ruminal fermentation and digestia passage rates in steers grazing dormant blue grama rangeland. J. Anim. Sci. 66:2262.

Chase, C. C., Jr., and C. A. Hibberd. 1987. Utilization of low-quality native grass hay by beef cows fed increasing quantities of com grain. J. Anim. Sci. 65:557.

Clay, B. R. 1973. Stocker cattle losses on small grain pastures. J. Okla. Vet. Med. Assn. 25:15.

Coleman, S. W. 1977. Energy supplementation of grazing cattle. Proc. of Amer. Forage and Grassland Council Rep. EC 80-218, p 9.

Coleman, S. W. and B. C. Evans. 1982. Effect of nutrition, age and size on compensatory growth in two breeds of steers. J. Anim. Sci. 63:1968.

Cravey, M. D., G. W. Horn, F. T. McCollum and P. A. Beck. 1992. Effect of high-starch versus high-fiber energy supplements on forage intake of steers grazing wheat pasture. J. Anim. Sci. 70 (Suppl. 1):89. (Abstr.).

DelCurto, T., R. C Cochran, L. R. Corah, A. A. Beharka, E. S. Vanzant and D. E. Johnson. 1990. Supplementation of dormant tallgrass-prairie. II. Performance and forage utilization characteristics in grazing beef cattle receiving supplements on different protein concentrations. J. Anim. Sci. 68:532.

Donefer, E., P. J. Nieman, E. W. Crampton and L. E. Loyd. 1963. Dry matter disappearance by enzyme and aqueous solutions to predict the nutritive value of forages. J. Dairy Sci. 46:965.

Elder, W. C. 1967. Winter grazing small grains in Oklahoma. Okla. Agr. Exp. Sta. Bull. B-654.

Ellis, W. C., J. P. Telford, H. Lippke and M. E. Riewe. 1984a. Forage and grazing effects on utilization of annual ryegrass by cattle. In: G. W. Horn (Ed.). Proc. Natl. Wheat Pasture Symp. Okla. Agr. Exp. Sta. Pub. MP-115.

Ellis, W. C., G. W. Horn, D. Delaney and K. R. Pond. 1984b. Effects of ionophores on grazed forage utilization and their economic value for cattle on wheat pastures. In: G. W. Horn (Ed.). Proc. Natl. Wheat Pasture Symp. Okla. Agr. Exp. Sta. Pub. MP-115.

Grigsby, K. N., F. M. Rouquette, Jr., W. C. Ellis and D. P. Hutcheson. 1991. Use of self-limiting fishmeal and corn supplements for calves grazing rye-ryegrass pastures. J. Prod. Agr. 4:476.

Grovum, W. L. 1988. Appetite, palatability and control of feed intake. In: D. C. Church (Ed.) The Ruminant Animal. pp. 202-216. Prentice Hall, Englewood Cliffs, NJ.

Gulbransen, B. 1976. Response to supplementary sorghum grain by cattle grazing oats. Aust. J. Exp. Agr. & Anim. Husb. 16:646.

Guthrie, M. J. 1984. Effect of protein or energy supplementation on intake, utilization and rate of passage of medium quality roughage. M.S. Thesis. Oklahoma State University.

Hatfield, P. G., J. W. Walker, H. A. Glimp and D. C. Adams. 1990. Effect of intake levels and supplemental barley on estimates of dry matter fecal output using a constant release chromic oxide bolus. J. Anim. Sci. 68 (Suppl. 1):184 (Abstr.).

Hibberd, C. A., C. C. Chase and C. Worthington. 1986. Corn vs soybean hull supplements for fall-calving beef cows in winter. Okla. Agr. Exp. Sta. Res. Rep. MP-118:192.

Hogan, J. P. 1982. Digestion and utilization of proteins. In: J. B. Hacker (Ed.). Nutritional Limits to Animal Production From Pastures. pp. 245-257.

Hogan, J. P. and R. H. Weston. 1970. Quantitative aspects of microbial protein synthesis in the rumen. In: A. T. Phillipson (Ed.). Physiology of Digestion and Metabolism in the Ruminant. p. 474.

Horn, G. W., T. L. Mader, S. L. Armbruster and R. R. Frahm. 1981. Effect of monensin on ruminal fermentation, forage intake and weight gains of wheat pasture stocker cattle. J. Anim. Sci. 52:447.

Horn, G. W. (Ed.). 1984. Proc. Natl. Wheat Pasture Symp. Okla. Agr. Exp. Sta. Pub. MP-115.

Horn, G. W., B. R. Clay and L. I. Croy. 1977. Wheat pasture bloat of stockers. Okla. Agr. Exp. Sta. Res. Rep. MP-101:206.

Horn, G. W. 1992. Supplementation strategies for wheat pasture stocker cattle. In: Proc. Wheatland Stocker Conference. August 21, Enid, OK.

Horn, G. W. and F. T. McCollum. 1987. Energy supplementation of grazing ruminants. pp. 125-137. Proc. of the Grazing Livestock Nutr. Conf. Univ. of Wyoming, Laramie.

Horn, G. W., J. L. Gordon, E. C. Prigge and F. N. Owens. 1979. Dietary buffers and ruminal blood parameters of subclinical lactic acidosis in steers. J. Anim. Sci. 48:683.

Huber, T. L. 1976. Physiological effects of acidosis on feedlot cattle. J. Anim. Sci. 43:902.

Jarrige, R., C. Demarquilly, J. P. Dulphy, A. Holden, J. Robelin, C. Beranger, Y. Geay, M. Journet, C. Malterre, D. Micol and M. Petit. 1986. The INRA "Fill Unit" system for predicting the voluntary intake of forage-based diets in ruminants: A review. J. Anim. Sci. 63:1737.

Johnson, R. R., F. P. Horn and A. D. Tillman. 1974. Influence of harvest date and N and K fertility levels on soluble carbohydrate and nitrogen fractions in winter wheat pasture. Okla. Agr. Exp. Sta. Res. Rep. MP-92:37.

Johnson, R. R., F. P. Horn and A. S. Tillman. 1974. Influence of harvest date and N and K fertility levels on soluble carbohydrate and nitrogen fractions in winter wheat pasture. Okla. Agr. Exp. Sta. Res. Rep. MP-92-37.

Lake, R. P., R. L. Hildebrand, D. C. Clanton and L. E. Jones. 1974. Limited energy supplementation of yearling steers grazing irrigated pasture and subsequent feedlot performance. 39:827.

Lamb, C. S. and J. Eadie. 1979. The effect of barley supplements on the voluntary intake and digestion of low quality roughages by sheep. J. Agric. Sci. (Camb.) 92:235.

Lowrey, R. S., G. V. Calvert, H. C. McCampbell and F. Woods. 1976a. Finishing weanling steers on winter pasture with or without grain. J. Anim. Sci. 42:260. (Abstr.).

Lowrey, R. S., H. C. McCampbell, G. V. Calvert, E. Beaty and F. Woods. 1976b. Effect of previous treatment and energy levels on finishing yearling steers on winter pasture. J. Anim. Sci. 42:260 (Abstr.).

MacRae, J. C. and D. G. Armstrong. 1969. Studies on intestinal digestion in sheep. 2. Digestion of some carbohydrate constituents in hay, cereal and hay-cereal rations. Brit. J. Nutr. 23:377.

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.

McCollum, F. T. III, M. D. Cravey, S. A. Gunter, J. M. Mieres, P. A. Beck, R. San Julian and G. W. Horn. 1992. Forage availability affects wheat forage intake by stocker cattle. Okla. Agr. Exp. Sta. Res. Rep. MP-136.

McDonald, P., R. A. Edwards and J. F .D. Greenhalgh. 1988. Animal Nutrition. William Clowes Ltd. London, England.

McDonnell, M. L., T. J. Klopfenstein and J. K. Merrill. 1982. Soybean hulls as energy source for ruminants. Beef Cattle Rep., Nebraska-Lincoln, MP 43:54.

McDonnell, M. L., T. J. Klopfenstein and J. K. Merrill. 1983. Soybean hulls can replace corn in growing rations. NK Beef Cattle Rep. MP-43:54.

Mieres, J. M. and F. T. McCollum III. 1992. Forage intake and digestibility by growing beef cattle supllemented with corn while grazing tallgrass prairie. J. Anim. Sci. 70:183. (Abstr.).

Merrill, J. K. and T. J. Klopfenstein. 1984. Soybean hulls for grazing beef cattle. Beef Cattle Rep., Nebraska-Lincoln, MP 47:40.

Mertens, D. R. and J. R. Loften. 1980. The effect of starch on forage fiber digestion kinetics in vitro. J. Dairy Sci. 63:1437.

Minson, D. J. .1982. Effects of chemical and physical composition of herbage eaten upon intake. In: J. B. Hacker (Ed.). Nutritional Limits to Animal Production from Pastures. p 167. Commonwealth Agricultural Bureaux, Slough, UK.

Moore, J. E. 1992. Matching protein and energy supplements to forage quality. Proc. Third Florida Ruminant Nutrition Symposium. Gainesville, FL. p 31.

Mould, F. L., E. R. Ørskov and S. O. Mann. 1983. Associative effects of mixed feeds. I. Effects of type and level of supplementation and the influence of the rumen fluid pH on cellulolysis in vivo and dry matter digestion of various roughages. Anim. Feed Sci. Tech. 10:15.

Mould, F. L. and E. R. Ørskov. 1983. Manipulation of rumen fluid pH and its influence on cellulolysis in sacco, dry matter degradation and the rumen microflora of sheep offered either hay or concentrate. Anim. Feed Sci. Tech. 10:15.

NRC. 1984. Nutrient Requirements of Beef Cattle. Sixth Revised Edition. National Academy Press. Washington, D. C.

Owens, F. N. and A. L. Goetsch. 1988. Ruminal Fermentation. In: D. C. Church (Ed.) The Ruminant Animal. pp. 145-171. Prentice Hall, Englewood Cliffs, NJ.

Parker, W. J., S. N. McCutcheon, and D. H. Carr. 1989. Effect of herbage type and level of intake on the release of chromic oxide from intraruminal controlled release capsules in sheep. N.Z. J. Agric. Res. 32:537.

Parker, W. J., S. N. McCutcheon and D. J. Garrick. 1990. The suitability of chromic controlled release capsules for estimating herbage intake of grazing ruminants. Paper presented at 8th Aust. Assoc. Anim. Breed. Genet. Conf., Massey Univ., Palmerston North, New Zealand.

Patterson, J. A., S. Hannah, M. T. Rhodes and M. S. Kerley. 1988. Influence of energy supplements on tall fescue utilization. Anim. Sci. Rep. 116:30. Univ. Missouri-Columbia.

Phillip, L. E., J. G. Buchanan-Smith and W. L. Grovum. 1981. Food intake and ruminal osmolality in the sheep: Differentiation of the effect of osmolality from that of the products of maize silage fermentation. J. Agric. Sci. (Camb.) 96:439.

Pigden, W. J. and G. J. Brisson. 1956. Effect of frequency of administration of chromic oxide on its fecal excretion pattern by grazing wethers. Can. J. Anim. Sci. 36:146.

Pond, K. R., R. C. Burns, and D. S. Fisher. 1987. External markers-Use and methodology in grazing studies. In: Proc. Grazing Livest. Nutr. Conf. pp 49-53. Univ. of Wyoming, Jackson.

Poppi, D. P., B. W. Norton, D. J. Minson and R. E. Hendrickson. 1980. The validity of the critical size theory for particles leaving the rumen. J. Agr. Sci. (Camb.) 94:275.

Pordomingo, A. J., J. D. Wallace, A. S. Freeman and M. L. Galyean. 1991. Supplemental corn grain for steers grazing native rangeland during summer. J. Anim. Sci. 69:1678.

Rittenhouse, L. R., D. C. Clanton and C. L. Streeter. 1970. Intake and digestibility of winter-range forage by cattle with and without supplements. J. Anim. Sci. 37:1215.

Rouquette, F. M., Jr., M. J. Florence, D. P. Hutcheson and W. C. Ellis. 1990. Influence of level of daily supplement intake on performance of calves grazing rye-ryegrass pastures. Texas Agric. Exp. Sta. Tech. Rep. 90-1:190.

Russell, J. B. and D. B. Dombrowski. 1980. Effects of pH on the efficiency of growth by pure cultures of rumen bacteria in continuous culture. Appl. Environ. Microbiol. 39:604.

Rust, S. R. 1983. Associative effects in the ruminant animal. Ph.D. Dissertation. Oklahoma State University, Stillwater.

Shriver, B. J., W. H. Hoover, J. P. Sargent, R. J. Crawford, Jr. and W. V. Thayne. 1986. Fermentation of a high concentrate diet as affected by ruminal pH and digesta flow. J. Dairy Sci. 69:413.

Smith, A. M. and J. T. Reid. 1955. Use of chromic oxide as an indicator of fecal output for the purpose of determining the intake of pasture herbage by grazing cows. J. Dairy Sci. 38:515.

Stewart, B. A., D. L. Grunes, A. C. Mathers and F. P. Horn. 1981. Chemical composition of winter wheat forage grown where grass tetany and bloat occur. Agron. J. 73:77.

Stewart, C. S. 1977. Factors affecting the cellulolytic activity of rumen contents. Appl. Environ. Microbiol. 33:497.

Teller, E., M. Vanbelle, P. Kamatali, G. Collignon, B. Page and B. Matatu. 1990. Effects of chewing behavior and ruminal digestion processes on voluntary intake of grass silages by lactating dairy cows. J. Anim. Sci. 68:3897.

Tucker, W. B., J. F. Hogue, D. F. Waterman, T. S. Swenson, Z. Xin, R. W. Hemken, J. A. Jackson, G. D. Adams, and L. J. Spicer. 1992. Sulfur should be included when calculating the dietary cation-anion balance of diets for lactating dairy cows. Okla. Agr. Exp. Sta. Res. Rep. MP-136.

Tucker, W. B., G. A. Harrison and R. W. Hemken. 1988. Influence of dietary cation-anion balance on milk blood, urine and rumen fluid in lactating dairy cattle. J. Dairy Sci. 71:346.

Uhart, B. A. and F. D. Carrol. 1967. Acidosis in beef steers. J. Anim. Sci. 26:1195.

Utley, P. R. and W. C. McCormick. 1975. Dry or high-moisture corn for finishing steers in drylot or on oat pasture. J. Anim. Sci. 41:495.

Utley, P. R. and W. C. McCormick. 1976. Corn or grain sorghum for finishing steers in drylot or on rye pasture. J. Anim. Sci. 43:1141.

Van Soest, P. J. 1982. Nutritional Ecology of the Ruminant. O. and B. Books, Inc. Corvallis, OR.

Vogel, G. J. 1988. Kinetics of ruminal nitrogen digestion of wheat forage and high protein feedstuffs and the effects of supplemental protein on the performance of growing cattle on wheat pasture. Ph.D. Dissertation. Oklahoma State University, Stillwater.

Vogel, G. J., W. A. Phillips, G. W. Horn, M. J. Ford and R. W. McNew. 1989. Effects of supplemental silage on forage intake and utilization by steers grazing wheat pasture or bermudagrass. J. Anim. Sci. 67:232.

Vogel, G. J., M. A. Andersen and G. W. Horn. 1987. Rate and extent of ruminal digestion of wheat forage and protein supplements by steers grazing wheat pasture. Okla. Agr. Exp. Sta. Res. Rep. MP-119.

Wagner, D., R. Lowrey and M. Grigsby. 1984. Supplemental feeding of grain and protein for stocker cattle on small grain pastures. In : G. W. Horn (Ed.). Proc. Natl. Wheat Pasture Symp. Okla. Agr. Exp. Sta. Pub. MP-115:327.

Yokoyama, M. T. and K. A. Johnson. 1988. Microbiology of the Rumen and Intestine. In: D. C. Church (Ed.) The Ruminant Animal. pp. 125-144. Prentice Hall, Englewood Cliffs, NJ.

Zorrilla-Rios, J. G. W. Horn, R. W. McNew and K. B. Poling. 1985. In situ disappearance of dry matter and nitrogen of wheat forage, corn gluten meal, cottonseed meal and soybean meal in steers grazing wheat pasture at two stages of maturity. Okla. State Univ. Anim. Sci. Res. Rep. MP-117:169.

CHAPTER III

INFLUENCE OF HIGH-STARCH VERSUS HIGH-FIBER ENERGY SUPPLEMENTS ON PERFORMANCE OF STOCKER CATTLE GRAZING WHEAT PASTURE, SUBSEQUENT FEEDLOT PERFORMANCE AND CARCASS CHARACTERISTICS[1]

M. D. Cravey,[2,3] G. W. Horn,[2] F. T. McCollum,[2] C. A. Strasia[2] and P. L. Claypool[4]

Oklahoma Agricultural Experiment Station
Stillwater, OK 74078-0425

ABSTRACT

A study was conducted over three wheat grazing seasons (1989 - 92) to determine effects of high-starch (HS) or high-fiber (HF) energy supplements on performance of fall-weaned steers (n = 192, Experiments 1 and 2; n = 84, Experiment 3) grazing wheat pasture (Triticum aestivum variety 2157) and subsequent feedlot performance. The steers received 1) no supplement (CL) other than access to a free-choice mineral or were hand fed 6 d/week, or 2) a corn-based HS supplement, or 3) a soybean hull/wheat middling based HF supplement. In Experiment 1 (1989 - 90), a fourth treatment group was fed the HF supplement ad libitum (SFHF). Supplements were formulated to contain monensin at a concentration of about 88 mg/kg and the combination of ionophore, minerals and salt (8%) was used to limit intake of the SFHF supplement. Target level of consumption was .75% of mean BW. In Experiments 1 and 3 (1991 - 92), where supplements were fed, stocking rate was increased by 33% (i.e., from 1.24 to

---

[1]Journal article No. XXXX of the Oklahoma Agricultural Experiment Station.
[2]Animal Science Department.
[3]We thank Bobby McDaniel for his excellent work with animal care and maintenance of the Research Unit, Donna Perry for assistance with the laboratory analyses, and Paul Beck and Ken Poling for assistance with collection of data.
[4]Department of Statistics.

1.65 head/ha). Stocking rates were increased from 22 to 44% in Experiment 2 (1990 - 91). Sixteen pastures (7.29 to 9.72 ha) in Experiments 1 and 3, and seven pastures (7.29 to 9.72 ha) in Experiment 2, were available for grazing. Subsequent to the grazing seasons in Experiments 2 and 3, feedlot performance and carcass characteristics were evaluated. Supplementation increased daily gains in each experiment ($P < .02$). Daily gains of SFHF cattle (Experiment 1) tended to be lower ($P < .10$) than HF steers (1.02 vs 1.07). Treatments on wheat pasture exhibited no consistent influence on feedlot performance. Differences probably would become apparent as weights of the cattle and standing forage deviate from the ranges observed in this study. Over the 3-year period (pooled analysis), mean supplement consumption was .66 % BW/d. Daily gains were increased ($P < .001$) .15 kg by supplementation and were .92 kg, 1.06 kg and 1.08 kg for CL, HS and HF, respectively. Daily gains were not influenced ($P > .45$) by type of supplement. Mean supplement conversions (kg supplement fed•kg increased gain^{-1}• ha^{-1}) were 5.04 for HS and 5.02 for HF and did not differ ($P > .95$). This study indicated that supplementation of fall-weaned wheat pasture stocker cattle with a moderate (.66 % BW/d) amount of high-starch or high-fiber energy supplements allowed stocking rate to be increased by about one-third and increased daily gains by .15 kg.

(Key Words: Growing Cattle, Wheat Pasture, Energy Supplementation)

Introduction

Energy supplementation of cattle grazing wheat and other small grain forages is of interest in order to provide a more balanced nutrient supply and to deliver feed additives such as ionophores and bloat preventive compounds (i.e., poloxalene). However, the response of growing cattle to this supplementation practice has been relatively variable in terms of daily gain and supplement conversion. In studies reported by Elder (1967), Lowrey et al. (1976a and 1976b) and Utley and McCormick (1975 and 1976) steer grazing d/ha or stocking rates were increased 1.25 to 2-fold and daily gains were increased by .05 to .30 kg by feeding grain at levels

of 1 to 1.5% of BW. Supplement conversions (kg supplement fed•kg increased gain^{-1}•ha^{-1}) ranged from 6.7 to 9.4. Further research is needed before specific recommendations can be made.

Energy supplements may have very different effects on ruminal pH and forage intake and utilization depending on the feedstuff composition of the supplement, the form and type of roughage and resulting rates of particle fragmentation (and therefore chewing and rumination times and salivation). To prevent the adverse effects of starch on ruminal fermentation, high-fiber by-product feeds, such as wheat middlings, soybean hulls and corn gluten feed, offer alternatives to formulate energy supplements with fairly high energy densities. The potential for use of these by-product feeds in supplementing growing cattle on wheat pasture is particularly high because of the rapid rate of ruminal degradation of wheat forage and the relatively low ruminal pH values of these cattle (Andersen and Horn, 1987).

The objectives of this study were to evaluate the effects of a moderate amount (approximately .75% BW) of either a high-starch or high-fiber based energy supplement on performance of cattle grazing wheat pasture and subsequent feedlot performance.

Experimental Procedure

Study Site. The studies were conducted at the Wheat Pasture Research Unit in Logan County, OK near Marshall. Each year the area was planted (clean-till) to Triticum aestivum variety 2157, hard red winter wheat at a seeding rate of about 100 kg/ha. Fertilization was according to soil test each year and N, P and K were applied in amounts for production goals of 3350 kg forage DM/ha and 50 bushels of wheat/acre. Most of the N was applied prior to planting as anhydrous ammonia. Some N and needed amounts of P were applied as 18-46-0 using a fertilizer attachment to the grain drill.

Standing forage in each of the pastures was estimated during each experiment by hand clipping forage to ground level inside .5 m^2 quadrats along paced transects. Clipping dates were November 16 and January 8 for year 1; November 15, January 18 and February 21 for year 2;

and December 5, January 21 and February 27 for year 3. Mean forage availability estimates, by year, are shown in Table 1. A detailed summarization of clipping data and forage availability estimates for the Research Unit are shown in Appendix A.

Cattle. Fall-weaned steer calves were used each year. In year 1, the cattle were from two sources and consisted primarily of Hereford x Angus and Continental x British crossbred steers. In years 2 and 3, the steers were Brangus x Angus and Brangus x Hereford/Angus crossbred steers from a single ranch in Nebraska. Each year the steers were processed on arrival and were fed bermudagrass hay (free-choice) and .91 $kg \cdot head^{-1} \cdot d^{-1}$ of a soybean meal-based, high-protein supplement for about 28 d prior to being placed on wheat pasture. The steers were treated for internal and external parasites and vaccinated (IBR, PI_3, BVD, BRSV and a 5-way Clostridial vaccine) during processing. Steers were implanted with Synovex-S immediately prior to placement on wheat pasture.

Experiment 1. One-hundred and ninety-two (192) calves and 16 pastures were used. The steers were allocated randomly, within weight and breed groups, to four treatments of 48 steers each in a randomized complete block design with four blocks (i.e., potential north to south soil gradient). Steers received no supplement other than free-choice access to a commercial mineral mixture[5] (CI) or were hand fed 6 d/wk a corn-based energy supplement (i.e., high-starch supplement (HS) or a high-fiber energy supplement (HF) that contained about 47% soybean hulls and 46% wheat middlings (as-fed). The fourth treatment was fed the high-fiber energy supplement ad libitum (SFHF). Composition of the 5 mm pelleted supplements is shown in Table 2. Starch content (DM basis) was about 67% for HS compared to 18% for HF. All supplements contained monensin at a concentration of 88 mg/kg and the SFHF contained 8% salt. Stocking rate on wheat pasture was increased 33% (i.e., from 1.24 to 1.65 ha/head) where the energy supplements were fed. The supplements were fed for 96 d of the 115-d trial. Target level of consumption was .75% of mean BW.

---

[5]Wheat Gainer Mineral; Farmland Industries, Inc. The mineral contained 20% salt, 16% calcium, 4% phosphorus and 5.5% magnesium.

Supplement refusals were weighed weekly or more frequently in inclement weather (i.e., rain or snow) in order to keep fresh supplement in front of the cattle. If any of the refusals had accumulated moisture, they were mixed and samples were dried to constant weights, at 65° C, in a forced-air oven. Average daily consumption of supplement by cattle of each pasture was determined weekly, and used to calculate daily consumption over the total supplemental period. Supplement conversion was calculated as kg of supplement (as-fed) •kg increased gain^{-1}•ha^{-1}, with the control treatments, within blocks, being the basis for comparison. Initial, intermittent and final live weights of the steers were measured after overnight shrinks of 16 to 18 h without feed and water.

Statistical analyses were performed using the General Linear Models of SAS (1988). Experimental units were pastures and sampling units were steers. Variables of interest (i.e, pasture means) included ADG (kg/head), beef gain/ha (kg) and supplement conversion. Sources of variation for these performance measurements were supplementation treatment and block. F-values for treatment were calculated using the treatment X block interaction. Orthogonal contrasts included supplementation vs. no supplementation (i.e., CL vs the average of HS, HF and SFHF), type of supplement (i.e., HS vs. HF) and method of feeding the high-fiber supplement (i.e., HF vs. SFHF).

Experiment 2. Experiment 2 (107 d) was conducted to evaluate the two different types of hand-fed energy supplements at different stocking rates. The SFHF treatment was not included in this experiment. One-hundred and ninety-two (192) calves and 16 pastures were available for the experiment. Performance data from nine (9) head were not used in calculating pasture means on wheat because of extensive time spent in sick pens. The experiment was a completely randomized design. There were nine treatment combinations consisting of three supplementation treatments (CL, HS or HF) and three stocking rates (1.24, 1.51, 1.78 head/ha). There were two pastures per treatment per stocking rate combination except for the energy supplemented cattle at the lowest stocking rate in which there was one pasture for each type of supplement. Control cattle received no supplement other than free-choice access to a

commercial mineral mixture. All other cattle were hand-fed 6 d/wk either the HS or HF supplement as described for Experiment 1. Calculation of daily supplement consumption, supplement conversion and live weight gains of the cattle was also conducted as in Experiment 1. Supplements were fed for 100 d of the 107-d trial.

At the end of the fall/winter grazing period on wheat pasture (March 7, 1991), the steers were placed on native grass for two weeks. Because of very dry conditions and a shortage of wheat forage for graze-out, the steers were moved to the feedlot facility at Panhandle State University (Goodwell, OK) on March 21. Pen allotment in the feedlot was the same as on wheat pasture so that potential effects of the treatments on wheat pasture on subsequent feedlot performance could be measured. The steers were adapted to a rolled corn finishing ration (NEg of about 1.35 Mcal/kg DM) over an 18-d period. Feed intakes by pen and cattle weights were measured at approximate 28-d intervals. At the conclusion of the 125-d feeding period steers were processed at the Excel packing plant in Dodge City, KS. Hot carcass weights and carcass quality grades were measured. Final weight off feed was determined using an average dressing percent of 64.

Statistical methods involved regression analyses similar to that described by Bransby et al. (1988). Experimental units were pastures and sampling units were steers. Dummy variables were assigned to each supplementation treatment to facilitate regression analysis with treatments included. Variables of interest for the wheat grazing season were the same as in Experiment 1. For the feedlot analyses, performance measurements included feed DM intake, ADG and feed:gain. Sources of variation for both the grazing period and feedlot were supplementation treatment , steer days/metric ton of forage (SDMTF) , treatment X SDMTF, the quadratic effect for SDMTF ($SDMTF^2$), and treatment X $SDMTF^2$. Additionally, ADG on wheat was included in the feedlot models, as a covariate, to determine if it influenced feedlot performance. The term SDMTF was included in the analyses since it accounts for both stocking rate and forage availability. The F-values for all sources of variation were calculated using the mean square for pasture within treatment. Orthogonal contrasts included control vs

supplementation and type of energy supplement.

Experiment 3. The research plan was to repeat Experiment 2 during the 1991-92 wheat pasture year. However, because of extremely dry conditions during late summer and early fall there was a marked difference in forage growth by mid-November among two areas of the wheat pasture. Only 7 pastures with initial standing forage similar to the first two years were available. Eighty-four steers were allocated randomly within weight groups to 7 pastures. Two steers were subsequently identified as chronic bloaters and their performance data was deleted from the experiment, leaving 82 steers from which to calculate pasture means. Treatments were the same as in Experiment 1 except that the SFHF supplement was not included. Stocking rates were increased from 1.24 to 1.65 head/ha where the energy supplements were fed (i.e., increased by one-third). There were 2, 2 and 3 pastures for the CL, HS and HF energy supplement treatments, respectively. Supplements were fed for 69 d of the 84-d trial. Following the grazing season, steers remained on pasture for a 37-d grazeout period.

At the conclusion of the grazeout period, the steers were shipped to Cimmarron Feeders (Texoma, OK). All 82 head were fed in one pen due to constraints of the commercial feedlot. The steers were worked-up to a steam-flaked corn finishing ration (NEg of about 1.50 Mcal/kg DM) for a total of 120 d on feed. The cattle were processed at National Beef packing plant in Liberal, KS and hot carcass weights were measured. Final weight off feed was calculated using an average dressing percent of 64.

The experiment was analyzed as a completely randomized design, as in Experiment 2. Total df for terms included in the statistical models were limited to no more than about one-half of the df for the error term (i.e., 6 df for pasture within treatment and 3 df (maximum) for the model). This was done to retain sufficient df for testing and to prevent any overestimation or underestimation of significance. Thus, the sources of variation used in the analyses were treatment, SDMTF and treatment X SDMTF.

Three Year Study - Pooled. Daily gains from the three year study were used to develop prediction equations for ADG. The SFHF treatment was not included since it was only

represented in year 1. Because steers in the two HS pastures in year 3 did not consume enough supplement to approach experimental objectives (i.e., .37 vs .75% BW), data for their performance were deleted from the pooled analysis. Data were analyzed as in Experiment 2, as a completely randomized design. No year X treatment interaction was indicated by the data (P >.40) thus, pasture means for ADG were adjusted to the grand mean for the three year period utilizing the following equation: adjusted ADG = pasture mean + (three year grand mean - year mean); where pasture mean = mean ADG of cattle in the pasture, three year grand mean = the mean ADG of all cattle (all treatments) during the three year study and year mean = the mean ADG of all cattle (all treatments) in the year for which the adjusted ADG was being calculated. This effectively removed year effects so prediction equations could be defined without having to include year in the model. Orthogonal contrasts included supplementation vs. no supplementation and type of supplement.

Results

Experiment 1. Effects of the energy supplements on performance of steers grazing wheat are summarized in Table 3. Mean consumption of the HS and HF supplements (about .72% of BW) was similar to the pretest target level of .75% of BW. Steers consuming the SFHF supplement exhibited a mean intake of .84% BW, indicating the combination of salt, minerals and ionophore worked relatively well to limit intake. Daily gains of supplemented cattle (1.03 kg) were higher (P < .02) than for CL (.97 kg). Calves receiving the HF supplement had greater (P < .03) daily gains than HS supplemented steers (1.07 vs 1.00). High-fiber supplemented calves had a tendency to exhibit higher daily gains (P < .10) than SFHF calves (1.07 vs 1.02). Similar results were noted for beef gain/ha (kg). Beef gain/ha was 138, 189, 202 and 194 for CL, HS, HF and SFHF, respectively. Supplement conversion for steers receiving HS, HF and SFHF was 5.95, 4.88, and 6.54 kg supplement•kg increased gain^{-1}•ha^{-1}. Steers receiving HF had a lower conversion than HS supplemented cattle (P < .09) and hand-feeding the HF supplement was more efficient (P < .02) than providing it in a self-fed pellet.

Experiment 2. Neither the treatment x SDMTF interaction nor $SDMTF^2$ were important sources of variation (P > .55 and P > .40, respectively) in the analysis for ADG. Steer days/metric ton of forage influenced (P < .01) ADG on wheat pasture. For each SDMTF, ADG was decreased by about .002 kg. This is interpretable only within the constraints of this study (i.e., the range of standing forage and cattle weights). Table 4 summarizes the performance data of the cattle on wheat. The means are presented by stocking rate within treatment for descriptive purposes. Daily gains were greater (P < .001) for supplemented cattle than for CL (1.05 vs .90 kg/head), but were not influenced (P > .82) by type of supplement (i.e., HS vs HF).

The treatment x SDMTF interaction was not an important source of variation (P > .50) for the analysis of beef gain/ha. Beef gain/ha was greater (P < .001) for supplemented cattle (176 kg) than for CL (143 kg). However, type of energy supplement did not influence beef gain/ha (P > .85). For each SDMTF, beef gain/ha was increased (P < .07) by 2.05 ± .83 kg/ha.

Ten pastures (5 each for HS and HF) were available for the supplement conversion analysis. Supplement conversion did not differ (P > .62) between HS (5.32) and HF (5.96) and was not influenced by SDMTF or $SDMTF^2$ (P > .20).

The primary concern for the feedlot phase of this experiment was to determine if supplementation or cattle performance on wheat pasture influenced feedlot performance of the steers. Accordingly, ADG on wheat for the first 58 d, second 49 d and total 107 d were included as covariables in the statistical models, in addition to the variables previously referenced. Pasture means for ADG on wheat ranged from .89 to 1.19 kg for the first 58 d, .52 to 1.07 kg for the second 49 d and .73 to 1.14 kg for the grazing season. The data indicated a tendency (P < .11) for ADG during the second period on wheat (and within the range of gains listed above) to decrease ADG in the feedlot. The coefficient for the effect was -.001 kg and is considered to be biologically unimportant. The analyses indicated early ADG and total ADG on wheat did not significantly influence feedlot gain, feed DM intake or feed:gain.

Feedlot performance of the steers is presented in Table 5. Control steers were lighter (P < .001) than supplemented cattle (309 vs 329 kg) at the initiation of the feedlot phase, but were

heavier ($P < .09$) at the end of the 125-d feeding period (540 vs 525 kg). Neither feed DM intake, daily gain nor feed:gain during the first 56 or 83 d were influenced ($P > .13$) by supplementation or type of supplement. Cumulative daily gains (125 d) of the CL steers were higher ($P < .05$) than those of supplemented cattle (1.72 vs 1.63). However, feed DM intake and feed:gain were not affected by previous treatments on wheat. Hot carcass weights were 345, 336 and 337 kg for CL, HS and HF cattle, respectively, and tended ($P > .12$) to be heavier for CL steers. All three treatments exhibited mean carcass quality grades of low choice.

Experiment 3. Influence of energy supplementation on performance of steers grazing wheat pasture is shown in Table 6. In the analysis of ADG on wheat, treatment and SDMTF were statistically significant. Pasture means for ADG ranged from .98 to 1.00 (CL), 1.08 to 1.15 (HS) and 1.10 to 1.20 kg (HF). Pasture means for SDMTF ranged from 63 to 67 (CL), 105 to 118 (HS) and 93 to 113 (HF). Because of the large difference in forage availability between CL and supplemented pastures, the adjustment made for SDMTF, when calculating least square means, was of sufficient magnitude to result in means that were "biologically unreal". For example, least square means, adjusted for treatment only, were .99 (CL), 1.11 (HS) and 1.16 (HF), while least square means adjusted for treatment and SDMTF were .78 (CL), 1.23 (HS) and 1.23 (HF). Since the least square means adjusted for SDMTF and treatment, substantially exceeded the range of simple means observed, it was deemed appropriate to report least square means adjusted for treatment only (i.e., simple means), in Table 6. The same phenomenon was observed for beef gain/ha and therefore, simple means for beef gain/ha are also used in Table 6. Daily gains were increased .15 kg ($P < .002$) by supplementation and were higher ($P < .05$) for HF steers. For each SDMTF, ADG was decreased ($P < .01$) by .005 ± .0009 kg/d.

Beef gain/ha was improved by supplementation ($P < .001$) and was greater ($P < .05$) for HF than HS steers. Supplement consumption (i.e., .37 and .57% of BW/d for HS and HF, respectively) was less than the previous years. We have no definitive explanation for this but it could be attributable to the extremely mild weather we experienced in year 3. Supplement conversions were reflective of the low intakes and were lower ($P < .05$) for HS (2.40) than HF

steers (3.31).

Average daily gains of steers on wheat during the 37-d grazeout period were 1.45 (CL), 1.43 (HS) and 1.34 kg (HF). Daily gains of CL and supplemented steers did not differ ($P > .13$), however, gains of HF had a tendancy to be lower ($P < .10$) than CL and HS steers. Steer days/metric ton of forage during the supplementation period did not influence ($P > 45$) daily gains during the grazeout period.

One-hundred and twenty-d feedlot performance is summarized in Table 7. Neither supplementation, nor SDMTF influenced cattle performance in the feedlot ($P > .45$). Daily gains were 1.52, 1.49 and 1.54 kg for CL, HS, and HF steers, respectively. Average daily gains on wheat pasture (84 d, 37-d grazeout period and overall 121 d ADG) did not affect ($P > .54$) feedlot final weight, ADG or hot carcass weights.

Three Year Study - Pooled. Results for the pooled analysis for ADG are illustrated in Figure 1. Daily gains were increased ($P < .001$) .15 kg by supplementation and were .92 kg for CL, .1.06 kg for HS and 1.08 kg for HF steers. Type of supplement did not influence ADG ($P > .30$). The analysis showed that ADG was not influenced by the treatment x SDMTF interaction ($P > .60$) or $SDMTF^2$ ($P > .20$). However, for each SDMTF, ADG was decreased ($P < .001$) by .001 ± .0003 kg. The derived prediction equation for CL steers was ADG = 1.0392 - .00106(SDMTF); $R^2 = .43$, $S_{y \cdot x} = .059$. The equation for supplemented steers was ADG = 1.3071 - .00215(SDMTF); $R^2 = .36$, $S_{y \cdot x} = .058$.

Discussion

Supplementation increased daily gains of cattle on wheat each year. The mean response to supplementation over the three year period was an increase ($P < .001$) of .15 $kg \cdot head^{-1} \cdot d^{-1}$. Mean supplement consumption was .66% of BW. Grigsby et al. (1991) and Rouquette et al. (1990) report supplementation responses in ADG between .15 and .57 kg when steers grazing rye-ryegrass pastures were supplemented with a corn ration very similar to that fed in this study, but fed at a level of about .15 to .2% of BW. Daily gains of cattle on rye-

ryegrass pastures and supplemented with a corn ration at a level of about .4% of BW were reported to be .11 kg greater than controls (Rouquette et al., 1990). In this study, stocking rate was arbitrarily increased from 22 to 44% were supplements were fed. Stocking rate was not increased in any of the studies cited above. In studies reported by Elder (1967), Lowrey et al. (1976a and 1976b) and Utley and McCormick (1975 and 1976) steer grazing d/ha or stocking rates were increased 1.25- to 2-fold by feeding grain at levels of 1 to 1.5% of BW and daily gains were increased by .05 to .30 kg. Wagner et al. (1984) reported increased daily gains, averaged over a four year study, of .14 kg (.78 vs .64 kg) for steers supplemented with about 2.5 kg of grain/d.

In a study by Branine and Galyean (1990) involving steers grazing wheat pasture and supplemented with 1) no grain (C), 2) .5 kg•head^{-1}•d^{-1} steam-flaked milo (G) or 3) G plus 170 mg monensin•head^{-1}•d^{-1}, ruminal NH_3 was decreased by G and M in mid-May. The authors concluded that supplemental energy and not monensin was responsible for the decreased ruminal NH_3 concentrations. Dietary carbohydrate apparently reduced ruminal NH_3 concentration by facilitating the incorporation of NAN into microbial protein, subsequently increasing ammonia N flow to the small intestine. These results support the concept of improving performance of cattle on high-quality pastures by reducing the dietary N:digestible OM (DOM) ratio with supplemental energy (Hogan, 1982).

Feeding of by-product feeds such as soybean hulls, wheat middlings and corn gluten feed to cattle grazing pastures or in drylot has generally resulted in higher ruminal pH, decreased substitution ratios of supplement for forage and improved performance (McDonnell et al., 1982 and 1983; Merrill and Klopfenstein, 1984; Hibberd et al., 1986) However, in this study, daily gains and beef gain/ha were similar between HS and HF supplemented cattle. In general, one would expect the difference in response by grazing cattle to decrease as the amount of supplement fed decreases and as crude protein content of the forage increases. The level of supplement fed in this study was relatively low and the forage contained excess protein.

It was apparent during this study that the cattle consumed the HF supplement much

more readily than the HS supplement. Generally, the cattle consumed the HF supplement in a matter of 10-30 minutes in the morning, whereas, the corn-based supplement was usually consumed over at least 2 feeding periods during the d (morning and mid-afternoon). From a feed and bunk management standpoint, this difference in the supplements is important on days of inclement weather (i.e., rain, snow, etc.) and in situations of bird predation. Contamination of feed bunks by bird excreta was substantial for the HS supplement. In addition, the potential for lactic acid acidosis is much less for the HF supplement provided the wheat middlings used do not contain large amounts of fine starch.

Mean supplement conversions in this study were 5.04 for HS and 5.02 for HF and did not differ ($P > .95$). Work by Grigsby et al. (1991) reflects supplement conversions of about 3 kg of feed per kg increased gain over controls when supplements were fed at a level of about .2% BW to steers grazing cool season annuals. The difference in conversions from the two studies is probably due to the substitutive effect of the additional .45% of BW of supplement fed in this study. In another study by the authors (Cravey, 1992) a substitution ratio (units change in forage intake per unit increase in concentrate intake) of about -.93 was detected for HS supplemented steers, although consistent substitution ratios were not evident for HF supplemented steers. Substitution effects are likely responsible for the supplement conversions of about 7 to 10 reported by other researchers, where cattle were fed at levels of 1 to 1.5% of BW (Elder, 1967; Utley and McCormick, 1976; and Lowrey et al., 1976a and 1976b). Stocking rates were increased where cattle were supplemented, yet ADG of these cattle was greater than that of CL steers.

Although CL steers had higher ($P < .05$) daily gains than supplemented steers (1.72 vs 1.63), in the feedlot, in Experiment 2, treatments on wheat pasture (i.e., supplementation and stocking rate) exhibited no consistent influence on feedlot performance. Bryant et al. (1965) reported that calves, but not yearlings, fed corn (1% BW) on pasture (bluegrass, orchardgrass and white clover mix) gained more in drylot than calves and yearlings not supplemented on pasture. Furthermore, carcass grade of yearlings was not improved by feeding corn on pasture,

but carcass grades of calves fed corn on pasture were one-half grade higher than those not fed corn. Lake et al. (1974) reported the supplementation of energy (ground corn) to yearling steers grazing irrigated pastures (i.e., orchardgrass, smooth bromegrass and alfalfa mixtures) and their subsequent feedlot performance in two trials. Influences of supplementation treatments on wheat, on subsequent feedlot performance of the steers were inconsistent. The magnitude of the effects of the energy supplementation stratefy, appears to be dependent on numerous factors such as age, level and type of supplement fed and length of the grazing and feeding periods. In this study, differences probably would become apparent as weights of the cattle and standing forage deviate from the ranges observed.

Implications

The energy supplementation strategy described allowed stocking rate to be increased by at least one-third and improved daily gains of stocker cattle grazing wheat pasture by about .15 kg. There was no observed difference in daily gains between HS and HF. Equations, including forage availability terms, were developed to aid in predicting ADG on wheat. The influence of forage availability on cattle performance warrants development of producer-oriented methods of estimating standing forage. Furthermore, the supplements fed appear to have little to no effect on subsequent feedlot performance.

Literature Cited

Andersen, M. A. and G. W. Horn. 1987. Effect of lasalocid on weight gains, ruminal fermentation and forage intake of stocker cattle grazing winter wheat pasture. J. Anim. Sci. 65:865.

Branine, M. E. and M. L. Galyean. 1990. Influence of grain and monensin supplementation on ruminal fermentation, intake, digesta kinetics and incidence and severity of frothy bloat in steers grazing winter wheat pasture. J. Anim. Sci, 68:1139.

Bransby, D. I., B. E. Conrad, H. M. Dicks and J. W. Drane. 1988. Justification for grazing intensity experiments: Analyzing and interpreting grazing data. J. Range Manage. 41:274.

Bryant, H. T., R. C. Hammes, Jr., R. E. Blaser and J. P. Fontenot. 1965. Effects of feeding grain to grazing steers to be fed fattened in drylot. J. Anim. Sci. 24:676.

Cravey, M. D. 1993. Effect of high-starch versus high-fiber energy supplements on forage intake and utilization by steers grazing wheat pasture. Ph.D. Dissertation. Oklahoma State University.

Elder, W. C. 1967. Winter grazing small grains in Oklahoma. Okla. Agr. Exp. Sta. Bull. B-654.

Grigsby, K. N., F. M. Rouquette, Jr., W. C. Ellis and D. P. Hutcheson. 1991. Use of self-limiting fishmeal and corn supplements for calves grazing rye-ryegrass pastures. J. Prod. Agr. 4:476.

Hogan, J. P. 1982. Digestion and utilization of proteins. In: J. B. Hacker (Ed.). Nutritional Limits to Animal Production From Pastures. pp. 245-257.

Hibberd, C. A., C. C. Chase and C. Worthington. 1986. Corn vs soybean hull supplements for fall-calving beef cows in winter. Okla. Agr. Exp. Sta. Res. Rep. MP-118:192.

Lake, R. P., R. L. Hildebrand, D. C. Clanton and L. E. Jones. 1974. Limited energy supplementation of yearling steers grazing irrigated pasture and subsequent feedlot performance. J. Anim. Sci. 39:827.

Lowrey, R. S., G. V. Calvert, H. C. McCampbell and F. Woods. 1976a. Finishing weanling steers on winter pasture with or without grain. J. Anim. Sci. 42:260 (Abstr.).

Lowrey, R. S., H. C. McCampbell, G. V. Calvert, E. Beaty and F. Woods. 1976b. Effect of previous treatment and energy levels on finishing yearling steers on winter pasture. J. Anim. Sci. 42:260 (Abstr.).

McDonnell, M. L., T. J. Klopfenstein and J. K. Merrill. 1982. Soybean hulls as an energy source for ruminants. NK Beef Cattle Rep. MP-43:54.

McDonnell, M. L., T. J. Klopfenstein and J. K. Merrill. 1983. Soybean hulls can replace corn in growing rations. NK Beef Cattle Rep. MP-43:54.

Merrill, J. and T. Klopfenstein. 1984. Soybean hulls for grazing beef cattle. NK Beef Cattle Rep. MP-47:40.

Rouquette, F. M., Jr., M. J. Florence, D. P. Hutcheson and W. C. Ellis. 1990. Influence of level of daily supplement intake on performance of calves grazing rye-ryegrass pastures. Texas Agric. Exp. Sta. Tech. Rep. 90-1:190.

SAS. 1985. SAS User's Guide: Statistics. SAS Inst. Carry, NC.

Utley, P. R. and W. C. McCormick. 1975. Dry or high-moisture corn for finishing steers in drylot or on oat pasture. J. Anim. Sci. 41:495.

Utley, P. R. and W. C. McCormick. 1976. Corn or grain sorghum for finishing steers in drylot or on rye pasture. J. Anim. Sci. 43:1141.

Wagner, D., R. Lowrey and M. Grigsby. 1984. Supplemental feeding of grain and protein for stocker cattle on small grain pastures. In : G. W. Horn (Ed.). Proc. Natl. Wheat Pasture Symp. Okla. Agr. Exp. Sta. Pub. MP-115:327.

Table 1. Forage available for grazing by steers on wheat pasture[a].

	Kilograms of forage DM per ha		Steer days per metric ton of forage DM	
Year	Mean ± SE	Range	Mean ± SE	Range
1	1780 ± 20	1200 - 2160	100 ± 7.4	66 - 158
2	1480 ± 20	930 - 1920	119 ± 8.6	71 - 211
3	1430 ± 20	1180 - 1800	87 ± 9.5	63 - 113

[a]Estimates were derived from clipping residual forage to ground level using .5 m^2 quadrats 2 to 3 times per grazing season. Clipping dates were scheduled as close to cattle weigh dates as possible.

Table 2. Composition (% as-fed) of energy supplements[a].

Ingredient	Type of supplement	
	High-starch	High-fiber
Ground corn	78.94	-----
Soybean hulls	-----	46.94
Wheat middlings	8.90[b]	41.74
Molasses (sugarcane)	4.95	4.95
Calcium carbonate	1.75	1.50
Dicalcium phosphate	.60	-----
Micro-lite	4.15	4.15
Salt	.65	.65
Rumensin 60 Premix	.067	.067
Calculated nutrient content (as-fed basis)		
NEgain, Mcal/kg	1.16	.87
Crude protein, %	8.2	11.5
Calcium, %	.89	.89
Phosphorus, %	.44	.53
Magnesium, %	.46	.55
Monensin content, mg/kg	88	88
Starch, % DM	67	18

[a]Fed as 5 mm pellets.
[b]Added to improve pellet quality (decrease fines) of the high-starch supplement.

Table 3. Effect of type of energy supplement and method of feeding on performance of steers grazing wheat pasture, Experiment 1.

Treatment: Method of feeding:	Control	High-starch Hand-fed	High-fiber Hand-fed	High-fiber Free-choice	SE	Contrasts[f] S	T	M
Number of steers	48[a]	48	48	48				
Stocking density, head/ha	1.24	1.65	1.65	1.65				
Initial beef/ha, kg	260	346	345	348	.66			
Initial forage/ha, kg	2010	1620	1780	1620	170			
Initial forage/hd, kg	1630	980	1080	980	280			
Supplement consumption[b,c]								
kg/day	----	1.91	1.94	2.26	.09			
% of body wt	----	.71	.72	.84	.05			
Initial wt, kg (11/17)	210	210	210	211	.49			
Final wt, kg (3/12)	322	325	332	329	8.93			
Daily gain[d], kg (115 days)	.97	1.00	1.07	1.02	.02	P<.02	P<.03	P<.10
Beef gain/ha[d], kg	138	189	202	194	1.18	P<.001	P<.02	P<.08
Supplement conversion[de]	----	5.95	4.88	6.54	.17	----	P<.09	P<.02

[a]Four treatments (12 steers per treatment) in four blocks.
[b]Control steers had free-choice access to a commercial mineral supplement.
[c]Supplements were fed 96 days of the 115-day trial.
[d]Least squares means.
[e]Kg of supplement (as-fed) per kg of increased gain per hectare.
[f]S=control vs supplementation, T=type of supplement (hand-fed high-starch vs hand-fed high-fiber), M=method of feeding high-fiber supplement.

Table 4. Effect of type of energy supplement and stocking density on performance of steers grazing wheat pasture, Experiment 2.

	Treatment							
	None[a]				High-starch			
Stocking density, ha/hd	1.24	1.51	1.78	SE	1.24	1.51	1.78	SE
Number of steers	24	22	26		12	22	26	
Number of pastures	2	2	2		1	2	2	
Initial beef/ha, kg	263	323	382	1.5	263	327	383	2.6
Initial forage/ha, kg	1469	1484	1314	128	1639	1333	1430	91
Initial forage/hd, kg	2938	2429	1819	195	3278	2181	1980	139
Supplement consumption								
kg as-fed/day	---	---	---	---	1.66	1.67	1.79	0.04
% of body weight	---	---	---	---	.60	.62	.66	0.02
Initial wt., kg (11/21)	213	214	214	.57	213	217	215	1.1
Final wt., kg (3/3)	310	314	300	3.4	335	325	328	3.2
Daily gain[b], kg (107)	.91	.94	.80	.03	1.14	1.02	1.06	.04
Beef gain/ha[c], kg	120	151	153	7.6	151	163	201	11.8
Supplement conversion[d,e]	---	---	---	---	6.62	6.04	3.95	.79

Table 4. Continued.

	Treatment High-fiber			
Stocking density, ha/hd	1.23	1.51	1.78	SE
Number of steers	12	22	26	
Number of pastures	1	2	2	
Initial beef/ha, kg	264	325	382	.84
Initial forage/ha, kg	1770	1380	1460	120
Initial forage/hd, kg	3530	2260	2020	180
Supplement consumption				
kg as-fed/day	1.77	1.84	1.83	.05
% of body weight	.65	.68	.68	.01
Initial wt., kg (11/21)	214	215	214	.34
Final wt., kg (3/3)	332	327	325	8.1
Daily gain[b], kg (107)	1.10	1.05	1.03	.08.
Beef gain/ha[c], kg	145	170	197	13.8
Supplement conversion[d,e]	8.78	6.12	4.38	.42

[a]Steers had free-choice access to commercial mineral mixture.

[b]Control vs supplementation (P<.001); high-starch vs high-fiber not significant (P=.82).

[c]Control vs supplementation (P<.005); high-starch vs high-fiber not significant (P=.90).

[d]High-starch vs high-fiber not significant (P=.62).

[e]Kilograms of supplement (as-fed) per kg of increased gain per hectare. Control cattle (light stocking density) equal base.

Table 5. Feedlot performance of steers, Experiment 2[a].

	Treatment on wheat pasture				Contrasts[b]	
	Control	High-starch	High-fiber	SE	S	T
Number of steers	69	57	60			
Initial weight, kg	309	329	328	5.8	P<.001	P>.70
Final weight, kg						
(125 days)	540	524	525	7.1	P<.09	P>.85
First 56 days						
Feed DM intake,						
kg/hd/day	12.20	11.96	11.13	.52	P>.30	P>.25
Daily gain, kg	2.05	2.03	1.96	.06	P>.40	P>.45
Feed DM/gain	5.97	5.92	5.69	.32	P>.65	P>.60
First 83 days						
Feed DM intake,						
kg/hd/day	11.93	11.86	11.18	.47	P>.45	P>.30
Daily gain, kg	1.85	1.76	1.74	.05	P>.13	P>.85
Feed DM/gain	6.52	6.44	6.76	.35	P>.85	P>.54
Overall (125 days)						
Feed DM intake,						
kg/hd/day	11.66	11.21	11.14	.39	P>.30	P>.90
Daily gain, kg	1.72	1.62	1.64	.04	P<.05	P>.60
Feed DM/gain	6.77	6.92	6.80	.24	P>.75	P>.70
Carcass Caracteristics						
Hot weight, kg	345	336	337	3.72	P>.12	P>.75
Quality grade, kg	C-[c]	C-	C-	---	P>.95	P>.98

[a]Least squares means.
[b]S=control vs supplementation, T=type of supplement (hand-fed high-starch vs hand-fed high-fiber), M=method of feeding high-fiber supplement.
[c]Low choice.

Table 6. Effect of type of energy supplement on performance of steers grazing wheat pasture, Experiment 3.

	Type of energy supplement				Contrasts[f]	
Treatment:	Control	High-starch	High-fiber	SE	S	T
Number of pastures	2	2	3			
Number of steers	23[a]	24	35[a]			
Stocking density, ha/head	1.23	1.51	1.78			
Initial beef/ha, kg	300	401	401	.19		
Initial forage/ha, kg	1240	1140	1130	100		
Initial forage/hd, kg	2470	1800	1700	160		
Supplement consumption[b,c]						
kg/day	---	1.08	1.66	.15		
% of body wt	---	.37	.57	.05		
Initial wt, kg (12/5)	243	244	244	.13		
Final wt, kg (2/28)	327	338	342	2.2		
Daily gain, kg (84 d)[d]	.99	1.11	1.16	.03	P<.002	P<.05
Beef gain/ha[d], kg	103	142	174	10.4	P<.001	P<.05
Supplement conversion[de]	---	2.40	3.31	.25	---	P<.05
Grazeout daily gain, kg (37 d)	1.45	1.43	1.34	.03	P > .13	P < .10

[a]At initiation of the grazing season, CL = 24 and HF= 36 steers. Data for two steers deleted due to chronic bloat.
[b]Control steers had free-choice access to a commercial mineral supplement.
[c]Supplements were fed 69 days of the 84 day trial.
[d]Least squares means.
[e]Kilograms of supplement (as-fed) per kg of increased gain per hectare.
[f]S=control vs supplementation, T=type of supplement (high-starch vs high-fiber).

Table 7. Feedlot performance of steers, Experiment 3[a].

	Treatment on wheat pasture				Contrasts[b]	
	Control	High-starch	High-fiber	SE	S	T
Number of steer	24	24	36			
Initial weight, kg	381	391	392	2.3	P>.05	P>.80
Final weight, kg (120 d)	563	554	564	15.4	P>.55	P>.60
Daily gain, kg	1.52	1.49	1.54	.04	P>.80	P>.45
Hot Carcass Weight, kg	361	355	361	10.0	P>.55	P>.60

[a]Least squares means.
[b]S=control vs supplementation, T=type of supplement (high-starch vs high-fiber).

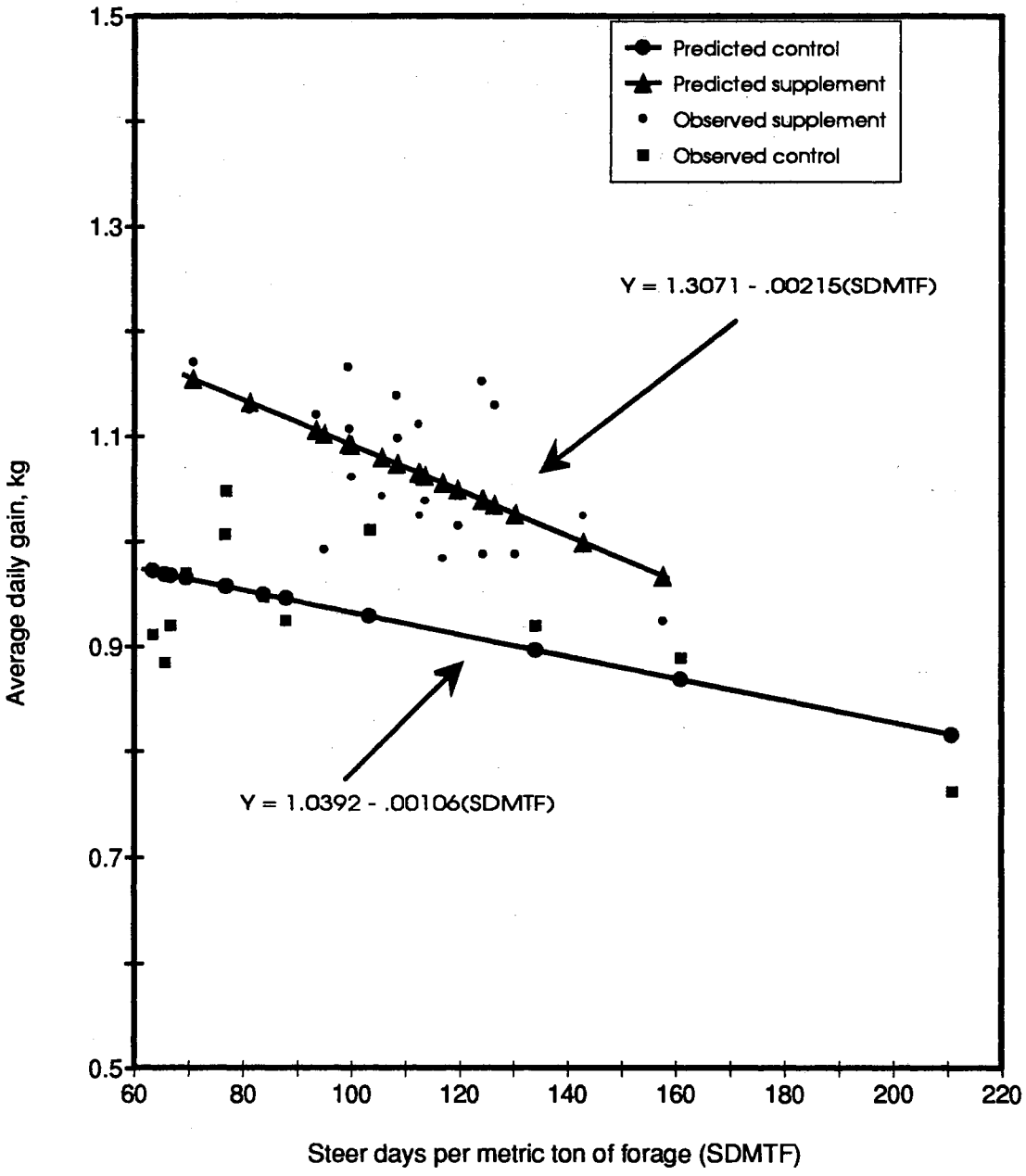

Figure 1. Influence of supplementation and stocking density on average daily gain of steers grazing wheat pasture.

CHAPTER IV

EFFECT OF HIGH-STARCH VERSUS HIGH-FIBER ENERGY SUPPLEMENTS ON FORAGE INTAKE AND UTILIZATION BY STEERS GRAZING WHEAT PASTURE[1]

M. D. Cravey,[2,3] G. W. Horn,[2] F. T. McCollum III[2] and D. L. Weeks[4]

Oklahoma Agricultural Experiment Station
Stillwater, OK 74078-0425

ABSTRACT

Two experiments utilizing 21 (Experiment 1) and 28 (Experiment 2) fall-weaned steers grazing wheat pasture (Triticum aestivum variety Chisholm) were conducted to determine the influence of high-starch (HS, 67% starch) versus high-fiber (HF, 18% starch) energy supplements on forage intake and utilization. Steers were assigned to one of seven supplementation treatments that consisted of either no supplement or one of the two supplements fed at levels (as-fed basis) of .4, .8, or approximately 1.2% BW/d. The pelleted supplements were hand fed at 0800 in individual feeding stalls for a 10 to 12 d adaptation period and a 5 d fecal sampling period. The HS supplement contained 79% ground corn (as-fed) and the HF supplement contained 47% soybean hulls and 42% wheat middlings. Fecal grab samples were taken from the rectum of each steer and fecal output was estimated (Captec-Chrome capsule Experiment 1; Cr gelatin capsules, Experiment 2) and partitioned into forage and

---

[1]Journal article No. XXXX of the Oklahoma Agricultural Experiment Station.
[2]Animal Science Department.
[3]We thank Ken Poling for assistance with animal care, Donna Perry and Carolyn Bowen for assistance with the laboratory analyses, and Paul Beck for assistance with collection of samples.
[4]Department of Statistics.

supplement components based on 72 h IVOMD (Experiment 1) or 72 h in situ OM digestibilities (Experiment 2) of supplements and forage. Daily forage intake ranged from 4.46 to 10.71 kg OM across all treatments. Substitution ratios (i.e., units change in forage OM intake per unit increase in supplement OM intake) were calculated by regression of forage intake on amount of supplement consumed. In Experiment 1, the substitution ratio did not differ for the HS and HF supplements ($P > .60$) and was -.91 ± 19. A substitution ratio of -.93 ± .30 was indicated for the HS steers in Experiment 2. In Experiment 2, we were unable to define a "good fit" of the data for HF steers ($R^2 = .06$, $S_{y \cdot x} = 1.35$) because of a wide variation in forage intake. Therefore, ratios for HF cattle were inconclusive. Differences in supplement intakes, ruminal pH as related to potential metabolic acidosis and buffering capacity of the supplements may explain the inconsistent results for HF steers.

(Key Words: Growing Cattle, Wheat Pasture, Energy Supplementation, Substitution)

Introduction

Substitution ratios (units change in forage intake per unit increase in concentrate intake) vary depending on quality of forage, the amount and type of supplement consumed and species of livestock. Moore (1992), in a review paper, reported negative substitution ratios for grain supplements on a variety of forages. Work by Coleman (1977), Jarrige et al. (1986) and a review by Horn and McCollum (1987) suggests that substitution of energy supplements for forage becomes more negative with increasing forage digestibility. Effects of high-starch and high-fiber energy supplements have not been quantified for steers grazing wheat pasture.

Quantifying forage intake of grazing animals requires knowledge of forage digestibility and fecal output (FO) of the animal. Use of external markers, such as chromic oxide (Cr_2O_3), have been investigated by researchers for many years as a means of estimating fecal output (Smith and Reid, 1955; Pigden and Brisson, 1956). Buntinx et al. (1992) recently reported on the efficacy of a controlled-release Cr_2O_3 capsule for estimating fecal output of grazing sheep. The capsule was developed to reduce the labor and potentially adverse effects of repeated dosing

and the presence of fecal bags during total fecal collection.

This study was conducted to evaluate the effects of increasing amounts of two types of energy supplements on wheat forage intake and utilization by grazing steers. A secondary objective was to evaluate the release rate and accuracy of a controlled-release Cr_2O_3 capsule[5] for estimating FO by steers grazing wheat pasture.

Materials and Methods

Experiment 1

Pasture and Cattle Management. Twenty one fall-weaned Angus X Hereford steer calves (BW = 268 ± 2.84 kg, Trial 1; 357 ± 3.27 kg, Trial 2) were used to evaluate the effects of increasing amounts of two different types of energy supplements on wheat forage intake and utilization. Four ruminally cannulated Angus X Hereford steers (BW = 286 ± 1.4 kg) were used for determination of actual FO, release rate of the controlled-release capsule and as a source of ruminal fluid for determination of ruminal fermentation characteristics of steers grazing wheat pasture. Three esophageally cannulated steers were used to collect diet (masticate) samples. Prior to each trial, the cattle grazed wheat pastures that bordered the 3.7 ha (Trial 1) and 2.5 ha (Trial 2) experimental pastures. On d 1 (1/3/91, Trial 1; 3/1/91, Trial 2) the twenty-one intact and four ruminally cannulated steers were moved to the respective experimental pastures for the duration of the trials. All pastures were planted (clean-till) to Triticum aestivum variety Chisholm, hard red winter wheat in early September of the previous fall. Standing forage in the experimental pastures was estimated by hand clipping forage (d 14, Trial 1; d 13 Trial 2) to ground level inside fifty, .1 m^2 quadrats along paced transects. Clipped samples were weighed, dried to a constant weight in a forced-air oven at 55°C and then re-weighed to determine DM %.

Effects of Energy Supplementation on Forage Intake. In each trial, steers were randomly allotted to one of seven supplementation treatments for a 12-d (Trial 1) and a 10-d (Trial 2) adaptation period and 5 d sampling periods. Beginning on d 1 of both trials, the cattle were fed

[5]Captec, Nufarm, Auckland, New Zealand.

in individual feeding stalls (0800) either, no supplement (CL) or .4, .8 or 1.2% BW of a high-starch (HS) or high-fiber (HF) byproduct feed-based energy supplement. The cattle were allowed to consume supplement until they stopped eating (approximately 1-1/2 h), and were returned to pasture.

On d 7 (Trial 1) and d 3 (Trial 2), each steer was orally administered a controlled-release Cr capsule. Beginning on d 13 (Trial 1) and d 11 (Trial 2), supplement orts were weighed back daily to facilitate determination of actual supplement consumption by each steer. Subsequently, mean supplement intake over each 5-d period was calculated for individual steers. Composition of the corn-based, HS (67% starch, DM basis) and soybean hull, wheat middling-based (18% starch) supplements are shown in Table 1. Supplements were sampled daily during the 5 d sampling periods, composited across days and analyzed for starch. Starch was analyzed as alpha-linked glucose (MacRae and Armstrong, 1968) modified by the use of o-Toluidine (Sigma[6]) as the colorimetric reagent. Both supplements contained about 88 mg monensin/kg.

During the 5-d sampling periods, daily fecal grab samples were taken from the rectum of each steer (after feed was consumed and before being placed back on pasture). Fecal samples were dried to constant weights in a forced-air oven at 55°C and ground in a Wiley mill through a 2 mm mesh screen. All fecal samples were composited, by weight, across days and by steer. Approximately 1 g from each composited sample was ashed at 500°C for 8 h and analyzed for Cr concentration by atomic absorption spectrophotometry using an air-acetylene flame as described by Williams et al. (1962). Mean fecal output was calculated by Cr dilution for each steer.

Ruminal fluid samples were collected (approximately 5 h post-feeding) by hand, via cannulae, from the four rumen canulated steers on d 12 (Trial 1) and d 15 (Trial 2). A 250-ml beaker was used to obtain fluid from four sites within the rumen (i.e., anterior dorsal, anterior ventral, posterior dorsal and posterior ventral sacks). Samples were strained through four layers of cheesecloth and pH was immediately measured with a pH meter and glass electrode. One

[6]Sigma Chemical Company; St. Louis, MO. 63178.

hundred ml aliquots of strained fluid were acidified with 2 ml 20% sulfuric acid and then stored in an ice slurry until ammonia analyses were conducted by a modification (Andersen and Horn, 1987) of the magnesium oxide distillation method (AOAC, 1990). Five-milliliter aliquots of strained ruminal fluid were prepared for VFA analysis by deproteinization with 1 ml of 25% (w/v) metaphosphoric acid that contained 2-ethylbutyric acid as an internal standard. Volatile fatty acids concentrations were analyzed by GLC on an Auto System GC.[7]

Three esophageally cannulated steers were used to collect esophageal masticate (d 13 and 15, Trial 1; d 13 and 14, Trial 2). Masticate samples were frozen, lyophilized, ground through a 2 mm mesh screen in a Wiley mill and composited across days within trial. Soluble carbohydrates were determined by the procedure of Balwani (1965) and N by the Kjeldahl procedure (AOAC, 1990). Extensive time was required to lyophilize masticate samples of this study and a subsequent study. In order to determine in vitro OM digestibility of masticate samples and supplements (Tilley and Terry, 1963), ruminal fluid was obtained from a rumen cannulated steer, grazing wheat pasture, towards the end of the grazing season (May 15, 1991).

Prediction of Chromium Release Rate and Fecal Output. To determine Cr release rate from the controlled-release capsule, the four ruminally cannulated steers were orally administered one Captec-Chrome capsule on d 5 (Trial 1) or d 3 (Trial 2). Prior to administration of the capsules, the distance between the top of the Cr_2O_3 matrix in the capsule and the bottom of the matrix was determined using calipers and a metric ruler. At 0800 on 3, 6, 9, 12 and 15 d after bolusing, the capsules were removed via the cannulae and plunger travel (mm) was recorded. The capsules were then immediately returned to the rumen, to a location similar to that from which they were removed. At the time of capsule matrix measurement, fecal grab samples were taken from the rectum of each steer, for subsequent analysis of CR, and dried to a constant weight in a forced-air oven at 55°C.

Actual fecal output (FO) was measured (Trial 1 only) by collecting total feces in fecal bags attached to the four ruminally cannulated steers. Total fecal collections were taken 10, 11

[7]Perkin-Elmer; Norwalk, CT 06859-0156.

and 12 d after bolusing. Bags were removed from the steers at 0800 and 1600 h and the contents were weighed after each period. Daily total fecal collections (composited by steer) were thoroughly mixed in a paddle-type feed mixer and sub-samples were taken, for each steer, for determination of DM and Cr concentrations. Actual fecal output data from one steer, on d 12, was deleted because of a failure of the collection bag to catch total feces excreted that day.

Statistical Analysis. Data for one steer on the medium (.8% of BW) high-fiber (M-HF) treatment, in both trials, were deleted from the analysis of the effects of the supplements on forage intake because the steer's estimated forage intake was greater than 3 SD from the overall mean. Data were analyzed using the GLM procedure of SAS (1985), as a completely randomized design. Forage intake of each steer was the response variable studied. The full model included type of supplement (TYPE), supplement intake (SI), TYPE x SI, steer within TYPE x SI, trial, trial x TYPE, trial x SI and trial x TYPE x SI. No interactions were found to be statistically significant ($P > .75$), therefore, data were pooled across trials and a model with the terms SI, TYPE and SI X TYPE was computed, with F-values being calculated using the residual mean square. The ability for polynomials to correctly fit the data was tested using Type I sum of squares.

Daily plunger travel (mm) of the controlled-release capsule was estimated using within animal analyses. A model including steer, trial, steer x trial and day was fitted, with each observation being weighted by the inverse of the estimated variance for each day to adjust for non-homogeneous variation among days. Mean daily plunger travel indicated by the analysis was 2.00 ± .03 mm (Figure 1). Information from the manufacturer indicated a linear density of the matrix and release rate in the controlled-release capsule of 910 mg/mm and 1740 mg Cr_2O_3/d (MRR), respectively. The experimentally derived release rate (DRR) was calculated to be 1820 mg Cr_2O_3 (DRR; 2.00 mm/d X 910 mg/mm). Conformity between actual FO and predicted FO (determined from DRR and MRR) was examined by regression analysis using the REG procedure of SAS (1985). The model included method of release rate determination (i.e., DRR or MRR), steer and the steer X method interaction. Terms were tested by the residual error

(days within steer X method).

Experiment 2.

Pasture and Cattle Management. Twenty eight fall-weaned Angus X Hereford steer calves (BW = 357 ± 5.55 kg) were used in the experiment to evaluate the effects of increasing amounts of two different types of energy supplements on wheat forage intake and utilization. Nine ruminally canulated Angus X Hereford steers (BW = 455 ± 8.49 kg) were used as a source of ruminal fluid for determination of ruminal fermentation characteristics, and to determine in situ extent of digestion of the two supplements and rate and extent of digestion of wheat forage. Three esophageally cannulated steers were used to collect diet (masticate) samples. As in Experiment 1, the cattle were maintained, prior to the experiment, on wheat pastures that bordered the 3.7 ha experimental pasture. On d 1 (3/5/92) the twenty-eight intact and nine ruminally cannulated steers were moved to the respective experimental pastures for the duration of the trials. All pastures were planted (clean-till) to Triticum aestivum variety Chisholm, hard red winter wheat in early September of the previous fall. Standing forage in the experimental pastures was estimated by hand clipping forage (d 11) to ground level inside twenty, .18 m^2 quadrats along paced transects. Clipped samples were weighed, dried to a constant weight in a forced-air oven at 55°C and then re-weighed to determine DM %.

Effects of Energy Supplementation on Forage Intake. The twenty-eight Angus X Hereford steers were randomly assigned to one of seven supplementation treatments, as described in Experiment 1, for a 9-d adaptation period and a 5-d sampling period. Beginning on d 1 the cattle were individually bolused with chromic oxide (4 g) in gelatin capsules, twice daily at 0800 and 1600, and fed in metabolism stalls (0800) as described in Experiment 1. Supplements (Table 1) were sampled and analyzed by methods described in Experiment 1

During the 5-d sampling period, fecal grab samples were taken (0800 and 1600) from the rectum of each steer, dried to a constant weight in a forced-air oven at 55°C and ground through a Wiley mill through a 2 mm mesh screen. All fecal samples were composited and analyzed for Cr concentration by methods described in Experiment 1. Fecal output was calculated by Cr

dilution for each steer.

Three esophageally cannulated steers were used to collect masticate (diet) samples on d 10. Masticate samples were frozen, lyophilized and ground through a 2 mm mesh screen in a Wiley mill for analysis of soluble carbohydrates and N as described in Experiment 1.

In Situ Procedure. The nine ruminally cannulated steers were randomly assigned to one of three supplementation treatments (3 steers/treatment). Beginning on d 1, the steers received no supplement (controls, CL) or 1% of BW of either the high-starch or the high-fiber supplement. The supplements were placed directly into the rumen. The cannulated steers were adapted to the diets for 8 d. On d 7 hand-clipped wheat forage samples were collected from randomly selected locations in the experimental pasture and stored in a walk-in cooler maintained at 5°C. On d 8 the hand-clipped wheat forage samples were cut to an average particle length of about 2.5 cm and samples of the two supplements were ground through a 2 mm mesh screen in a Wiley mill. Beginning on d 9, duplicate dacron bags containing approximately 20 g (as-is) of the hand-clipped wheat forage (i.e., about 4 g of wheat forage DM), were incubated in situ in the rumen of each steer for 0, 12, 24, 36, 48 or 72 h. Duplicate bags containing 5 g (as-is) of either the high-starch or high-fiber supplement were incubated for 72 h. Dry matter and OM were determined on triplicate samples of forage (12 g as-is) and supplement (3 g as- is) immediately before dacron bags were placed in the rumen for each incubation period. After removal from the rumen, bags were initially rinsed under tap water to remove digesta from outside the bag. This was followed by successive washings with deionized water until the effluent from the bags was clear. After washing, all bags were dried to a constant weight in a forced air oven at 55°C and then re-weighed. Approximately .5 g of each sample residue was ashed at 500°C for 8 h for determination of OM. Extent of wheat forage OM digestion, and extent of supplement OM digestion, were calculated for each period, for each steer. These 72 h OM digestibilities were used to partition fecal output of the twenty-eight steers used in the forage intake portion of the experiment into that attributable to supplement and forage.

Ruminal fluid samples were collected (approximately 4 hours post-feeding) by hand, via

the cannulae of each of the nine steers on d 12, by methods described in Experiment 1. Samples were analyzed for pH, NH_3 and VFA as in Experiment 1.

Statistical Analysis. Data for the forage intake trial were analyzed as a completely randomized design, using the GLM procedure of SAS (1985). The full model included TYPE, SI, TYPE x SI, SI^2, TYPE x SI^2, SI^3 and TYPE x SI^3. The F-values of terms were calculated using the residual error. The terms SI2, Type x SI2, SI3 and TYPE xSI3 were not found to be statistically significant ($P > .18$) and therefore, a model with the terms TYPE, SI and TYPE x SI was fitted. The mean rate of in situ wheat forage OM digestion, for each treatment, was calculated using the natural logarithm of the percent of digestible OM remaining at each incubation period (h) using the REG procedure of SAS (1985).

Results and Discussion

Experiment 1.

Chemical composition and digestibility of the wheat forage, available for grazing in Experiment 1 is shown in Table 2. In Trial 1, a hard freeze occurred during the period in which steers were being acclimated to the supplements and prior to the fecal sampling period. As a result, forage DM content was high (i.e., about 52%) and the wheat turned light brown in color. Relatively low values for soluble carbohydrates and IVOMD were also observed. However, CP levels were as expected (about 24% of DM) for this time of the grazing season (January) and available forage was sufficient to meet demands for intake by the grazing steers. During Trial 2 (March), temperatures were more moderate and the forage was rapidly growing as indicated by the lower DM content (31%), higher maturity, and thus lower CP (about 21% of DM) than in Trial 1. In vitro OM digestibility was somewhat higher than in Trial 1.

Effects of Energy Supplementation on Forage Intake. Estimated forage intake ranged from 4.46 to 9.57 kg OM/d (mean = 6.30 ± .18), and supplement intake ranged from 0 to 2.30 kg OM/d (mean = 1.01 ± .12) or 0 to .83% BW (mean = .33 ± .04). Fecal OM output (% BW) ranged from .48 to .92 (mean = .67 ± .02). Cattle offered 1.2% BW of either the HS or HF

supplement did not always consume the entire amount, but other steers generally consumed all that was fed. Accordingly, the results discussed herein must be interpreted within the range of supplement intakes listed above. Results of this analysis are illustrated in Figure 2. The data were best described by the linear function of forage OM intake = 7.23 ± -.91(SI), R^2 = .35; $S_{y \cdot x}$ = .97. There was no evidence of a polynomial fit to the data (P > .35). The slope (i.e., substitution ratio) was -.91 ± .19 kg, or for each kg of supplement OM intake, forage OM intake was decreased by .91 kg. Vogel et al. (1989) reported a substitution ratio of -.66 in studies of effects of increasing amounts of supplemental silage on voluntary intake of wheat forage by steers. Lake et al. (1974) also noted a decrease in forage intake when steers were fed corn (from 0 to 2.7 kg/d) while grazing irrigated pastures (i.e., orchardgrass, smooth bromegrass and alfalfa mixtures). Studies by Coleman (1977), Jarrige et al. (1986) and Horn and McCollum (1987) suggest that greater substitution ratios are associated with high-quality forages. Moore's (1992) review of the literature tends to support the findings of this study. He reported that substitution ranged from +.21 (protein supplement) to -1.48 (barley) when supplement was fed at levels from .17 to 1.74% of BW.

Ruminal fermentation characteristics of cannulated steers are shown in Table 3. Rumen pH ranged form 6.26 to 6.66. Ammonia nitrogen was substantially lower in Trial 1 than in Trial 2 (i.e., 14.20 vs 34.20). The hard freeze experienced during Trial 1 may have had an effect on ruminal degradation of the forage. Total VFA concentrations were much lower in Trial 1 but molar percentages of individual VFA and acetate:propionate were similar between the two trials.

Prediction of Chromium Release Rate and Fecal Output. The analysis indicated the derived Cr release rate was 4.6%/d greater than that stated by the manufacturer. However, data from the analysis (Table 4 and Figure 3) showed that mean DRR FO and MRR FO were 1314 and 1256 g OM/d, respectively, and did not differ (P > .40). Fecal outputs from DRR and MRR underestimated actual FO by 14.3 and 19.6%, respectively. Since DRR FO was numerically closer to actual FO, DRR FO of each steer was adjusted upward by 14.3% and used as the estimate of actual FO.

Buntinx et al. (1992) reported on the accuracy of the controlled-release Cr capsule for estimating fecal output of lambs grazing alfalfa. The capsule underestimated fecal output by 13 to 20%, which is similar to the findings of this study. However, in two other trials conducted by the authors, utilizing bermudagrass, the capsule overestimated fecal output by 4 to 64%. A study with confined steers fed restricted (.75% BW) or higher (1.12% BW) levels of prairie hay, and a trial where steers were fed prairie hay (1.12% BW) or alfalfa hay (1.3%) was reported on by Pinchak and Hutcheson (1992). In all cases, the capsule overestimated actual fecal output. As concluded by Buntinx et al. (1992) and Pinchak and Hutcheson (1992) further development of the controlled-release capsule is needed before it can be used as the sole method for predicting actual fecal output.

Experiment 2.

Chemical composition and digestibility of the wheat forage, available for grazing in Experiment 2 is shown in Table 2. January and February were characterized by very mild temperatures and therefore, forage growth was rapid. The wheat forage was entering the "jointing" stage of growth around the first of March. Additionally a hard freeze occurred several days prior to the experiment. Thus, the forage DM was high (i.e., about 51%) as in Trial 1 of Experiment 1. However, CP was approximately 25% of DM and the grazing steers had adequate forage (131 kg/100 kg BW) to meet demands for intake. Relatively low soluble carbohydrate values were observed.

In Situ Procedure. Rate and extent of OM digestion of wheat forage are shown in Table 5. Rate of OM digestion of the wheat forage was 7.93 ± .01, 3.64 ± .01 and 4.71 ± .01 %/h, for CL, HS and HF steers, respectfully. Although rate of digestion was numerically highest for CL it did not differ between treatments ($P > .13$). Branine and Galyean (1990) also reported no statistical differences between treatments in rate of in situ wheat forage digestion where steers were supplemented with either 0, .5 kg•head^{-1}•d^{-1} of grain, or grain with 170 mg monensin•head^{-1}•d^{-1}. However, the authors reported rates of digestion, for supplemented cattle, that were generally higher than those observed in this study (5.4 to 7.3 vs 3.64 to 4.71,

respectively). Rate of digestion of wheat forage could vary with DM %, soluble carbohydrate content and other animal related factors.

Extent of digestion was highest ($P < .05$) for CL steers at 12 h of incubation and was higher ($P < .05$) for HF than HS at this time (48.37 vs 41.19 %). By 72 h of incubation, extent of OM digestion did not differ ($P > .16$) between treatments, similar to results reported by Branine and Galyean (1990), but was numerically greater for HF steers (83.22 %) than HS (76.83 %) and CL (80.85 %). A numerically lower rumen pH was observed in HS steers (Table 3). The low-starch, HF supplemented steers may have had a tendency ($P > .16$) to exhibit a greater extent of forage digestion than HS steers because addition of starch to the rumen was minimal (i.e., HF was only 18% starch). Mould et al. (1983) indicated the depression of roughage digestion when readily fermentable carbohydrates were fed was of a "composite nature", due in part to the decreased rumen pH and also to the amount of readily degradable substrate associated with supplementation.

Effects of energy supplementation on forage intake. Estimated forage intake ranged from 4.52 to 10.71 kg OM/d (mean = 7.55 ± .30), and supplement intake ranged from 0 to 2.54 kg OM/d (mean = .88 ± .14) or 0 to .25% BW. Fecal OM output (% BW) ranged from .35 to .56 (mean = .44 ± .01). As in Experiment 1, cattle offered 1.2% BW of either the HS or HF supplement did not always consume the entire amount. Steers fed moderate amounts of supplement (i.e., .4 or .8% BW) generally consumed all that was fed.

Statistical methods indicated that supplement type differed ($P < .08$) and should be analyzed separately. A linear fit of the data for HS supplemented steers was indicated by the analysis ($P < .03$). Results, as illustrated in Figure 4, were best described by the linear function (forage intake = 7.28 ± -.93(SI), $R^2 = .40$; $S_{y \cdot x} = 1.00$). The slope (i.e., substitution ratio) was -.93 ± .30 kg, or for each kg of supplement intake, forage intake was decreased by .93 kg. This ratio is similar to that observed in Experiment 1.

Because of wide variation in forage intake for HF steers, we were unable to define a "good fit" of the data (i.e., $R^2 = .06$, $S_{y \cdot x} = 1.35$). The F-values for terms were: SI = .89 ($P >$

.36), SI^2 = .13 (P > .73), SI^3 = .14 (P > .74). It was noted from a plot of the data (Figure 5) that little to no slope was evident across supplement intakes, indicating minimal substitution for HF steers. We have no definitive explanation for the differences in substitution observed in Experiments 1 and 2. However, Meijs (1986) reported that the mean substitution rate for lactating Dutch Friesian cows grazing perennial ryegrass pastures was reduced from .45 kg forage OM/kg concentrate OM ("high-starch" concentrate) to .21 with a "high-fiber" concentrate. Secondly, mean supplement OM intake of steers offered the HF supplement was .50% BW (25 g DM/kg $BW^{.75}$) in Experiment 1 and only .33% BW (16 g DM/kg $BW^{.75}$) in Experiment 2. Whereas, intakes of the HS supplemented steers were more similar and were .40% BW (19 g DM/kg $BW^{.75}$) in Experiment 1 and .33% BW (16 g DM/kg $BW^{.75}$). Smaller intakes of supplement should result in lower substitution ratios (Horn and McCollum, 1987). Finally, ruminal pH values were much lower in Experiment 2 than Experiment 1 (i.e., 6.66 vs 5.84 for CL steers; Table 3) and although it was not measured, there was probably a greater likelihood of metabolic acidosis in steers in Experiment 2. Perhaps the soybean hull/wheat middling components of the HF supplement provided a greater buffering capacity than the HS supplement and therefore differences in substitution in Experiment 2 were apparent. McBurney et al. (1983) reported significant differences in the buffering capacity of the NDF of feedstuffs. The amount of DM which yielded the equivalent buffering capacity of 100 g of calcium carbonate was 5.6, 10.6, 17.5 and 31.6 kg, respectively, for sugar beet pulp, lucerne hay, wheat middlings and oats.

Ruminal fermentation characteristics (Table 3) indicate generally lower pH values than in Experiment 1. Chemical analyses of the forage provided no insight into the differences. High levels of soluble carbohydrates in wheat forage could contribute to lower rumen pH, but differences in soluble carbohydrates were small between experiments. High-starch supplemented steers showed a tendency (P = .12) for a lower mean ruminal pH than CL but not HF steers (P > .22). Ruminal ammonia nitrogen was substantially lower for HS than CL or HF steers. The readily fermentable carbohydrate of the HS supplement was probably incorporated with NH_3 for bacterial protein synthesis. Differences among treatments were not indicated (P >

.10) for total VFA or molar percentages of individual VFA. However, total VFA were numerically higher than those of Trial 1 of Experiment 1, while acetate:propionate ratios for all treatments were much lower than in Experiment 1. As previously discussed, the markedly different ruminal fermentation characteristics, as well as supplement intakes, between steers in the two experiments could potentially account for the differences in substitution ratios observed for HF cattle.

Implications

Consistent substitution ratios (kg forage OM intake:kg supplement OM intake) of about -.92 were observed for HS steers. Ratios for HF cattle were not consistent and therefore, were inconclusive. Generally, one would expect a greater substitution for supplements containing higher amounts of readily fermentable carbohydrate because of the potential of altering forage digestibility in the rumen. Numerous factors may affect the substitutive effect of energy supplements. These factors might include DM and soluble carbohydrate content of the forage, level of supplement consumed, and ruminal fermentation parameters of the cattle. Differences in supplement intakes and ruminal pH as related to potential metabolic acidosis may explain the inconsistent results for HF steers. Further studies are needed to better understand the interrelationships between these factors and the mechanisms involved in reduced forage intake.

Literature Cited

AOAC. 1990. Official Methods of Analysis (15th ed.). Association of Official Analytical Chemists, Washington DC.

Andersen, M. A. and G. W. Horn. 1987. Effect of lasalocid on weight gains, ruminal fermentation and forage intake of stocker cattle grazing winter wheat pasture. J. Anim. Sci. 65:865.

Balwani, T. L. 1965. Soluble carbohydrates of the corn plant at different stages of maturity, and their digestibilities by rumen bacteria. M.S. Thesis. Ohio State University, Columbus.

Branine, M. E. and M. L. Galyean. 1990. Influence of grain and monensin supplementation on ruminal fermentation, intake, digesta kinetics and incidence and severity of frothy bloat in steers grazing winter wheat pasture. J. Anim. Sci. 68:1139.

Buntinx, S. E., K. R. Pond, D. S. Fisher and J. C. Burns. 1992. Evaluation of the Captec Chrome controlled release device for the estimation of fecal output by grazing sheep. J. Anim. Sci. 70:2243.

Coleman, S. W. 1977. Energy supplementation of grazing cattle. Proc. of Amer. Forage and Grassland Council Rep. EC 80-218, p 9.

Horn, G. W. and F. T. McCollum. 1987. Energy supplementation of grazing ruminants. pp. 125-137. Proc. of the Grazing Livestock Nutr. Conf. Univ. of Wyoming, Laramie.

Jarrige, R., C. Demarquilly, J. P. Dulphy, A. Holden, J. Robelin, C. Beranger, Y. Geay, M. Journet, C. Malterre, D. Micol and M. Petit. 1986. The INRA "Fill Unit" system for predicting the voluntary intake of forage-based diets in ruminants: A review. J. Anim. Sci. 63:1737.

Lake, R. P., R. L. Hildebrand, D. C. Clanton and L. E. Jones. 1974. Limited energy supplementation of yearling steers grazing irrigated pasture and subsequent feedlot performance. J. Anim. Sci. 39:827.

MacRae, J. C. and D. G. Armstrong. 1968. Enzyme methods for determination of alpha-linked glucose polymers in biological materials. J. Sci. Food Agric. 19:578.

McBurney, M. I., P. J. Van Soest and Larry E. Chase. 1983. Cation exchange capacity and buffering capacity of neutral-detergent fibers. J. Sci. Food Agric. 34:910.

Meijs, J. A. C. 1986. Concentrate supplementation of grazing dairy cows. 2. Effect of concentrate composition on herbage intake and milk production. Grass and Forage Sci. 41:229.

Moore, J. E. 1992. Matching protein and energy supplements to forage quality. Proc. Third Florida Ruminant Nutrition Symposium. Gainesville, FL. p 31.

Mould, F. L., E. R. Ørskov and S. O. Mann. 1983. Associative effects of mixed feeds. I. Effects of type and level of supplementation and the influence of the rumen fluid pH on cellulolysis in vivo and dry matter digestion of various roughages. Anim. Feed Sci. Tech. 10:15.

Pigden, W. J. and G. J. Brisson. 1956. Effect of frequency of administration of chromic oxide on its fecal excretion pattern by grazing wethers. Can. J. Anim. Sci. 36:146.

Pinchak, W. E. and D. P. Hutcheson. 1992. Effect of restricted forage intake in confinement on estimated fecal output from a sustained release bolus. J. Range Manage. 45:129.

SAS. 1985. SAS User's Guide: Statistics. SAS Inst., Inc. Carry, NC.

Smith, A. M. and J. T. Reid. 1955. Use of chromic oxide as an indicator of fecal output for the purpose of determining the intake of pasture herbage by grazing cows. J. Dairy Sci. 38:515.

Tilley, J. M. A. and Terry, R. A. 1963. A two-stage technique for the in vitro digestion of forage crops. J. British Grassl. Soc. 18:104.

Vogel, G. J., W. A. Phillips, G. W. Horn, M. J. Ford and R. W. McNew. 1989. Effects of supplemental silage on forage intake and utilization by steers grazing wheat pasture or bermudagrass. J. Anim. Sci. 67:232.

Williams, C. H., D. J. David and O. Lismaa. 1962. The determination of chromic oxide in feces samples by atomic absorption spechtrophotometry. J. Agr. Sci. Camb. 59:381.

Table 1. Composition (% as-fed) and digestibility of energy supplements[a].

	Type of supplement	
	High-starch	High-fiber
Ground corn	78.94	-----
Soybean hulls	-----	46.94
Wheat middlings	8.90[b]	41.74
Molasses (sugarcane)	4.95	4.95
Calcium carbonate	1.75	1.50
Dicalcium phosphate	.60	-----
Micro-lite	4.15	4.15
Salt	.65	.65
Rumensin 60 Premix	.067	.067
Calculated nutrient content (as-fed basis)		
NEgain, Mcal/kg	1.16	.87
Crude protein, %	8.2	11.5
Calcium, %	.89	.89
Phosphorous, %	.44	.53
Magnesium, %	.46	.55
Monensin content, mg/kg	88	88
Starch, % DM	67	18
IVOMD[c], %	83.62	73.34
In situ OMD[d], %	86.46	84.50

[a]Fed as 5 mm pellets.
[b]Added to improve pellet quality (decrease fines) of the high-starch supplement.
[c]Experiment 1.
[d]Experiment 2.

Table 2. Chemical composition and digestibility of wheat forage masticate in Experiments 1 and 2.

	Experiment 1		Experiment 2
	Trial 1	Trial 2	
n	3[a]	3[a]	3
DM, %	51.71	31.32	50.89
OM, % of DM	87.88	83.68	88.59
IVOMD, %	69.71	72.29	---
Crude protein, % of DM	24.28	20.94	25.67
Soluble carbohydrates, % of DM	13.74	13.09	17.19
Forage DM available			
kg/ha	1800	1880	3540
kg/100 kg BW	118	63	131

[a]Three esophagealy cannulated steers were used to collect masticate samples on two days. Samples were composited across days, within steer.

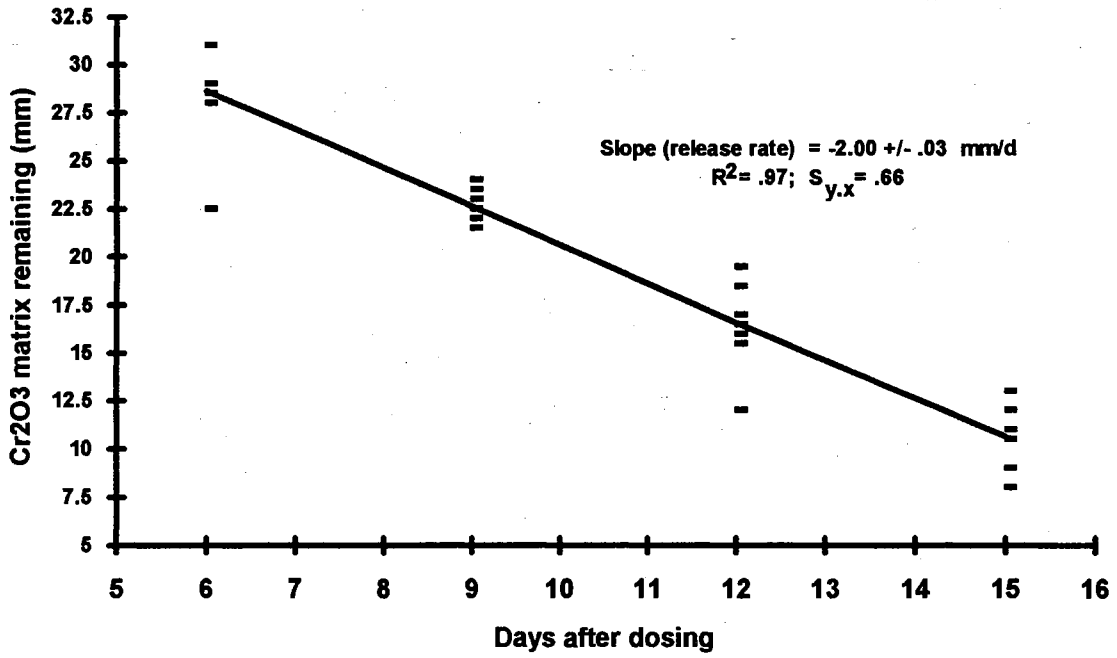

Figure 1. Predicted release of Cr by the controlled-release Cr capsule in steers grazing wheat pasture from d 6 to 15.

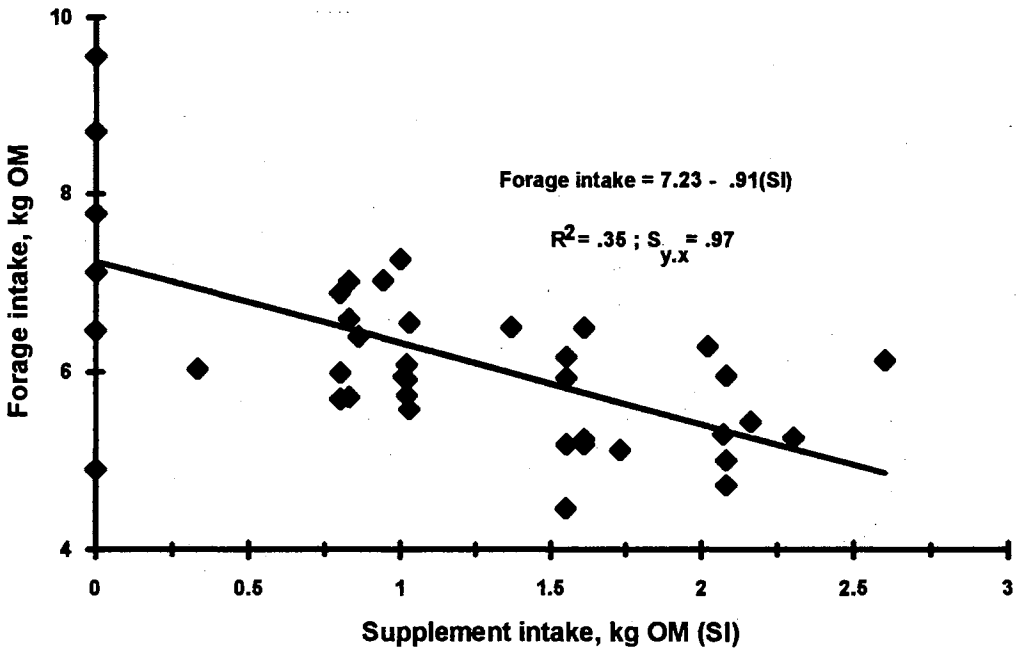

Figure 2. Substitution of energy supplement for wheat forage by steers grazing wheat pasture, Experiment 1.

Table 3. Means of ruminal fermentation data of steers grazing wheat pasture (Experiment 1) and grazing wheat pasture and supplemented wtih high-starch or high-fiber energy supplements (Experiment 2)[a].

	Experiment 1				Experiment 2			
	Trial 1		Trial 2					
Item	Control	SE[b]	Control	SE	Control	High-starch	High-fiber	SE
n	4		4		3	3	3	
pH	6.66	.27	6.26	.28	5.84	5.32	5.71	.29
NH_3-N, mg/dl	14.20	.90	34.20	.74	21.18[e]	3.03[f]	30.82[g]	.76
Total VFA[c],								
mmoles/liter	77.39	6.89	124.36	6.30	115.14	110.37	124.88	6.51
Acetate[d] (A)	66.13	1.22	64.44	.40	52.14	52.11	51.63	1.31
Propionate (P)	18.45	.77	18.15	.42	27.76	26.99	31.04	2.60
Butyrate	9.87	.30	12.11	.41	13.51	14.18	11.44	1.45
Isobutyrate	2.56	.32	1.77	.10	2.53	2.19	1.95	.15
Isovalerate	1.69	.10	2.12	.08	1.62	2.60	1.79	.31
Valerate	1.30	.15	1.41	.04	2.43	1.94	2.15	.15
A:P	3.65	.21	3.56	.08	2.08	1.96	1.74	.12

[a]Ruminaly cannulated steers.
[b]Standard error of the mean.
[c]Acetic, propionic, butyric, isobutyric, isovaleric, valeric.
[d]Molar percentages of total VFA.
[e,f,g]Means within a row lacking a common superscript differ ($P < .05$).

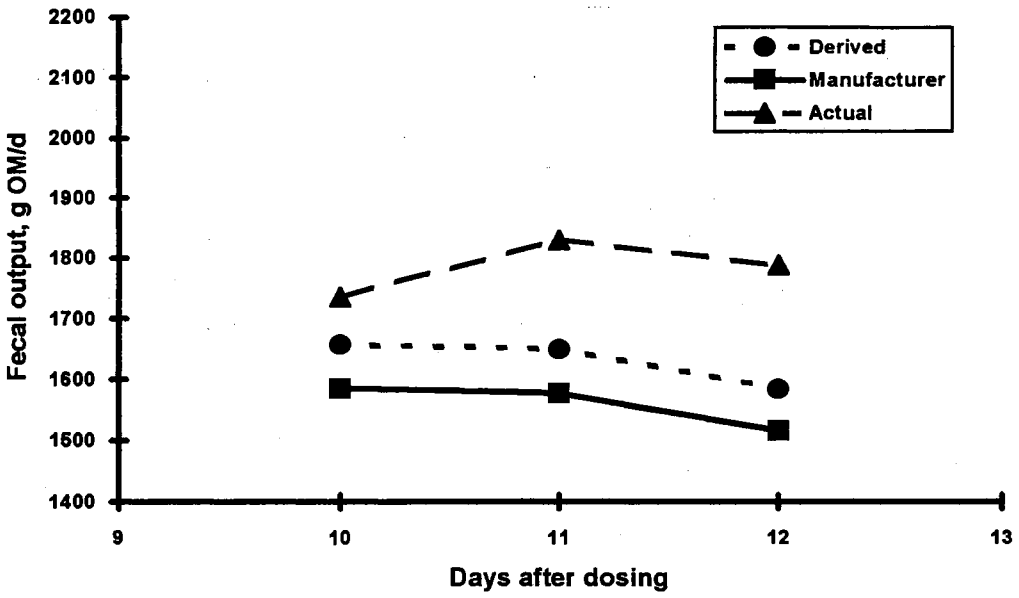

Figure 3. Actual (collected) and predicted (controlled-release Cr capsules; experimentally derived and manufacturer specified release rate) fecal output by steers grazing wheat pasture from d 10 to 12 after dosing.

Table 4. Means for actual and predicted fecal outputs (FO) by steers grazing wheat pasture 10 to 12 days after administration of controlled-release Cr capsules (Experiment 1)

Item	Actual FO	DRR FO[a]	MRR FO[b]
FO, g OM	1502	1314[c]	1256[c]
FO, % BW	.53	.46	.44
n	11	11	11
SE	2.95	2.86	2.80
Underestimation of actual FO, %	---	14.3	19.6

[a]FO calulated using the experimentally derived release rate of the bolus.
[b]FO calculated using the manufacturer's release rate of the bolus.
[c]Means within a row lacking a common superscript differ ($P < .01$).

Table 5. Means of rate and extent of in situ wheat forage OM digestion by steers grazing wheat pasture and supplemented wtih high-starch or high-fiber energy supplements (Experiment 2).

Item	Control	High-starch	High-fiber	SE[a]
Rate of OM disappearance[b], %/h	7.93	3.64	4.71	1.8
In situ OM disappearance, % of initital				
12 h	54.74[c]	41.19[d]	48.37[e]	1.7
24 h	63.99	59.52	65.47	3.6
36 h	66.69	59.88	73.47	5.9
48 h	76.97	67.91	75.94	3.6
72 h	80.85	76.83	83.22	2.8

[a]Standard error of the mean.
[b]Percent of potentially digestible OM.
[c,d,e]Means within the row lacking a common superscript differ ($P < .05$).

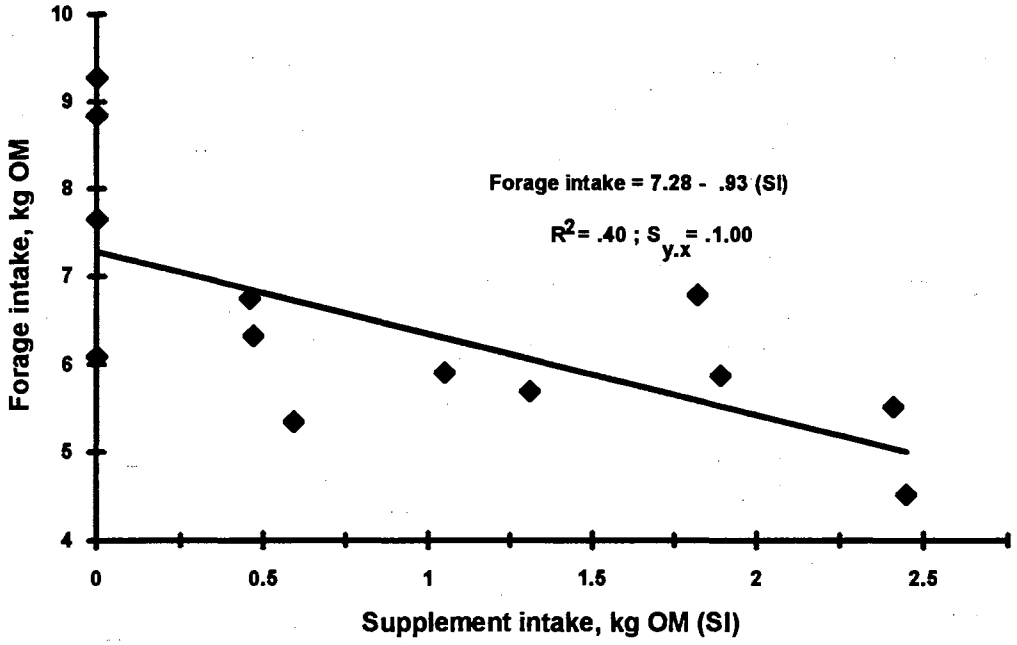

Figure 4. Effects of consumption of a high-starch energy supplement on wheat forage intake by steers grazing wheat pasture, Experiment 2.

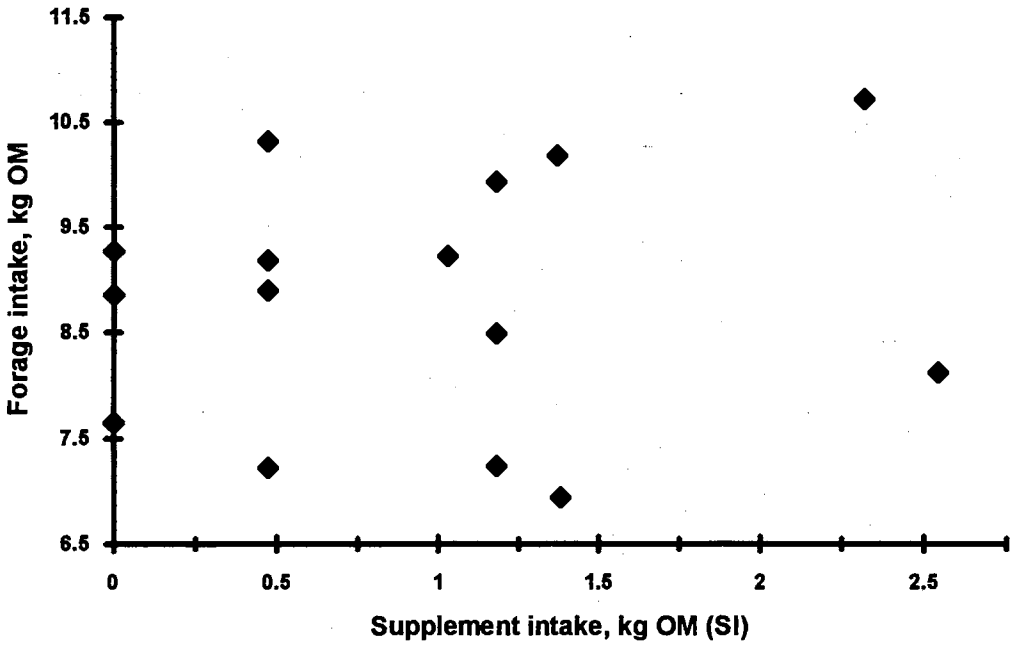

Figure 5. Forage intake versus supplement intake for steers supplemented with increasing amounts of a high-fiber energy supplement and grazing wheat pasture, Experiment 2.

CHAPTER V

EFFECT OF HIGH-STARCH VERSUS HIGH-FIBER ENERGY SUPPLEMENTS ON RUMEN AND BLOOD ACID-BASE PARAMETERS OF STOCKER CATTLE GRAZING WHEAT PASTURE[1]

M. D. Cravey,[2,3] G. W. Horn,[2] and D. L. Weeks[4]

Oklahoma Agricultural Experiment Station
Stillwater, OK 74078-0425

ABSTRACT

Nine ruminally cannulated Angus X Hereford steers grazing wheat pasture were randomly assigned to one of three supplementation treatments and received no supplement (CL) or 1% of mean BW/d of either a corn-based, high-starch supplement (HS) or a high-fiber byproduct feed-based energy supplement (HF). Supplements were fed for a 14-d adaptation period and a 1-d rumen and blood sampling period. Ruminal and blood samples were collected at 0, 4, 8, 12, 18, and 24 h post-feeding on d 15. Fecal grab samples were taken (0800) from the rectum of each steer (d 11 through 14) for determination of fecal output and forage intake. Effects of the energy supplements on ruminal and blood parameters were measured. Ruminal pH was lowest 4 h post-feeding for supplemented cattle. Steers fed the HS supplement exhibited a mean ruminal pH of 5.24 and 5.28 at h 4 and 8, respectively. Calculated mean pH-hours below 6.0 were 6.12 ± .98 (HS), 3.36 ± .68 (HF) and 1.35 ± .66 (CL) and were negatively

---

[1]Journal article No. XXXX of the Oklahoma Agricultural Experiment Station.
[2]Animal Science Department.
[3]We thank Ken Poling for assistance with animal care, Donna Perry and Carolyn Bowen for assistance with the laboratory analyses, and Paul Beck for assistance with the collection of samples.
[4]Department of Statistics.

correlated to forage intake (-.68; P < .05). Ruminal ammonia N (mg/dl) values dropped from 12.52 at h 0 to 7.90 at h 8, for HS, before rising to 10.34 by h 24. Ammonia N values of HF steers rose from an initial value of 21.92 to 38.36 at h 4, before decreasing to 10.49 at h 24. Ruminal fluid osmolality increased from 358 to 467 (HS) and 361 to 480 mOsmol/liter (HF) from h 0 to 4. Osmolality of control steers ranged from 300 to 377. No significant changes in blood pH, HCO_3, or base excess from h 0 were observed between treatments. Bicarbonate:carbonic acid ratios of all steers never decreased below 19.7 and were usually above the normal 20:1 ratio (pH 7.4), indicating excess buffering capacity in the blood. Blood pCO_2 increased by about 2 mm Hg from h 0 to 8 for HS and HF steers, but immediately decreased during the next 4 h period. Total ruminal VFA were highest for HF steers (188.4 mmoles/liter). Molar proportions of acetate were lower and propionate higher for HS and HF than for CL. Monensin in the supplement was probably responsible for this result. Acetate:propionate ratios were 2.03, 2.45 and 3.33 for HS, HF and CL, respectively. This study indicates that feeding a high-starch energy supplement at 1% BW/d to steers, has a short term negative influence on wheat forage digestion and intake, and is partially explained by a decrease in ruminal pH, pH-hours below 6.0 and elevation of ruminal osmolality. Impact on forage intake was greater for the HS supplement.

(Key Words: Cattle, Wheat Pasture, Energy Supplementation, Rumen, Blood Acid-Base)

Introduction

Numerous mechanisms have been suggested for the adverse effects of energy supplements on forage intake and/or fiber digestion, including decreased ruminal pH (Mould et al., 1983), a decline in numbers of cellulolytic bacteria (Henning et al., 1980), elevated ruminal osmolality (Carter and Grovum, 1990) and altered blood acid-base status (Horn and McCollum, 1987; Uhart and Carrol, 1967; Huber, 1976). However, energy supplements may have very different effects on ruminal pH and forage intake and utilization depending on the feedstuff composition of the supplement, the form and type of roughage and resulting rates of particle

fragmentation (and therefore, chewing and rumination times and salivation). To prevent the adverse effects of starch on ruminal fermentation, high-fiber by-product feeds, such as wheat middlings, soybean hulls and corn gluten feed, offer opportunities to formulate energy supplements with fairly high energy densities. The potential for use of these by-product feeds in supplementing growing cattle on wheat pasture is particularly high because of the rapid rate of ruminal degradation of wheat forage and the relative low ruminal pH values of these cattle (Anderson and Horn, 1987). The objective of this study was to investigate the effects of high-starch, corn-based and high-fiber, soybean hull and wheat middling-based energy supplements on ruminal and blood acid-base parameters in relation to their effect on wheat forage intake by steers.

Materials and Methods

Nine Angus X Hereford steers (BW = 355 ± 6.66 kg) grazing wheat pasture (Triticum aestivum variety Chisholm) and fitted with permanent ruminal cannulae were randomly assigned to one of three supplementation treatments for a 15 d trial (3/22 to 4/5/91). Prior to the trial, cattle were maintained on wheat pastures that bordered a 2.7 ha experimental pasture. On d 1, the steers were moved to the experimental pasture for the duration of the trial. All pastures were planted (clean-till) in early September of the previous fall. Standing forage in the 2.7 ha pasture was estimated by hand clipping forage (d 14) to ground level inside twenty, .1 m^2 quadrats along paced transects. Clipped samples were weighed, dried to a constant weight in a forced-air oven at 55°C and then re-weighed to determine DM %. Chemical composition and digestibility of the wheat forage is shown in Table 1.

On d 3, each steer was orally administered one controlled-release Cr capsule[5] to facilitate determination of fecal output. At 0800 of each d, the cattle were placed in a chute and received either no supplement (CL) or 1% BW/d of a high-starch (HS) or high-fiber (HF) by-product feed-based energy supplement. The supplements were placed directly into the rumen.

[5]Captec, Nufarm, Auckland, New Zealand.

Composition of the corn-based, HS (67% starch, DM basis) and soybean hull, wheat middling-based (18% starch) supplements are shown in Table 2. Both supplements contained about 88 mg of monensin/kg. Supplements were sampled daily on d 12 through 15, composited across days and analyzed for starch. Starch was analyzed as alpha-linked glucose (MacRae and Armstrong, 1968) modified by the use of o-Toluidine (Sigma[6]) as the colorimetric reagent. Rectal grab fecal samples were collected each morning (d 11 through 14) and dried to a constant weight in a forced-air oven at 55°C. After receiving supplement and collection of fecal samples, all steers were returned to pasture. Dried samples were ground in a Wiley mill through a 2 mm mesh screen and composited by weight, across days and within steer. Approximately 1 g from each sample was ashed at 500°C for 8 h and analyzed for Cr concentration by atomic absorption spectrophotometry using an air-acetylene flame as outlined by Williams et al. (1962). It was determined in a previous trial (Cravey, 1993) that the controlled-release bolus underestimated actual fecal output (via bag collection) by 14.3%. According to information provided by the manufacturer, the boluses used in this study were from the same batch as those used in the work of Cravey (1993). Therefore, fecal outputs in this study were adjusted upward by 14.3%.

Ruminal fluid and jugular blood samples were collected from each steer on d 15 at 0, 4, 8, 12, 18 and 24 h post-feeding. Ruminal fluid pH was measured immediately after removal of the fluid, and microbial activity was stopped by the addition of .5 ml of 20% sulfuric acid per 100 ml following straining through 4 layers of cheesecloth. Ruminal fluid samples were stored in an ice slurry for further analyses. Lactic acid concentration of protein-free filtrates of the rumen fluid samples was determined by the colorimetric procedure of Barker and Summerson (1948). Remaining aliquots of ruminal fluid were frozen for subsequent determinations of osmolality and ruminal ammonia nitrogen. Ruminal fluid osmolalities were determined by centrifuging thawed rumen fluid at 12,000 *g* for 20 min and measuring osmolality of the supernatant fluids by the freezing-point depression technique on a Precision Osmometer.[7] Ammonia analysis was

---

[6]Sigma Chemical Company; St. Louis, MO. 63178.
[7]Precision Instruments, Inc.; Sudbury, MA.

conducted by a modification of the magnesium oxide distillation method (AOAC, 1990) described by Anderson and Horn (1987). Five-milliliter aliquots of strained ruminal fluid collected at h 4 were prepared for VFA analysis by deproteinization with 1 ml of 25% (w/v) metaphosphoric acid that contained 2-ethylbutyric acid as an internal standard. Volatile fatty acid concentrations were analyzed by GLC on an Auto System GC[8].

Blood samples were collected from each steer using heperanized needles and syringes. The samples were immediately placed in an ice slurry and analyzed for pH, HCO_3, pCO_2 and base excess within 1 h of collection. Blood parameters were measured with a System 1304 pH/Blood Gas Analyzer[9].

Three esophageaIy cannulated steers were used to collect forage diet samples (d 12 and d 14). Screen bottom canvas collection bags, double-lined with plastic bags, were used to collect masticate. Subsamples from each steer were stored in tin pans wrapped in plastic bags and an effort was made to retain the liquid portion of the masticate samples. Masticates were immediately frozen, lyophilized and ground through a 2 mm mesh screen in a Wiley mill for subsequent analysis of in vitro OM digestibility (Tilley and Terry, 1963), soluble carbohydrates as described by Balwani (1965) and N by the Kjeldahl procedure (AOAC, 1990). Extensive time was required to lyophilize masticate samples of this study and other previous studies. Therefore, in order to determine in vitro OM digestibility of masticate samples and supplements (Tilley and Terry, 1963), rumen fluid was obtained from a rumen cannulated steer, grazing wheat pasture, towards the end of the grazing season (May 15, 1993).

Statistical analyses of all ruminal and blood data followed standard split plot in time designs (Steel and Torrie, 1980). Because substantial differences occurred among treatments in the initial 0 h values for many of the response variables (e.g., ammonia nitrogen and pCO_2), treatment effects at subsequent times were analyzed by comparing the change from zero time for each treatment. Ruminal pH-hours were calculated from the area of the pH-time curve below

---

[8]Perkin-Elmer; Norwalk, CT 06859-0156.
[9]Instrumentation Laboratory; Lexington, MA 02173.

pH 6.0, for each steer using plane geometry. Correlation between forage intake and pH-hours was determined using the CORR procedure of SAS (1985). Treatment differences between mean forage intake and between ph-hours below 6.0 were tested using least significant difference (Steel and Torrie, 1980).

Results and Discussion

Ruminal Parameters. Values of ruminal fermentation parameters are shown in Table 3. Ruminal lactic acid concentrations of steers in this study were low at each sampling period and averaged only 1.03 ± .40 mmoles/liter at h 4. Therefore, they are not reported. High-starch supplemented steers showed the greatest trend for depressed ruminal pH after feeding (Figure 1). Steers fed the HF supplement showed a trend for depressed ruminal pH that was intermediate to CL and HS. Maximum pH depression occurred 4 to 8 h post-feeding for the HF and HS diets. Ruminal pH fell to lows of 5.24 for HS and 5.56 for HF steers, at 4 h post-feeding, while mean ruminal pH of CL cattle never dropped below 5.78 (h 12). Ruminal pH of HS steers at h 4 and 8 were 5.24 and 5.28, respectively. This may be of importance since Kay et al. (1969) reported irreversible damage to the ruminal epithelium occurs at a rumen pH below 5.5.

Henning et al. (1980) discussed the importance of the concept of "pH-hours below 6.0". The authors suggested that the length of time and the extent to which the pH falls below 6 may influence growth of cellulolytic bacteria and therefore depress fiber digestion. Mean forage OM intake (Table 3) was greatest ($P < .05$) for CL (6.40 kg OM/d) and was greater ($P < .10$) for HF steers (4.79 kg OM/d) than HS steers (3.56 kg OM/d). Analysis of the data showed a negative correlation between pH-hours below 6.0 and forage intake (-.68; $P < .05$). The tendency ($P = .14$) for lower pH-hour values and higher ($P < .10$) daily forage intakes of HF steers indicates a smaller negative influence on fiber digestion than that of the HS supplement. Mould and Ørskov (1983) reported that in situ ruminal degradation of grass hay at 24 h of incubation in the rumen of sheep was decreased from 30 to 9% when rumen pH was reduced from 6.6 to below 6.0 by continuous infusion of an acid solution. Mould et al. (1983) indicated the depression of roughage

digestion when readily fermentable carbohydrates were fed was of a "composite nature", due in part to the decreased rumen pH and also to the amount of readily degradable substrate associated with supplementation. The authors also found a substantial reduction in rumen pH and number of cellulolytic bacteria when diets were changed from all hay to all barley. Huber (1976) showed the relationship between ruminal pH and endotoxins released from dead gram negative bacteria may be a contributing factor in lactic acid acidosis syndrome in ruminants. When sheep were dosed with 20 g glucose/kg BW intraruminally, rumen pH dropped from 6.9 (h 0) to 4.75 (h 72). No endotoxin was detected until pH fell below 5.4. Mullinax et al. (1966) reported rumen stasis in both cattle and sheep injected intravenously with endotoxin extracted from rumen bacteria. Endotoxins were also suspected to indirectly inhibit motility by releasing endogenous histamine from body cells. Thus, grazing animals consuming sufficient quantities of a high-starch supplement could experience a reduction in rumen pH and therefore, motility. A decrease in rumen motility would result in reduced digestion, passage rate and therefore, reduced forage intake. By 24 h post-feeding, all ruminal pH values had returned to, or exceeded the pH at time zero.

High-fiber supplemented steers exhibited the highest total VFA concentrations (188.4 mmoles/liter; Table 4). Although total VFA were only measured at h 4, they probably were highest during the first few h of feeding. Horn et al. (1979) reported that total VFA were highest 1 to 2 h post-feeding, in steers fed ground, ensiled high-moisture corn diets with or without various buffers. Molar percentages of acetate and butyrate were lower ($P < .05$) for HS and HF than for CL steers. Propionate concentrations were highest for HS steers, intermediate for HF and lowest for CL. Therefore, HS supplemented steers exhibited the lowest acetate:propionate ratio. Butyrate levels were greater ($P < .01$) for CL than HS steers. The monensin contained in the supplements probably contributed to the higher proportions of propionate and less butyrate in supplemented cattle (Branine and Galyean, 1990; Horn et al., 1981).

A pattern of decreased ruminal NH_3-N was observed in the first 12 h post-feeding for HS steers (Figure 2.). This may be due to an incorporation of readily fermentable carbohydrate with

free ammonia nitrogen for the synthesis of bacterial protein. High-fiber supplemented steers exhibited an increase ($P < .05$, Table 3) in NH_3-N during the first 4 h post-feeding. One would expect higher concentrations of ruminal NH_3-N in HF cattle during the early post-feeding period because of differences in fermentable energy between supplements.

Owens and Goetsch (1988) report that normal fermentation occurs at osmolarities between 260 and 340 mOsmol/liter in ruminants. In this study, control steers exhibited osmolalities in the range of 300 to 377 mOsmol. Supplemented steers had osmolalities between 296 and 467 (HS) and 331 and 480 mOsmol (HF), with significant increases during the first 4 h post-feeding. Phillip et al. (1981) found an inverse linear relationship between feed intake in sheep and ruminal fluid tonicity over the range of 200 to 500 mOsmol/kg after infusions of hypertonic extracts of fresh and ensiled whole corn plant and NaCl solutions into the rumen. Although the authors reported their values as osmolarities (mOsmol/weight, i.e., kg), quantitative differences between osmolarity and osmolality are reported to be less than 1% for the dilute solutions found in the body (Carter and Grovum, 1990). All rumen osmolalities returned to a level of about 25 to 50 mOsm/liter below the initial range, by 24 h (Figure 3). Hypertonic effects in the rumen, due to supplementation, were probably influential in limiting short-term forage intake.

Blood Parameters. Blood acid-base parameters of the steers are shown in Table 5. Blood pH values of CL steers were numerically higher than those of supplemented steers at time 0. Changes in blood pH with time were similar for CL and HF steers and never decreased below 7.41. These results are consistent with those of Horn et al. (1979) who also reported that pH never decreased below 7.37 in steers fed ground, ensiled high-moisture corn diets with or without various buffers. Blood pH of HS steers tended to decrease from 4 to 8 and 12 to 18 h post-feeding (Figure 4), but did not significantly differ in change from the 0 h when compared to CL or HF cattle.

Blood pCO_2 concentrations (mm/HG) significantly increased for HS and HF steers from h 0 to h 8, compared to controls, and were highest for HS steers (Figure 5). These changes are

illlustrated in Figure 4. These results suggest that HS steers were under the greatest stress from 4 to 8 h post-feeding. Blood bicarbonate concentrations followed a similar trend (Figure 6.) but no significant differences in change from the 0 h were noted among the treatments. Likewise no important differences in base excess (i.e., units above or below the "normal" bicarbonate:carbonic acid (HCO_3:H_2CO_3) ratio of 20:1, at pH 7.4) were noted between the treatments (Table 4 and Figure 7). This would be expected considering the minimal changes of blood pH noted. A reduction in blood pH should result in a temporary decrease in the HCO_3:H_2CO_3 ratio according to the Henderson-Hasselbalch equation. However, even with a decrease in the HCO_3:H_2CO_3 ratio, the increased CO_2 tension of blood and decrease in blood pH stimulates respiration and restores the desired HCO_3:H_2CO_3 ratio to near 20:1 (Huber, 1976). Uhart and Carroll (1967) reported that steers stopped eating their 90% grain diet when their blood HCO_3:H_2CO_3 ratio had fallen form 18.9 to 15.3 and blood pH had decreased from 7.37 to 7.29. The steers resumed eating when HCO_3:H_2CO_3 levels reached 16.1. Bicarbonate:carbonic acid levels stabilized at 18.2, similar to the initial ratio of 18.9. Bicarbonate:H_2CO_3 levels in this study (Table 4) never fell below 19.7.

Implications

Numerous changes were noted in ruminal fermentation parameters of HS steers indicating a temporary period of subclinical acidosis up to 12 h post-feeding. Accordingly, reduction in forage intake appears to be greatest when cattle consume the HS supplement. Changes in ruminal parameters of HF cattle were less extreme due to the lower content of readily fermentable carbohydrate. The pH-hours below 6.0 was negatively correlated with forage OM intake. Effects on blood acid-base parameters were minimal for all treatments. However, this may not be the case in situations where basal ruminal pH is lower than the approximate 6.2 observed in this study.

Literature Cited

AOAC. 1990. Official Methods of Analysis (15th ed.). Association of Official Analytical Chemists, Washington DC.

Andersen, M. A. and G. W. Horn. 1987. Effect of lasalocid on weight gains, ruminal fermentation and forage intake of stocker cattle grazing winter wheat pasture. J. Anim. Sci. 65:865.

Balwani, T. L. 1965. Soluble carbohydrates of the corn plant at different stages of maturity, and their digestibilities by rumen bacteria. M.S. Thesis. Ohio State University, Columbus.

Barker, S. B. and W. H. Summerson. 1948. The colorimetric determination of lactic acid in biological material. J. Biol. Chem. 138:535.

Branine, M. E. and M. L. Galyean. 1990. Influence of grain and monensin supplementation on ruminal fermentation, intake, digesta kinetics and incidence and severity of frothy bloat in steers grazing winter wheat pasture. J. Anim. Sci, 68:1139.

Carter, R. and W. L. Grovum. 1990. A review of the physiological significance of hypertonic body fluids on feed intake and ruminal function: Salivation, motility and microbes. J. Anim. Sci. 68:2811.

Cravey, M. D. 1993. Chapter IV: Effect of high-starch versus high-fiber energy supplements on forage intake of steers grazing wheat pasture. Ph.D. Dissertation. Oklahoma State University.

Cravey, M. D., G. W. Horn, F. T. McCollum and P. A. Beck. 1992. Effect of high-starch versus high-fiber energy supplements on forage intake of steers grazing wheat pasture. J. Anim. Sci. 70 (Suppl. 1):89 (Abstr.).

Henning, P. A., Y. Van der Linden, M. E. Mattheyse, W. K. Nauhaus and H. M. Schwartz. 1980. Factors affecting the intake and digestion of roughage by sheep fed maize straw supplemented with maize grain. J. Agric. Sci., Camb. 94:565.

Horn, G. W., T. L. Mader, S. L. Armbruster and R. R. Frahm. 1981. Effect of monensin on ruminal fermentation, forage intake and weight gains of wheat pasture stocker cattle. J. Anim. Sci. 52:447.

Horn, G. W. and F. T. McCollum. 1987. Energy supplementation of grazing ruminants. pp. 125-137. Proc. of the Grazing Livestock Nutr. Conf. Univ. of Wyoming, Laramie.

Horn, G. W., J. L. Gordon, E. C. Prigge and F. N. Owens. 1979. Dietary buffers and ruminal and blood parameters of subclinical lactic acidosis in steers. J. Anim. Sci. 48:683.

Huber, T. L. 1976. Physiological effects of acidosis on feedlot cattle. J. Anim. Sci. 43:902.

Kay, M., B. F. Fell and R. Boyne. 1969. The relationship between acidity of the rumen contents and rumenitis in calves fed on barley. Res. Vet. Sci. 10:181.

MacRae, J. C. and D. G. Armstrong. 1968. Enzyme methods for determination of alpha-linked glucose polymers in biological materials. J. Sci. Food Agric. 19:578.

Mould, F. L., E. R. Ørskov and S. O. Mann. 1983. Associative effects of mixed feeds. I. Effects of type and level of supplementation and the influence of the rumen fluid pH on cellulolysis in vivo and dry matter digestion of various roughages. Anim. Feed Sci. Tech. 10:15.

Mould, F. L. and E. R. Ørskov. 1983. Manipulation of rumen fluid pH and its influence on cellulolysis in sacco, dry matter degradation and the rumen microflora of sheep offered either hay or concentrate. Anim. Feed Sci. Technol. 10:15.

Mullinax, C. H., R. F. Keeler and M. J. Allison. 1966. Physiologic responses of ruminants to toxic factors extracted from rumen bacteria and rumen fluid. Amer. J. Vet. Res. 27:857.

Owens, F. N. and A. L. Goetsch. 1988. Ruminal Fermentation. In: D. C. Church (Ed.) The Ruminant Animal. pp. 145-171. Prentice Hall, Englewood Cliffs, NJ.

Phillip, L. E., J. G. Buchanan-Smith and W. L. Grovum. 1981. Food intake and ruminal osmolality in the sheep: Differentiation of the effect of osmolality from that of the products of maize silage fermentation. J. Agric. Sci. (Camb.) 96:439.

Uhart, B. A. and F. D. Carrol. 1967. Acidosis in beef steers. J. Anim. Sci. 26:1195.

SAS. 1985. SAS User's Guide: Statistics. SAS Inst., Inc. Carry, NC.

Steel, R. G. D. and J. H. Torrie. 1980. Principles and Procedures of Statistics. McGraw-Hill Book Co., New York. P. 377.

Tilley, J. M. A. and R. A. Terry. 1963. A two stage technique for in vitro digestion of forage crops. J. Br. Grassland Soc. 18:104.

Williams, C. H., D. J. David and O. Lismaa. 1962. The determination of chromic oxide in feces samples by atomic absorption spectrophotometry. J. Agr. Sci. Camb. 59:381.

Table 1. Chemical composition and digestibility of wheat forage grazed by steers.

DM, %	26.68
OM, % of DM	90.20
IVOMD, %	78.14
Crude protein, % of DM	20.90
Soluble carbohydrates, % of DM	15.92
Forage DM available	
kg/ha	1353
kg/100 kg BW	114

Table 2. Composition (% as-fed) and digestibility of energy supplements[a].

Ingredient	Type of supplement	
	High-starch	High-fiber
Ground corn	78.94	-----
Soybean hulls	-----	46.94
Wheat middlings	8.90[b]	41.74
Molasses (sugarcane)	4.95	4.95
Calcium carbonate	1.75	1.50
Dicalcium phosphate	.60	-----
Micro-lite	4.15	4.15
Salt	.65	.65
Rumensin 60 Premix	.067	.067
Calculated nutrient content (as-fed basis)		
NEgain, Mcal/kg	1.16	.87
Crude protein, %	8.2	11.5
Calcium, %	.89	.89
Phosphorous, %	.44	.53
Magnesium, %	.46	.55
Monensin content, mg/kg	88	88
Starch, % DM	67	18
IVOMD, %	83.62	73.34

[a]Fed as 5 mm pellets.
[b]Added to improve pellet quality (decrease fines) of the high-starch supplement.

Table 3. Ruminal fermentation parameters and forage intake of steers.

Parameter	Hours post-feeding	Supplementation treatment		
		Control	High-starch	High-fiber
pH	0	6.19	6.24	6.11
	4	6.05[a]	5.24[b]	5.56[c]
	8	5.92[a]	5.28[b]	5.82[a]
	12	5.78	5.70	5.76
	18	6.29	6.53	6.08
	24	6.20	6.51	6.15
pH-hours below 6.0		1.35[f]	6.12[g]	3.36[f,g]
NH_3-N, mg/dl	0	18.00	12.52	21.92
	4	18.57[a]	11.31[a]	38.36[b]
	8	22.52	7.90	30.02
	12	25.70	9.81	31.57
	18	11.28	12.74	15.54
	24	14.18[a,d]	10.34[a]	10.49[b,e]
Omolality, mOsmol/kg	0	357.3	358.0	361.0
	4	367.3[a]	466.7[b]	480.0[b]
	8	377.0[d]	437.3[e]	417.7
	12	322.7	295.7	335.7
	18	300.3	297.0	336.0
	24	321.3	305.0	330.7
Fecal output, % BW		.55	.43[f]	.59[g]
Forage intake, kg OM/d		6.40[f]	3.56[g,h]	4.79[g,i]

[a,b,c]Means in the same row with different superscripts differ in change from 0-h value ($P < .05$).

[d,e]Means in the same row with different superscripts differ in change from 0-h value ($P < .10$).

[f,g]Means in the same row with different superscripts differ ($P < .05$).

[h,i]Means in the same row with different superscripts differ ($P < .10$).

Table 4. Four-hour post-feeding ruminal fluid volatile fatty acid concentrations of steers grazing wheat pasture.

	Supplementation treatment			
	Control	High-starch	High-fiber	SE[b]
Total VFA's[a], mmoles/liter	128.1[d]	136.4[d]	188.4[e]	11.46
Acetate[c] (A)	63.52[d]	59.97[e]	60.45[e]	.67
Propionate (P)	19.06[d]	29.98[e]	24.79[f]	1.76
Butyrate	13.25[d]	7.14[e]	10.58	1.11
Isobutyrate	1.32	1.22	1.10	.07
Isovalerate	1.48	1.11	1.51	.13
Valerate	1.39	.56[g]	1.55[h]	.23
A:P	3.33[d]	2.03[e]	2.45[f]	.20

[a]Acetic, propionic, butyric, isobutyric, isovaleric, valeric.
[b]Standard error of the mean.
[c]Molar percentages of total VFA's.
[d,e,f]Means in the same row without common superscripts differ ($P < .05$).
[g,h]Means in the same row without common superscripts differ ($P < .10$).

Table 5. Blood acid-base parameters of steers.

Parameter	Hours post-feeding	Supplementation treatment		
		Control	High-starch	High-fiber
pH	0	7.44	7.40	7.41
	4	7.42	7.39	7.42
	8	7.43	7.38	7.42
	12	7.42	7.39	7.41
	18	7.42	7.37	7.41
	24	7.43	7.39	7.41
pCO_2, mm Hg	0	44.2	50.4	45.5
	4	43.8	48.8	45.1
	8	43.07[a]	52.2[b]	47.1[b]
	12	40.0	45.4	40.4
	18	41.4	46.8	40.3
	24	39.7[a]	44.8[a]	44.2[b]
HCO_3	0	30.0	31.4	29.3
	4	28.9	30.3	29.3
	8	29.1	30.8	30.7
	12	26.5	27.9	26.0
	18	26.9	27.6	25.9
	24	26.2	27.1	28.0
HCO_3:H_2CO_3[e]	0	22.6	20.8	21.5
	4	22.0	20.7	21.7
	8	22.5	19.7	21.7
	12	22.1	20.5	21.5
	18	21.7	19.7	21.4
	24	22.0	20.2	21.1
Base excess	0	5.57	5.87	4.53
	4	4.43	5.00	4.60
	8	4.87	4.80	5.83
	12	2.60	2.97	1.87
	18	2.73	2.30	3.05
	24	2.37	2.10	3.33

[a,b]Means in the same row with different superscripts differ in change from 0-h value ($P < .05$).

[c,d]Means in the same row with different superscripts differ in change from 0-h value ($P < .10$).

eH_2CO_3 = pCO_2 X .03.

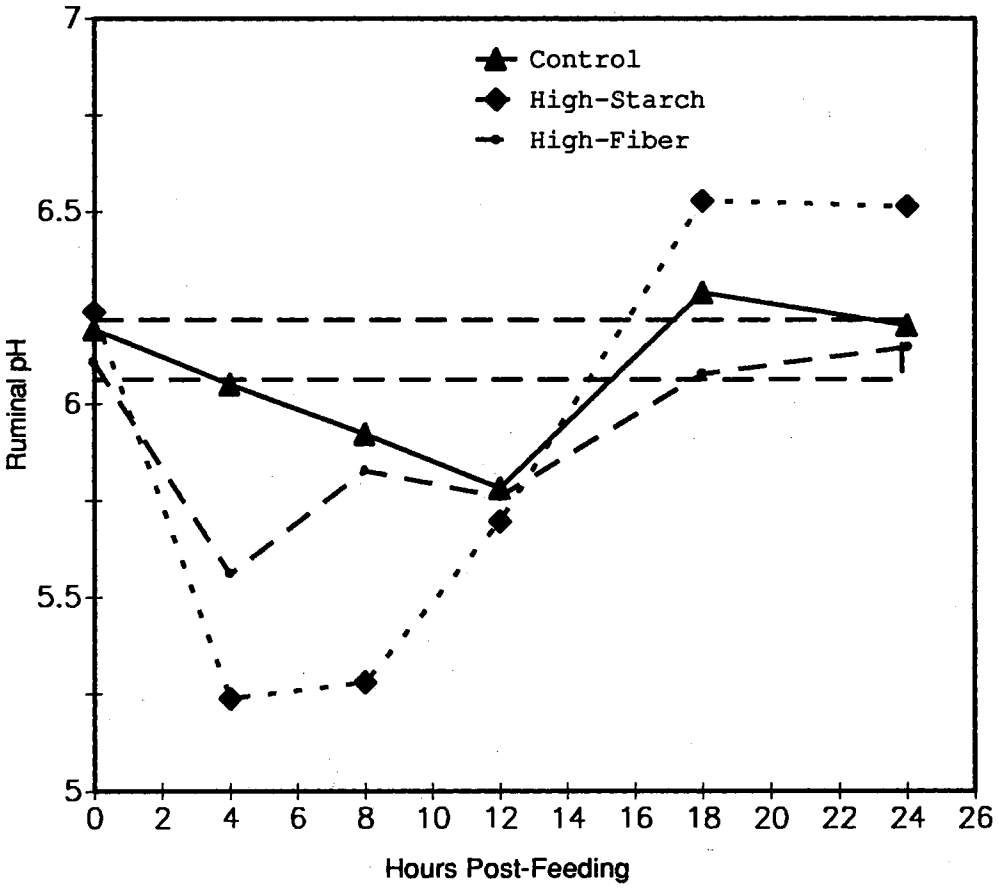

Figure 1. Time-course changes in ruminal pH. Dashed rectangle represents mean +/- SEM ruminal pH of all steers at time zero.

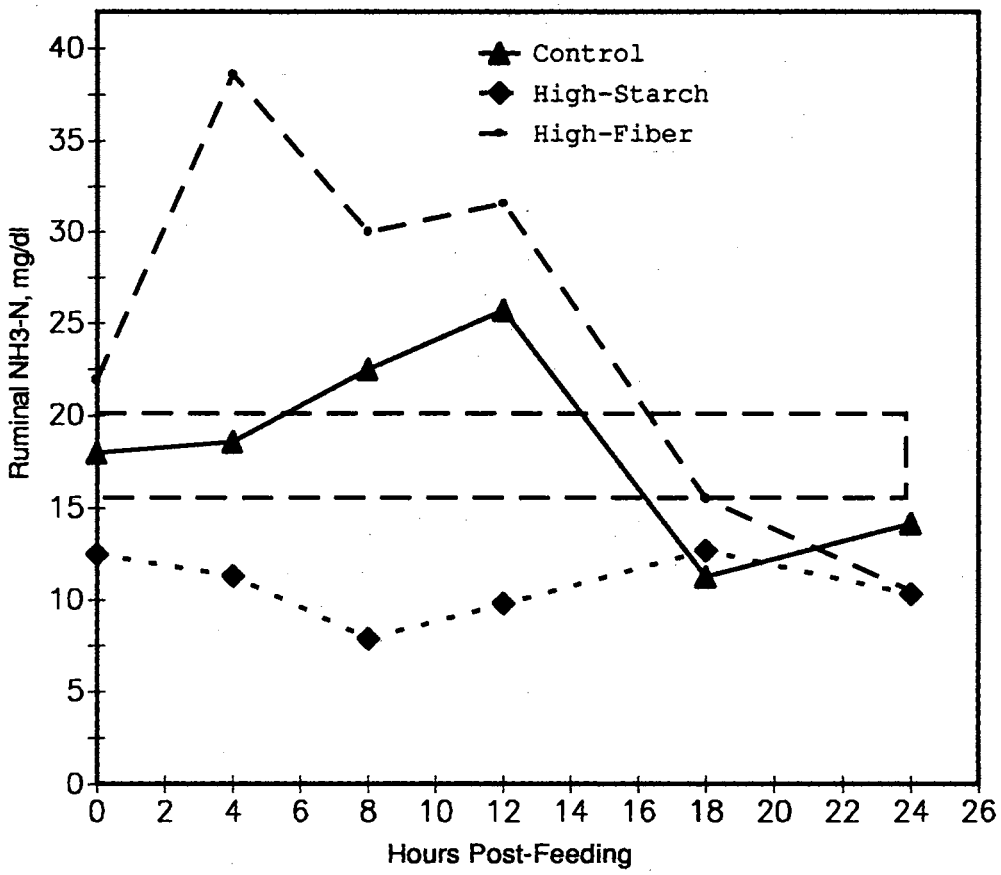

Figure 2. Time-course changes in ruminal ammonia N. Dashed rectangle represents mean +/- SEM ruminal ammonia N of all steers at time zero.

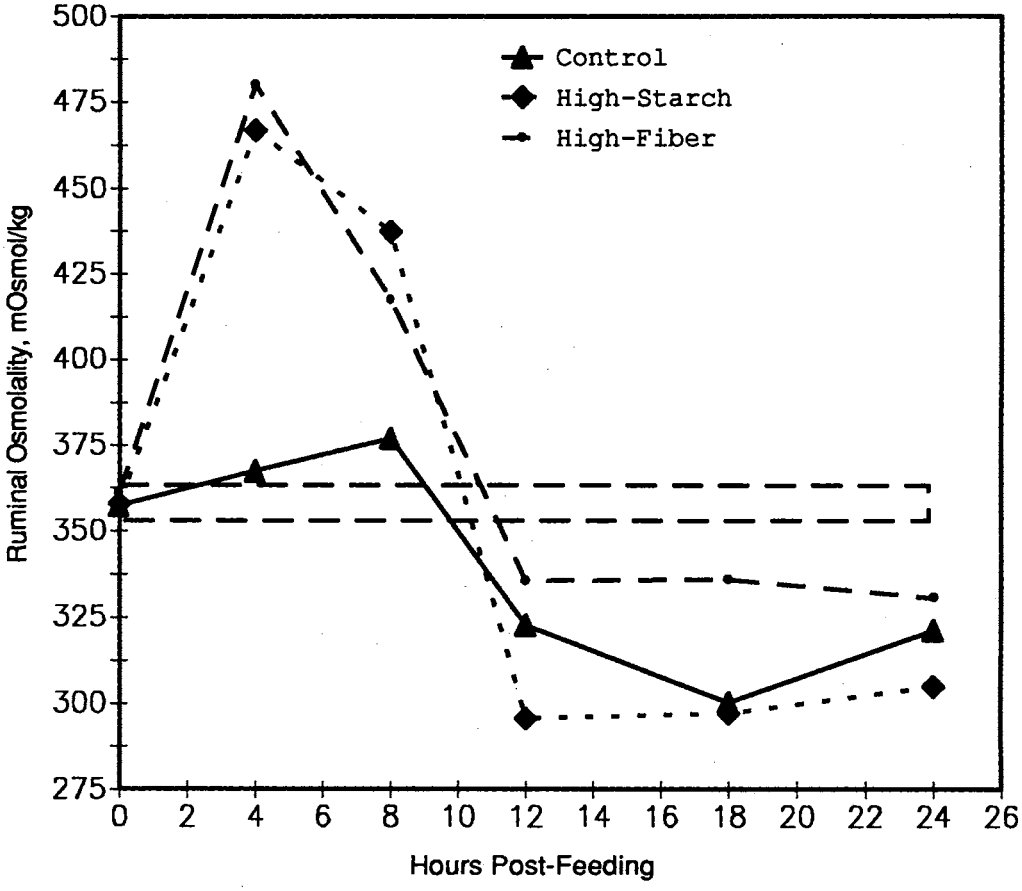

Figure 3. Time-course changes in ruminal osmolality. Dashed rectangle represents mean +/- SEM ruminal osmolality of all steers at time zero.

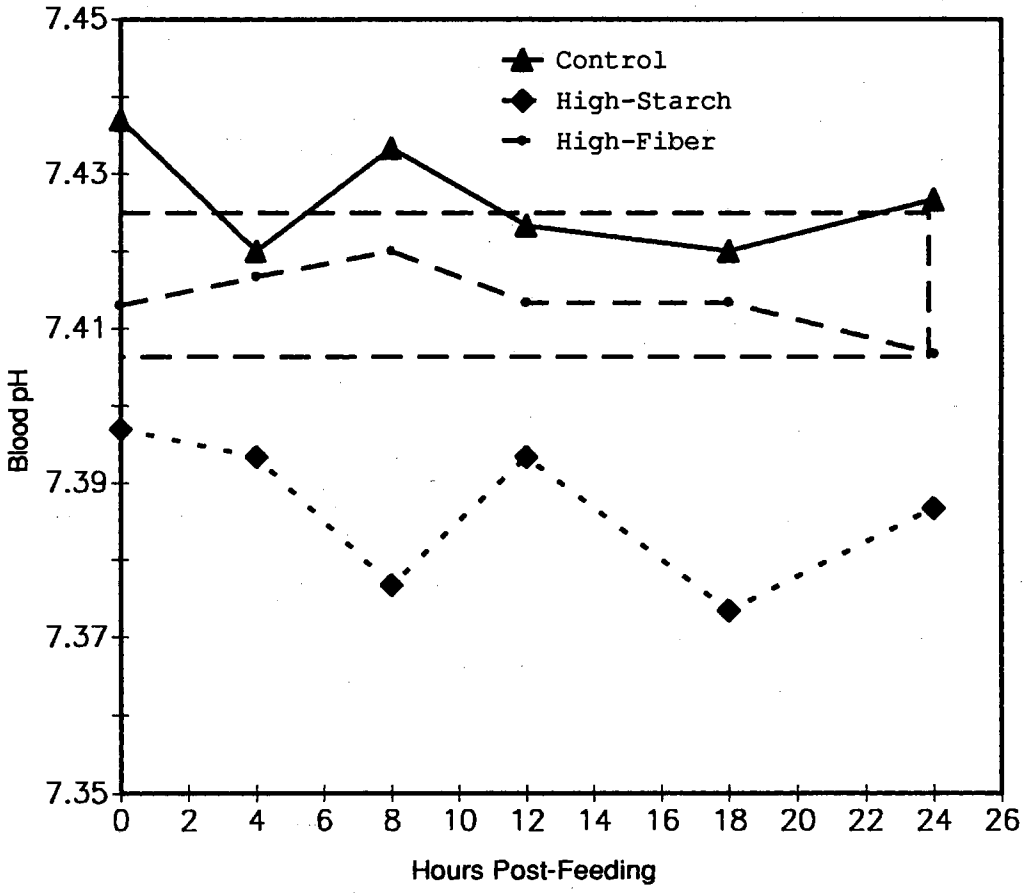

Figure 4. Time-course changes in blood pH. Dashed rectangle represents mean +/- SEM blood pH of all steers at time zero.

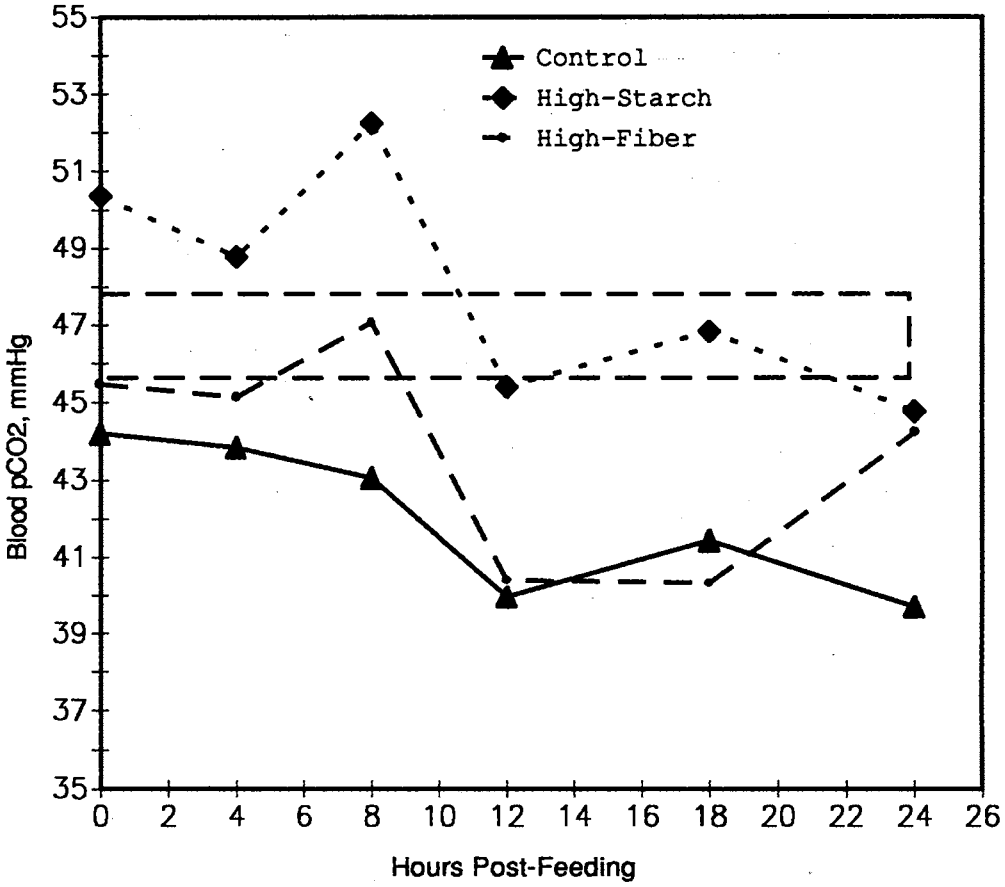

Figure 5. Time-course changes in blood pCO2. Dashed rectangle represents mean +/- SEM pCO2 of all steers at time zero.

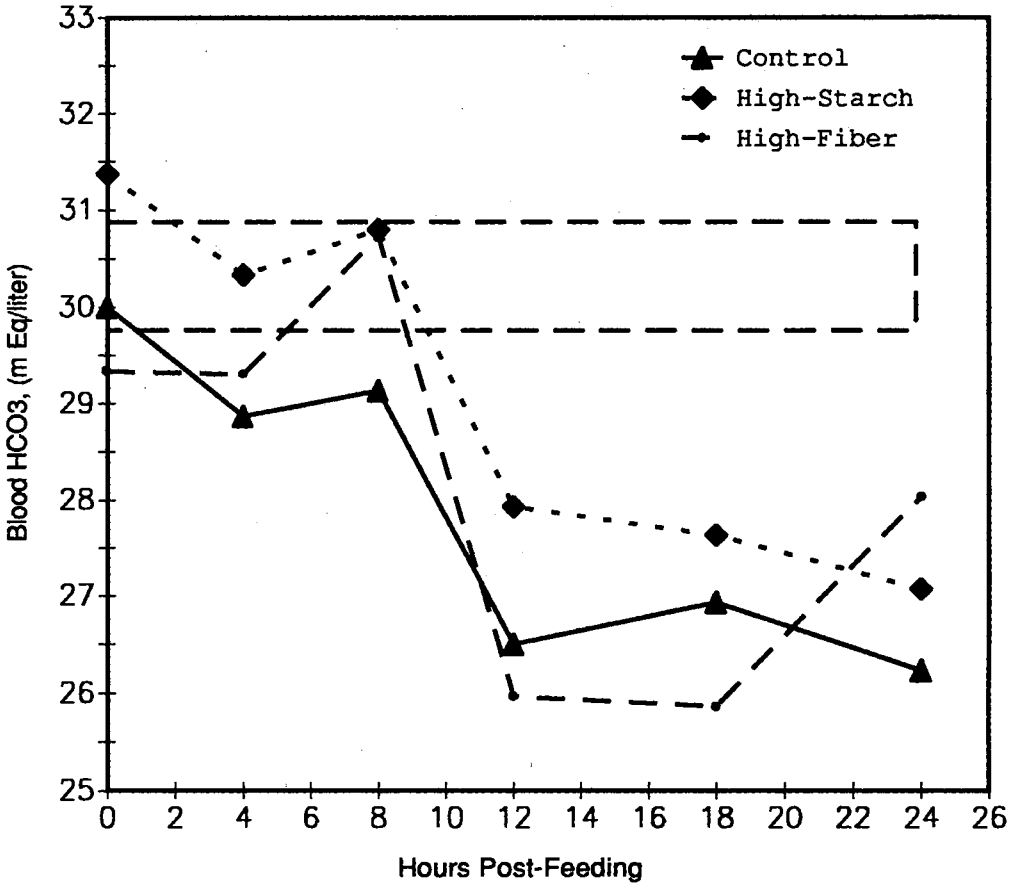

Figure 6. Time-course changes in blood HCO3. Dashed rectangle represents mean +/- SEM blood HCO3 of all steers at time zero.

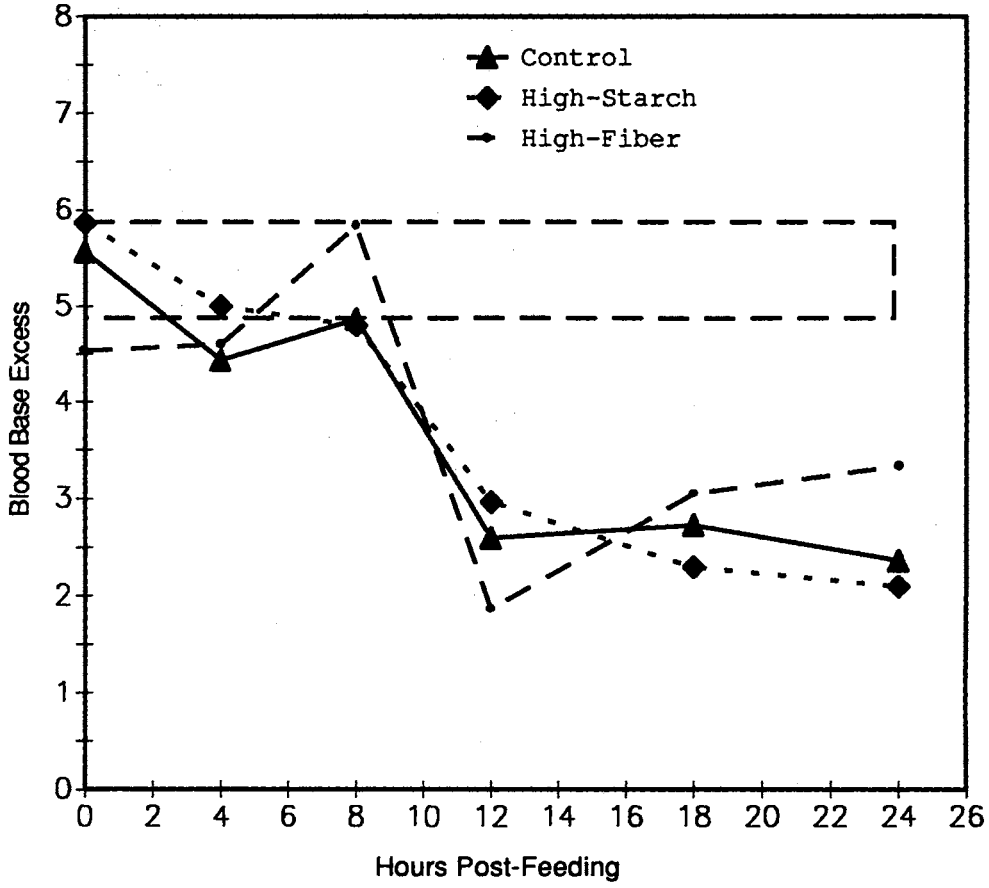

Figure 7. Time-course changes in blood base excess. Dashed rectangle represents mean +/- SEM blood base excess of all steers at time zero.

APPENDIX

Appendix A. Clipping data and forage estimates at the Marshall Wheat Pasture Research Unit, 1989 - 1992.

				Date							
				11/16/89	1/8/90	11/15/90	1/18/91	2/21/91	12/5/91	1/21/92	2/27/92
Pasture	Acres	Hectares	Sample no.	Sample, g DM							
1	24	9.72	1	103	167	124	95	46	41.6	88.5	129.2
			2	80	25	73	110	105	60.3	91.5	117.0
			3	86	100	69	122	68	70.3	115.0	141.3
			4	75	115	88	120	100	47.0	109.0	86.6
			5	88	82	75	132	107	43.7	102.0	89.2
			6	84	130	77	124	84	62.0	107.3	140.5
			7	84	98	74	141	91	76.2	64.7	95.1
			8	77	121	90	143	111	32.7	82.9	110.8
			9	94	127	68	123	75	89.3	78.7	143.9
			10	160	153	84	106	62	58.9	72.1	145.2
			lb/acre	1657	1990	1463	2164	1511	1039	1627	2139
			kg/ha	1856	2230	1639	2424	1693	1164	1823	2396
2	18	7.29	1	83	110	87	125	50	49.8	52.1	66.2
			2	70	112	83	148	52	57.9	132.0	60.7
			3	87	94	73	129	68	61.5	49.8	105.9
			4	87	104	75	96	48	85.9	91.5	63.2
			5	78	62	78	117	75	50.1	56.8	94.9
			6	87	101	40	107	68	44.4	47.8	72.1
			7	66	102	81	119	74	71.0	53.7	112.6
			8	96	87	68	79	60	34.5	86.7	66.4
			9	104	84	77	74	74	60.6	66.3	68.1
			10	75	62	109	83	95	85.5	72.6	64.7
			lb/acre	1483	1634	1372	1917	1182	1073	1266	1383
			kg/ha	1662	1831	1537	2148	1324	1202	1418	1549
3	18	7.29	1	89	106	89	98	96	47.7	56.4	100.5
			2	81	60	72	109	68	70.6	61.3	61.3
			3	75	80	94	92	79	54.3	45.9	68.7
			4	85	133	84	116	63	44.3	58.3	80.0
			5	84	124	88	104	46	27.2	52.5	53.7
			6	89	105	72	101	55	28.8	78.6	74.6
			7	50	107	77	75	54	53.1	52.9	63.2
			8	72	128	59	101	57	62.2	47.1	53.6
			9	55	107	56	97	61	58.4	73.4	61.8
			10	79	73	68	99	48	30.8	76.4	65.5
			lb/acre	1351	1821	1351	1766	1116	852	1076	1219
			kg/ha	1514	2040	1514	1979	1250	955	1206	1366

Appendix A. Continued.

Pasture	Acres	Hectares	Sample no.	Date 11/16/89	1/8/90	11/15/90	1/18/91	2/21/91	12/5/91	1/21/92	2/27/92
				Sample, g DM							
4	18	7.29	1	71	156	95	118	78	44.4	55.5	77.3
			2	112	96	89	130	61	52.5	57.1	75.9
			3	55	24	94	88	48	30.7	37.3	105.6
			4	69	105	85	81	48	92.0	48.6	85.8
			5	110	90	99	87	30	57.4	53.1	99.2
			6	78	114	67	113	50	35.8	59.5	59.1
			7	91	76	60	53	64	37.6	55.7	51.0
			8	73	81	66	78	76	81.7	72.6	66.1
			9	83	99	58	93	73	50.5	37.8	65.4
			10	91	125	59	92	102	52.6	68.6	77.5
			lb/acre	1483	1719	1374	1661	1121	955	974	1361
			kg/ha	1662	1926	1539	1861	1256	1070	1091	1525
5	24	9.72	1	82	129	87	77	83	61.2	61.0	99.9
			2	60	144	84	89	77	71.0	74.5	109.4
			3	75	124	74	107	69	69.0	104.8	106.6
			4	63	100	73	98	53	50.6	125.6	84.8
			5	79	98	69	94	42	107.3	99.7	148.3
			6	64	136	75	105	100	55.9	40.7	60.5
			7	57	76	67	82	77	44.5	58.5	94.1
			8	99	84	68	125	73	63.1	83.3	90.0
			9	91	73	54	88	89	73.2	79.5	109.3
			10	97	120	84	80	96	57.3	92.6	102.7
			lb/acre	1365	1930	1308	1682	1351	1165	1464	1794
			kg/ha	1529	2162	1465	1884	1514	1305	1640	2010
6	18	7.29	1	85	88	60	100	38	72.7	60.1	79.3
			2	137	88	65	95	59	92.6	65.3	88.3
			3	73	81	74	96	49	78.6	63.1	54.9
			4	74	74	81	102	50	73.5	67.1	71.1
			5	104	69	69	98	69	62.1	75.0	69.5
			6	107	127	77	68	94	56.0	54.0	76.8
			7	68	105	55	68	121	56.6	52.2	73.4
			8	78	94	83	67	73	67.0	52.8	69.1
			9	88	110	69	82	70	57.0	54.1	61.5
			10	105	145	57	87	89	51.0	47.6	67.8
			lb/acre	1636	1746	1228	1536	1267	1190	1055	1270
			kg/ha	1833	1956	1376	1721	1420	1333	1182	1423

Appendix A. Continued.

Pasture	Acres	Hectares	Sample no.	Date 11/16/89	1/8/90	11/15/90	1/18/91	2/21/91	12/5/91	1/21/92	2/27/92
				Sample, g DM							
7	18	7.29	1	54	91	91	89	53	72.3	77.4	96.8
			2	83	104	101	140	57	51.5	90.2	70.2
			3	64	63	79	121	48	47.6	101.3	74.6
			4	88	114	89	101	72	49.8	47.2	102.3
			5	75	104	108	99	47	61.7	78.3	109.4
			6	73	117	51	74	53	47.2	63.0	85.8
			7	79	64	83	70	48	81.1	54.2	128.2
			8	79	113	88	84	69	55.0	57.0	85.7
			9	113	99	86	106	81	50.8	76.6	86.6
			10	67	105	72	83	72	50.4	65.3	104.5
			lb/acre	1380	1734	1509	1721	1068	1012	1268	1685
			kg/ha	1546	1943	1691	1928	1197	1134	1421	1888
8	18	7.29	1	92	53	41	89	61	7.1	21.9	64.5
			2	49	103	99	81	64	29.8	16.1	52.4
			3	96	126	83	83	101	19.0	3.2	52.6
			4	73	73	61	84	59	26.8	3.8	53.6
			5	99	67	79	115	62	18.8	34.8	31.5
			6	107	35	79	83	87	6.2	1.3	43.0
			7	119	43	54	104	42	27.3	14.0	22.2
			8	95	83	77	48	59	3.0	14.8	53.4
			9	78	91	86	66	69	18.8	19.4	51.5
			10	89	102	59	98	50	17.6	24.2	31.3
			lb/acre	1597	1381	1278	1515	1164	311	274	814
			kg/ha	1789	1547	1432	1697	1304	348	307	912
9	24	9.72	1	84	56	154	133	71	20.6	28.1	56.9
			2	59	109	95	106	84	6.2	50.6	64.6
			3	56	148	104	78	74	35.8	32.5	65.1
			4	69	118	76	61	58	2.3	84.2	43.7
			5	97	89	68	78	71	39.9	24.1	30.3
			6	58	97	98	87	62	60.8	83.5	24.1
			7	56	106	113	77	78	40.5	31.8	37.5
			8	130	86	76	99	98	26.2	63.6	50.4
			9	101	94	40	95	75	9.8	46.5	44.0
			10	71	173	61	87	59	54.9	22.8	51.4
			lb/acre	1390	1915	1575	1604	1299	530	835	835
			kg/ha	1557	2146	1765	1797	1455	594	936	936

Appendix A. Continued.

Pasture	Acres	Hectares	Sample no.	Date 11/16/89	1/8/90	11/15/90	1/18/91	2/21/91	12/5/91	1/21/92	2/27/92
				Sample, g DM							
10	18	7.29	1	110	147	32	203	50	43.4	18.1	116.9
			2	78	184	95	83	64	53.6	54.3	64.4
			3	67	98	82	83	60	15.7	29.4	49.8
			4	76	112	48	93	68	18.6	48.2	66.6
			5	79	75	54	68	48	17.3	50.5	62.1
			6	75	88	58	63	56	28.2	37.6	24.3
			7	114	84	42	129	51	34.2	63.8	54.7
			8	156	125	51	105	58	32.5	32.5	17.3
			9	108	92	74	69	63	9.8	44.5	28.0
			10	78	54	83	57	47	18.9	43.6	48.6
			lb/acre	1675	1885	1102	1696	1006	486	754	951
			kg/ha	1877	2112	1235	1900	1127	545	845	1065
11	18	7.29	1	89	73	48	70	27	26.9	20.0	39.6
			2	103	78	85	66	28	23.5	28.5	49.0
			3	106	100	68	70	30	11.2	28.5	40.0
			4	124	40	97	84	34	17.5	28.8	78.4
			5	94	76	74	88	41	18.9	25.1	56.7
			6	59	66	81	58	39	17.4	56.7	45.2
			7	84	59	103	79	31	39.8	38.5	26.6
			8	125	71	77	95	35	30.8	57.0	51.6
			9	116	111	58	68	59	41.1	30.5	48.6
			10	111	87	55	53	33	15.5	14.6	57.6
			lb/acre	1800	1358	1328	1301	635	433	586	880
			kg/ha	2017	1521	1488	1458	711	485	657	986
12	18	7.29	1	83	68	58	85	29	39.0	62.3	52.1
			2	71	63	99	64	27	36.5	58.4	63.9
			3	96	48	68	49	34	18.1	32.9	56.7
			4	84	76	65	59	22	25.8	52.7	67.6
			5	80	62	48	52	22	34.6	36.7	73.1
			6	55	80	45	41	25	30.0	40.8	96.3
			7	86	114	38	75	24	34.4	23.5	43.8
			8	74	55	54	39	18	33.6	45.3	79.2
			9	121	115	35	73	26	45.3	47.6	83.3
			10	137	102	67	45	20	21.3	73.2	56.6
			lb/acre	1579	1394	1018	1036	440	569	845	1200
			kg/ha	1769	1562	1141	1161	493	637	947	1344

Appendix A. Continued.

Pasture	Acres	Hectares	Sample no.	Date 11/16/89	1/8/90	11/15/90	1/18/91	2/21/91	12/5/91	1/21/92	2/27/92
				Sample, g DM							
13	18	7.29	1	76	35	57	96	46	20.2	35.2	58.8
			2	75	46	108	98	59	26.1	47.3	85.9
			3	78	64	46	79	57	8.4	35.6	63.2
			4	88	48	58	80	22	15.9	43.0	55.3
			5	80	63	53	72	32	28.5	15.5	45.8
			6	98	58	78	76	14	15.5	37.6	25.5
			7	162	62	64	75	51	14.6	36.7	52.4
			8	100	50	56	99	38	28.3	29.6	54.0
			9	126	45	65	80	25	34.4	46.9	44.9
			10	185	47	56	71	51	16.0	21.3	41.7
			lb/acre	1901	922	1141	1470	703	371	622	941
			kg/ha	2130	1033	1278	1647	788	416	697	1054
14	18	7.29	1	53	150	49	118	47	5.7	37.4	40.5
			2	42	46	66	101	53	0.9	18.8	52.6
			3	47	73	68	70	53	11.6	22.7	47.5
			4	70	63	68	85	46	9.1	40.4	36.4
			5	70	68	68	129	37	16.9	28.9	29.5
			6	54	47	72	92	39	2.4	10.9	42.6
			7	57	37	39	74	70	14.3	19.1	33.2
			8	56	55	61	62	66	12.2	26.9	47.1
			9	53	65	57	66	55	14.6	30.8	31.3
			10	45	53	67	75	56	26.5	10.9	52.1
			lb/acre	974	1169	1095	1552	929	204	440	737
			kg/ha	1091	1310	1227	1739	1041	229	493	826
15	18	7.29	1	84	110	68	91	50	25.6	14.8	45.9
			2	66	134	76	67	52	15.9	47.9	49.5
			3	59	96	78	89	59	7.4	15.4	33.3
			4	45	103	76	62	57	4.4	27.2	47.5
			5	57	105	65	65	68	15.8	22.6	33.5
			6	34	125	48	79	86	16.3	17.4	35.5
			7	63	103	105	64	60	31.4	38.8	45.6
			8	51	124	43	90	36	28.4	20.6	72.0
			9	38	96	47	89	68	15.5	34.9	33.8
			10	85	121	69	89	71	11.0	33.8	34.4
			lb/acre	1036	1988	1202	1397	1080	306	488	769
			kg/ha	1161	2227	1347	1565	1210	343	547	862

Appendix A. Continued.

Pasture	Acres	Hectares	Sample no.	Date 11/16/89	1/8/90	11/15/90	1/18/91	2/21/91	12/5/91	1/21/92	2/27/92
				Sample, g DM							
16	24	9.72	1	160	105	54	74	76	28.6	8.6	45.2
			2	97	174	78	80	63	7.8	38.4	50.5
			3	170	115	74	98	76	32.3	33.8	74.0
			4	160	101	86	93	51	8.8	39.0	58.5
			5	109	127	102	109	64	19.1	16.5	54.3
			6	120	58	93	93	57	27.9	21.6	59.8
			7	101	58	48	90	72	23.1	31.7	66.0
			8	88	57	52	102	69	29.6	21.9	44.5
			9	134	70	73	106	64	23.4	23.8	53.4
			10	95	70	79	99	51	32.8	15.9	42.8
			lb/acre	2197	1664	1315	1680	1145	416	448	980
			kg/ha	2461	1864	1473	1882	1283	466	502	1098

VITA

Matthew David Cravey

Candidate for the Degree of

Doctor of Philosophy

Thesis: INFLUENCE OF HIGH-STARCH VERSUS HIGH-FIBER ENERGY SUPPLEMENTS ON PERFORMANCE AND FORAGE INTAKE AND UTILIZATION BY STOCKER CATTLE GRAZING WHEAT PASTURE

Major Field: Animal Nutrition

Biographical:

Personal Data: Born in Houston, Texas, October 16, 1959, the son of David O. and Nelda J. Cravey.

Education: Graduated from Westlake High School, Austin, Texas, in June, 1978; earned Bachelor of Science Degree from Texas A&M University in May, 1982; earned Master of Science degree from Texas A&M University in December, 1989; completed requirements for the Doctor of Philosophy degree at the Oklahoma State University in May, 1993.

Professional Experience: Commercial real estate appraiser from June, 1983 to December, 1987; Graduate Research and Teaching Assistant, Department of Animal Science, Texas A&M University, January 1988 to December, 1989; Graduate Research and Teaching Assistant January, 1990 to May, 1993, Oklahoma State University.

Professional Organizations: The American Society of Animal Science, Animal Science Graduate Student Association, Oklahoma State University.