EFFECTS OF MONENSIN AND DIETARY ENERGY INTAKE ON MAINTENANCE REQUIREMENTS IN BEEF COWS

A Thesis

by

CALEB JAY BOARDMAN

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

MASTER OF SCIENCE

Chair of Committee,	Tryon A. Wickersham
Committee Members,	Jason E. Sawyer
	Chris L. Skaggs
	William L. Mies
Head of Department,	H. Russell Cross

August 2015

Major Subject: Animal Science

ABSTRACT

A decrease in land availability and inventory of the cow herd has created a concern for the sustainability of beef cattle production. Intensifying production by feeding cows in a controlled environment (i.e. drylot) that allows for dietary manipulation could improve system efficiency, although logistical issues of feed delivery need to be solved. Subsequent trials were designed as 2 × 2 factorials to determine if limit-feeding an ionophore diet to cows during mid-gestation could reduce maintenance energy requirements. Both projects were designed to feed one diet at either 120% (**H**) or 80% (**L**) of NRC requirements with either **0** or **200** mg·hd^{-1}·d^{-1} of monensin. Forty cows were fed for 56 d to determine performance, while sixteen ruminally cannulated steers were used for intake and digestion. To aid in feed delivery, bulk density and void space were calculated for common feed ingredients to determine mix-ability and maximum payloads.

Steers fed L had greater ($P < 0.01$) DM digestion, OM, ADF and GE than H, while monensin did not significantly affect digestion ($P > 0.15$). Passage rate was slower for L than H ($P < 0.01$) and 200 than 0 ($P < 0.03$). Acetate:propionate was lower in 200 than 0 ($P < 0.01$) while rumen pH was increased ($P < 0.05$). Cows gained more BW when fed at H versus L ($P < 0.01$) with no effect of monensin ($P = 0.97$). Retained energy per EBW$^{0.75}$ was greater for H than L ($P < 0.01$) although heat production was also greater ($P < 0.01$). Monensin had no effect on either RE ($P = 0.94$) or HE ($P = 0.53$). Monensin did not alter feed required for maintenance or fasting heat production.

However, FHP was estimated to be 62.85 kcal·EBW$^{-0.75}$·d^{-1}, a decrease of 26.1% from NRC requirements. Roughages had lower (P <0.01) bulk density and greater void space (P < 0.01) than concentrates. Accurate predictions of maximum payload of multiple ingredients were able to be made from these calculations.

Overall, it appears limit-feeding diets can increase production efficiency of cow-calf systems. Use of bulk density and void space data may allow optimization of mixing and reduce delivery costs of high-roughage diets to large numbers of cattle in confinement systems.

DEDICATION

I dedicate this thesis to my parents Russ and Lesley and my wife Kylie.

Mom and Dad, thank you for your lifelong support of my dreams. Thank you for always being there for me and pushing me to be my best. You have given me the opportunities in life that most will only dream of having. More than anything, thank you for raising me in a Christian home and introducing me to Christ. The two of you have shown Kylie and I what a great marriage looks like and how to raise a wonderful family.

Kylie, thank you for supporting me and being there for me for while I have followed my passions. Thank you for working a job you didn't love and putting off your school so I could do this. Thank you for helping me with my project and encouraging me when I didn't think I would make it through. You are a wonderful wife and I thank God every day that I am lucky enough to have such a wonderful partner to go through life with.

ACKNOWLEDGEMENTS

I would like to extend my sincere gratitude to several people that were instrumental in my completion of this thesis and degree. Thank you to my advisors and committee co-chairs, Drs. Tryon Wickersham and Jason Sawyer, for your leadership and willingness to work with me the past two-plus years. Thank you for understanding my additional responsibilities with coaching the livestock judging team and patience while I tried to balance everything. I have learned so much from the two of you, and will always be proud to say that you are two of my mentors. Also thank you to Dr. Bill Mies for serving on my committee and being such a great professor and person that so many people look up to. I hope that my future students will respect me the way that all students respect the three of you. To Dr. Chris Skaggs, thank you for giving me the opportunity to coach the 2013 and 2014 teams and serving on my committee as well as providing me funding from the San Antonio Livestock Show. I'm confident the opportunities that I have throughout my career will stem from the situations you entrusted me in. As I continue my coaching career, I can only hope to garner the respect that you have gained as a mentor and coach to so many people in our industry.

To Dr. Jake Franke, Cody Sloan and Jake Thorne, thank you for giving me the opportunity to come to Texas A&M and be on the 2011 livestock team, and more importantly for trusting in me to continue on as a coach and for your personal friendship to myself and Kylie. Also, thank you to Brant Poe for allowing me to work with yourself and continue to be a part of the program and for the friendship you and Lauren gave to

us. To Cassidy Hayes, I thank you for keeping me sane for the last two years and being a wonderful office mate and friend. I sincerely enjoyed and appreciated my time getting to coach with the two of you and having the opportunity of bringing the bull back to Kleberg.

I would also like to thank all of the members of the 2013 and 2014 judging teams that I had the opportunity to coach. Much of my time over the last two years was dedicated to coaching you, and it would not have been enjoyable without each of you having the dedication, hard work and character that you possess. It is an honor for me to call each of you my friends, and it is because of the experience I had with all of you that I want to continue my coaching career.

Finally, thank you to all of the 017b lab mates that aided in my projects, helped me in classes and gave me support along the way. Also thank you to Matt Balderama and Jeremy Horn at McGregor for all the assistance with my project and managing the cows on a daily basis. Special thanks goes to Levi Trubenbach for his friendship and guidance he has given me while I have done this. I could not have done it without you.

TABLE OF CONTENTS

Page

LIST OF FIGURES

Page

LIST OF TABLES

Page

CHAPTER I

INTRODUCTION AND REVIEW OF LITERATURE

Introduction

New estimates predict the global population to reach 9 billion people by 2050 (United Nations, 2012), and median incomes of third-world countries to increase dramatically (PWC, 2013). Increases in both population and house-hold spending power will presumably further increase an already growing global demand for beef, which has experienced increased exports of over 850,000 metric tons since 2004 (USMEF, 2013). While there has been an increase in demand, the United States cow herd has experienced a continual decrease in size since it peaked in the late 1970's (NASS, 2015; Figure 1).

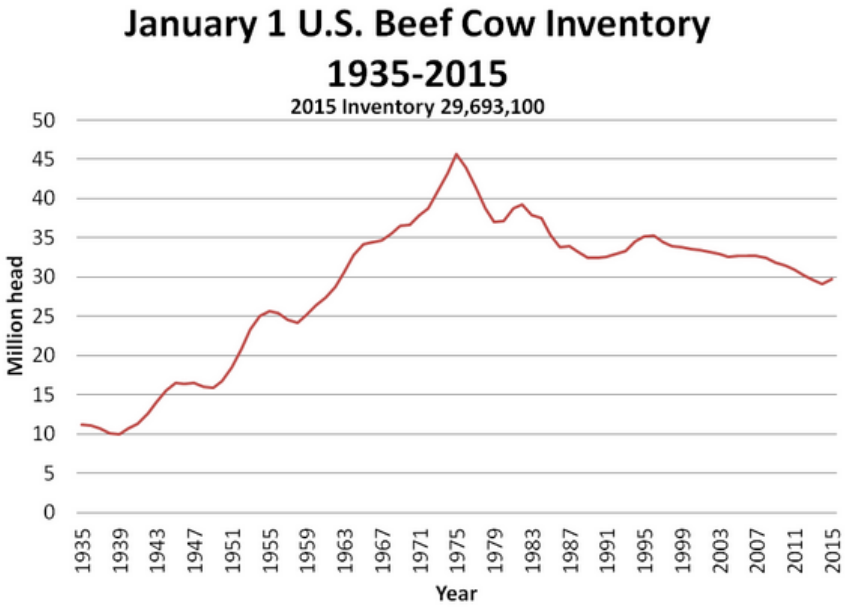

Figure 1 Beef cow inventory on January 1st by year (NASS, 2015)

Traditional production practices have caused cow/calf producers to be heavily reliant upon rainfall and subsequent grass production in their local geographical region. Southern U.S. cow herd's experienced massive liquidation (Texas alone lost 12% of the state's inventory) after a severe drought struck in 2011 (NASS, 2014). With increased demand and strains on supply, cattle prices have responded with a two-fold increase since the turn of the 21st century after remaining relatively stagnant during the 1990's (USDA, 2014). Although significant improvements in technology and genetics have helped maintain total beef supplies by increasing production per unit (NASS, 2014; Figure 2), these new technologies shouldn't be the only source counted on to meet the continual increase in demand.

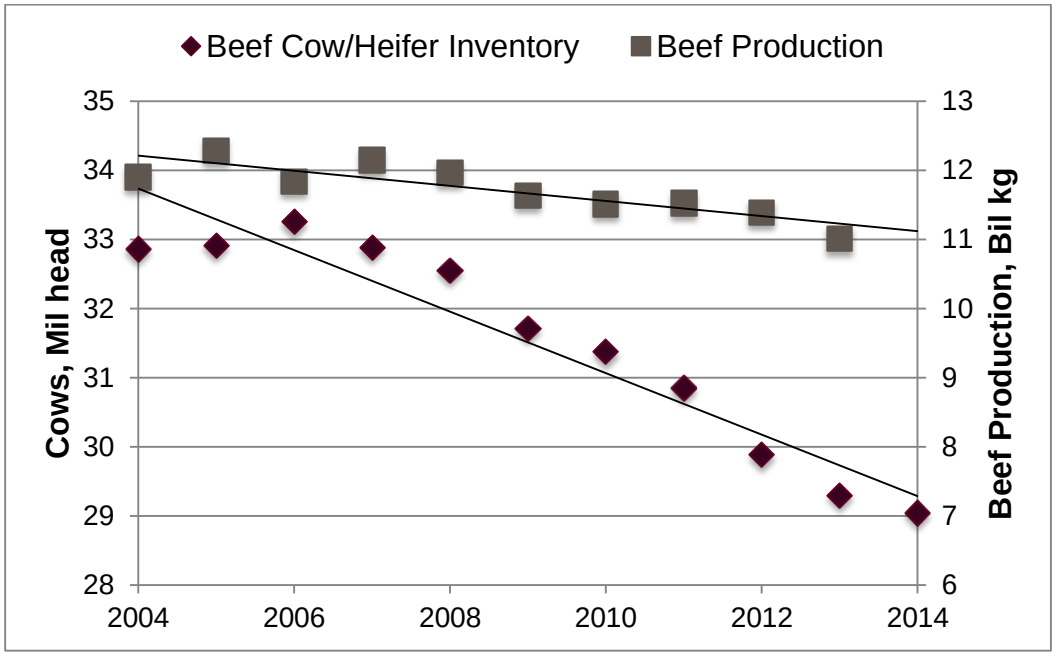

Figure 2 Current trend of beef cow inventory and beef production (NASS, 2014)

Bioenergetics

Research of dietary energetics traces back to the 15th century during the era of Leonardo da Vinci and significant research into bioenergetic efficiency of animal production started as early as the 19th century (Ferrell and Oltjen, 2008). Foundational data and concepts for current net energy (NE) system were first reported by Armsby and Fries (1919) when they concluded that NE of a feed was significantly less than its ME value. Additionally, they were the first to fraction energy or "starch" values into use for maintenance and use for production. They theorized that energy values for maintenance would be greater than those for production. Following this development, basic definitions for energy values were developed, with additional terminology being invented and added to the NE system as needed.

Current descriptions of energy utilization used for most feeding systems were fully developed in the NRC (1981; Figure 3). In this system, ME is defined as the energy available to the animal for metabolism and is calculated as the gross energy (GE) in the feedstuff less fecal energy, urinary energy and gaseous energy losses. Metabolizable energy is the sum of retained energy (RE) and heat energy (HE), that is ME = RE + HE. Retained energy is stored as a form of tissue energy through biochemical processes whereas HE is not retained and therefore represents a loss of energy from the system.

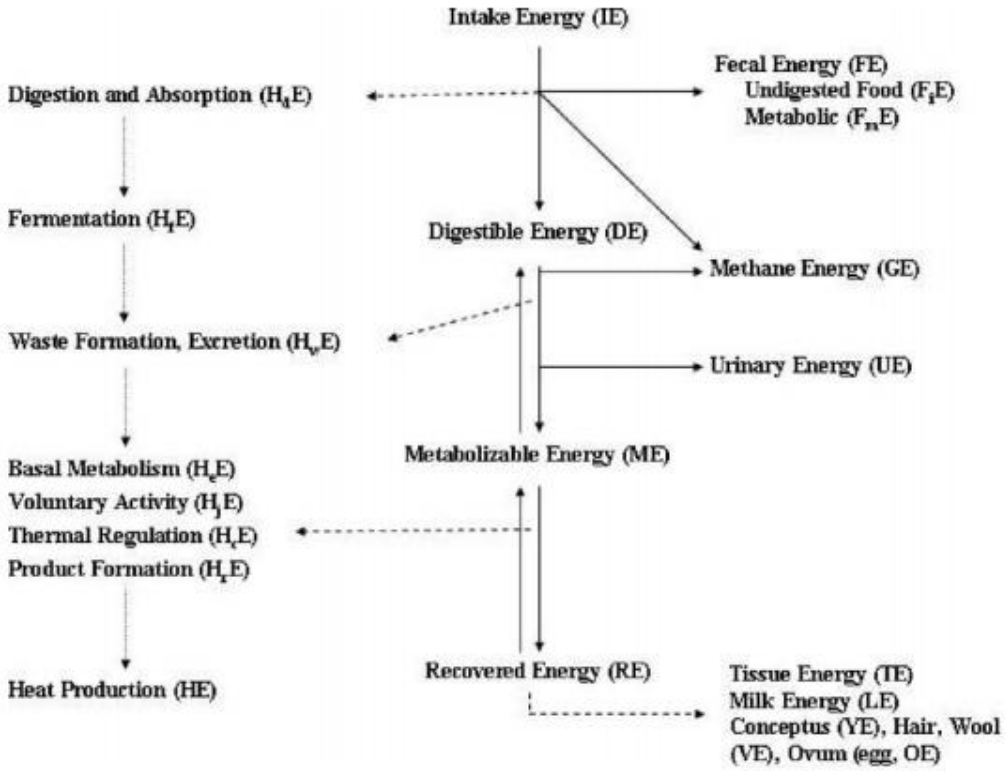

Figure 3 Energy utilization in the animal (NRC, 1981)

Partial efficiency is the proportion of ME that becomes RE. To determine partial efficiency, RE typically has to be measured at multiple levels of MEI, above and below maintenance requirements. Blaxter and Wainman (1961) defined the net availability of ME for production as the slope of a linear regression of positive energy retention on the corresponding MEI. Availability of ME as use for maintenance was defined as the slope of a linear regression between negative energy storage and corresponding MEI. Where the two lines intersect represents RE = 0 and is considered maintenance. Blaxter et al. (1966) described the interrelationship between metabolizability and partial efficiency

and defined the two slopes as k_p (RE > 0) and k_m (RE < 0). They concluded that partial efficiency of ME (RE/MEI) was greater below maintenance than above, that is $k_m > k_p$. Garrett and Johnson (1983) found the relationship is actually curvilinear and a graphic illustration (Figure 4) was presented by Ferrell and Oltjen (2008). This illustration depicts k_g, which is synonymous with k_p.

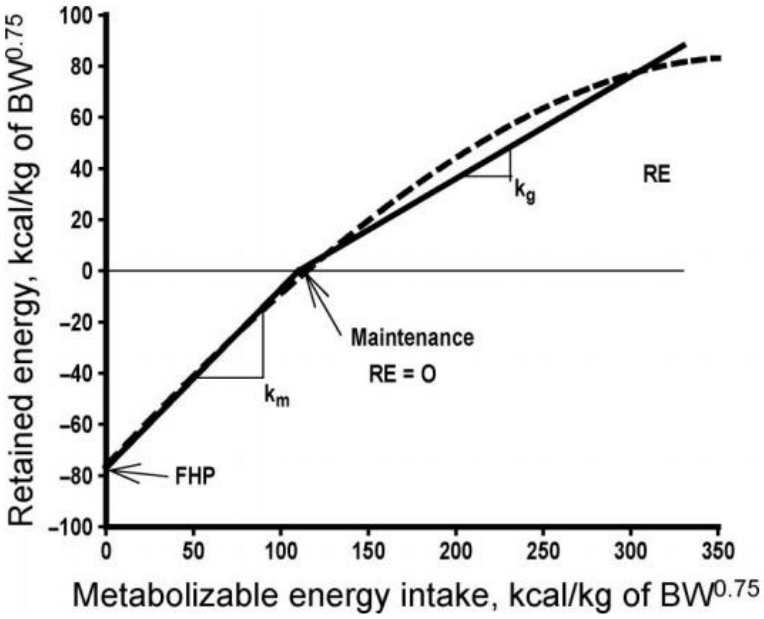

Figure 4 Representation of the relationship between RE and ME (Ferrell and Oltjen, 2008)

Heat energy is divided up into two primary categories: fasting heat production (FHP) and heat increment (HI). Fasting heat production is equivalent to the basal metabolism of an animal at zero feed intake and thus is considered the net energy

required for maintenance (NE_m). For practical considerations, heat of voluntary activity is also included into NE_m. Heat increment is the increase in heat production following consumption of feed by an animal in a thermoneutral environment and includes four different measurements of heat production: heat of product formation, heat of digestion and absorption, heat of fermentation, and heat of waste formation and excretion. This modifies the original energy balance equation to be $ME = RE + NE_m + HI$.

Increasing beef cattle sustainability

Increased land costs and a decrease in the availability of land and forage have placed constraints upon traditional production practices and are beginning to challenge the sustainability of the industry. Improving production efficiency, raising cattle in non-traditional practices and manipulating maintenance requirements are all current focuses of cow-calf systems that could prevent further restraints being placed on U.S. beef cattle production. Non-traditional intensified systems (limit-feeding outside sources of MEI to cows) may be able to increase partial efficiency of RE by reducing maintenance energy costs within the cow.

Klosterman and Parker (1976) reported that only 13.4% of the metabolizable energy (ME) fed in cow/calf production is recovered as energy in the meat of the calves slaughtered. An estimated 50% of all feed energy consumed by beef cattle is used for cow maintenance (Ferrell and Jenkins, 1984), as approximately 65-75% of energy consumed by beef cattle is used by the cow herd (Gregory, 1972; Klosterman and Parker, 1976) and 70-75% of the energy fed to the cow herd is used strictly for maintenance (Ferrell and Jenkins 1985).

Limiting MEI and adding ionophores into diets could help reduce maintenance energy requirements. Total MEI affects both NE_m and HI (Freetly and Nienaber, 1998). Inclusion of ionophores affects maintenance equilibrium of ruminants by improving the VFA profile (Richardson et al., 1976) and decreasing methane production (Joyner et al., 1979), theoretically decreasing HI and increasing diet NE_m concentration. This review will examine the effects of both MEI and ionophores on maintenance requirements in beef cows, to identify opportunities for improving cow-calf efficiency.

Effects of MEI on production and utilization

Increasing MEI is a common practice in growing and finishing phases of cattle as the production goal is to maximize daily gains. Sainz et al. (1995) found that greater MEI (399 vs. 226 kcal·kg $EBW^{-0.75}$·d^{-1}) during the growing phase of steers resulted in greater EBW, backfat, abdominal fat, kidney, pelvic and heart fat (KPH), marbling scores, carcass fat and empty body fat. Although heat production was increased (247 vs. 177 kcal·kg $EBW^{-0.75}$), gain:feed ratio and retained energy (152 vs. 49 kcal·kg $EBW^{-0.75}$·d^{-1}) were also increased for the high MEI steers. Reynolds et al. (1991) found similar results as heifers receiving higher intakes had a greater loss of energy in the form of feces, methane, urine and heat, but still displayed greater digested, metabolized and tissue energy. This illustrates a dilution of maintenance, which is the decreased proportion of ME needed for maintenance as the growth rate per animal increases (Capper and Hayes, 2012). A dilution of maintenance is not likely to be practical in cow-calf systems however, as an increase in lactation would not likely be enough to offset increased feed cost.

As was mentioned previously, the growing steers in the Sainz et al. (1995) study continued on trial through the finishing phase. Treatments were assigned such that high intake steers remained on a high intake diet (Control), while low intake steers were either placed on high intake (Realimented) or continued to receive a low intake (Restricted). Steers restricted during the growing phase (Realimented and Restricted) had reduced maintenance requirements during the finishing phase compared to Control steers (102 and 102 vs. 123 kcal NE_m·kg $EBW^{-0.75}$ respectively). This allowed the Realimented treatment to have increased energy retention during the finishing phase compared to Control steers (102 vs. 69 kcal RE·kg $EBW^{-0.75}$ respectively), showing that restricting MEI followed by realimentation can cause a net gain in efficiency due to a continual reduction in maintenance from reduced losses in heat energy.

Freetly and Nienaber (1998) evaluated changes in energy and N balance of mature non-lactating cows that were subject to changes in MEI. Two treatments were used: control, fed a fixed amount of chopped brome hay at a level of intake to meet estimated maintenance requirements for the full 224 d period; restricted, fed 65% of control intake for first 112 d followed by realimentation to consume 135% of control intake for an equivalent period of time. Total energy intake did not differ between treatments over the entirety of the 224 d period. Restricted cows lost body weight over the first period, and gained weight during the second period. Compared to the control, restricted cows had reduced heat production of 14.6% during period 1 and increased heat production of 12.9% during period 2. Similar to energy intake, there was no differences in total heat production between treatments over the entire 224 d. Nitrogen intake

followed MEI during the entirety of the study and there were no differences in total N intake over the 224 d period. Treated cows were in negative N balance on d 28, but did not differ from zero on the other days. After d 112 treated cows were in positive N balance during all of period 2, and had a greater efficiency of N retention during this same time. Total N during period 1 did not differ between treatments, but net N retention was higher in treated cows than control cows during the second period.

Kleiber (1975) reported that in prolonged feed restriction, as in fasting, daily weight loss is rapid early in restriction and decreases as restriction is prolonged. Freetly and Nienaber (1998) found similar results as the majority of weight loss occurred during the first 14 d of restriction, although no data was reported to account for the weight loss due to fill. The majority of decreased heat production also occurred during the first 14 d of feed restriction, due partly to a decrease in heat associated with digestion, and partly with a lower metabolic rate. These changes in heat production are consistent with results previously reported in Charolais cattle by Ortigues et al. (1993). Similar results were seen following realimentation as most of the increases in heat production occurred during the first 14 d, however, it took more than 28 d to reach a new equilibrium of heat production.

Jenkins and Ferrell (1997) suggested that cows achieve a new equilibrium for maintenance requirements with altered levels of intake. Freetly and Nienaber (1998) confirmed this suggestion as restricted cows had a negative energy balance from the beginning of the trial until d 84, but by d 112 energy balance was not different from zero. Reaching a new maintenance equilibrium could pertain to physiological adaptation

which results in greater dietary energy efficiency or a decrease in maintenance requirements. It was shown that digestibility of the diet was not found to be different between periods, indicating energy availability was not altered by intake. Heat production was shown to be greater on d 0 than on d 112 (15,000 vs. 11,000 kcal·d^{-1}), suggesting that changes in heat production were in fact due to changes in FHP. If realimentation followed the same pattern as restriction, rates of energy retention should increase following an increase in feed intake and subsequently return to zero as animals reach their new targets. As expected, restricted cows had a positive energy balance following increased energy intake. However, unlike during the restricted phase, the cows maintained this energy balance for the entire 112 d, suggesting that reaching a new equilibrium of maintenance energy requirements during realimentation may require more time than does adaptation to restriction. A longer adaptation period during refeeding could explain for the increased efficiency (RE/MEI) that is seen over an entire period of restriction and realimentation.

Camacho et al. (2014) found similar results in a trial evaluating the restriction of MEI on the maternal performance of gestating cows. Cows were assigned to treatments after being confirmed bred (d 30) and fed a diet consisting of grass hay in order to meet 100% NE requirements for maintenance and fetal growth (CON), or the same diet at 60 % of maintenance (RES) for a 55 d period. Both treatment groups lost BW during this period, but RES lost a greater percentage of maternal BW than CON. On d 85, cows either continued on control, remained restricted (LONG), or were realimented to the control level of the diet (SHORT). During the second period (d 85-d 140) LONG cows

lost the greatest percentage of body weight, followed by SHORT and CON respectively. On d 140 LONG cows were realimented to the control level of the diet. During the final 114 d period, SHORT cows had the greatest percentage increase in BW as well as efficiency of gain, followed by LONG and CON respectively. This supports the findings by Freetly and Nienaber (1998) in suggesting that there may be metabolic alterations during nutrient restriction that increase efficiency and weight gain during realimentation.

Freetly et al. (2000) had previously reported similar results in gestating cows that were allowed to weight cycle by losing BW during a period of nutrient restriction, followed by a period of realimentation and BW gain. Cow reproductive performance and calf performance were also measured to determine if detrimental effects occurred due to nutrient restriction during gestation. Cows were assigned to one of three treatments: fed at maintenance from second trimester through breeding (control); restricted during the second trimester and realimented during the third trimester to be of equal weight to control cows at calving (short restricted); restricted from the second trimester until 28 days post-partum and then fed an increased amount of energy so as to be of equal weight and BCS as other two treatments at breeding (long restricted). Total DMI, BW and BCS did not differ over the study between control and short restricted cows, confirming the work done on non-pregnant/non-lactating cows by Freetly and Nienaber, (1998) is also applicable to pregnant cows during mid gestation. Meyer et al. (2010) showed similar results of increased feed efficiency and weight gain during realimentation in a study which restricted intake during early to mid-gestation and then restricted cows were refed so they were of equal BCS after 120 d of realimentation to the control cows. This study

also reported that there were no differences due to nutrient restriction on fetus weight or fetal organ mass during restriction or realimentation. Trubenbach (2014) reported no differences in calf performance between cows restricted (80% of maintenance) or fed increased MEI (120% of maintenance) during mid-gestation. Calf birth weight, ADG and adjusted 205 day weaning weight did not differ between treatments.

Freetly et al. (2000) also found restriction can continue through late gestation and not adversely affect reproduction or calf performance as there were no differences in conception rate or calf weight after 60 d among any of the treatments. The fact that long restricted cows were able to gain weight back faster and more efficiently after calving and realimentation, which resulted in this treatment being the heaviest at breeding, confirm the suggestion from Freetly and Nienabar (1998) that adaptation to a lower maintenance equilibrium is achieved during restriction and added efficiency is thus gained during realimentation. Cow BW of all treatments did not differ at palpation following breeding from the weight recorded during mid gestation, showing that cows were able to recover their lost weight effectively during an annual production cycle. Trubenbach (2014) confirmed these findings as cow BW and BCS did not differ between treatments at pre-weaning.

Long restricted cows from the Freetly et al. (2000) study tended to be heavier at similar BCS, suggesting there is an extended period of N retention and in turn protein gain in cows gaining weight after nutrient restriction as was reported in the Freetly and Nienabar (1998) study. These findings suggest restricting MEI during mid to late

gestation can increase feed efficiency during realimentation due to a lower maintenance requirement without affecting pregnancy rates or weaning weights on the calves.

Effects of MEI on splanchnic organ mass

Splanchnic tissue mass is a key factor in determining whether ME is converted to RE or lost as HE. Splanchnic tissue consists of the liver plus the portal-drained viscera (PDV) which consists of the gastrointestinal tract, pancreas, spleen and mesenteric fat. Splanchnic organ masses account for 45 to 50% of whole-body heat energy but comprise only 10 to 13% of whole-body tissue mass (Seal and Reynolds, 1993).

Burrin et al. (1990) reported both the absolute weights of all visceral organs and the relative weight of the liver, stomach, and small intestines were increased in lambs fed *ad libitum* compared to lambs fed at maintenance levels. When lambs were restricted back to maintenance, the liver weighed 52% of that in the *ad libitum* lambs, with more than half the decrease occurring in the first 7 d period. McLeod and Baldwin (2000)

reported similar results for these same organs as well as increases in the mass of the large intestine, heart, kidneys and lungs on both an absolute and EBW basis. The increase on an EBW comparison demonstrates that tissue specific growth occurs at a more rapid pace than carcass growth. Increasing organ mass ultimately results in greater HE production.

Effects of MEI on organ mass in pregnant ruminant animals are not fully understood as conflicting results have been found. Meyer et al. (2010) reported that nutrient restricted cattle during early to mid-gestation had lower digestive tract (22.9 vs. 25.6 kg), pancreatic (0.935 vs. 1.042 kg) and liver (3.8 vs. 5.8 kg) weights when

compared to cows fed at maintenance. Both the entire stomach complex and rumen weighed less during restriction, but were similar after 120 d of realimentation. This is in agreement with Camacho et al. (2014) who found that while energy restriction had no effect on BCS or gravid uterine weight on d 140 of gestation, restricted cows had decreased liver (3.74 vs. 4.37 kg) and rumen (6.05 vs. 8.29 kg) weight compared to control cows. Following realimentation of all restricted cows visceral organ mass was not found to be different from control cows. Carlson et al. (2009) also found that nutrient restriction caused decreased stomach complex weight in ewe lambs, but unlike Meyer et al. (2010), weights remained reduced compared to control even after realimentation. This difference could be in part due to the fact that both cow trials realimented the restricted treatments by feeding above maintenance for a longer period of time in order to regain weight, whereas ewes in the Carlson et al. (2009) study were realimented only at maintenance levels for a short period of time.

Wood et al. (2013) found contrasting results when the effects of moderately limiting (Low) NE consumption (85% of maintenance) or feeding 140% above (High) maintenance were evaluated. Cows on Low treatment showed no differences in total or mass specific weight of any splanchnic tissue other than rumen mass compared to High cows. This suggests severe restriction may be necessary for degradation to occur in pregnant females, and minimal decreases or increases may not result in differences in splanchnic organ mass.

Both Meyer et al. (2010) and Carlson et al. (2009) found small and large intestine weights were not affected by nutrient restriction during mid-gestation. However Carlson

et al. (2009) also reported small intestine mass was decreased when nutrient restriction occurred during late gestation or during both mid and late-gestation. This implies that the small intestine may become more efficient when there is increased requirements from the fetus.

Effects of MEI on oxygen consumption and blood flow

Reynolds et al. (1991) found both heart rate and blood flow across the PDV (75%), liver (71%) and kidneys (10%) increased with greater MEI in growing heifers. This confirms work done by Webster et al. (1975) in sheep that showed PDV blood flow increased at a curvilinear rate with increases in MEI, with greater increases as MEI went further above maintenance requirements. Burrin et al. (1989) reported similar results in that portal and hepatic vein blood flows in lambs fed at maintenance were 25-41% lower than lambs fed *ad libitum*.

Blood oxygen concentration is measured before and after the PDV and liver to determine oxygen consumption. Arterial blood is used to measure blood oxygen concentration before tissue consumption. After blood passes through visceral organs and becomes oxygen-depleted, it is transported to the liver via the portal vein. The difference in oxygen concentration between portal vein blood and arterial blood represents the amount of oxygen consumed by PDV. Blood then leaves the liver through the hepatic vein and is transported to the inferior vena cava, which contains oxygen-depleted blood from both the liver and abdominal organs. In the previously discussed Reynolds et al. (1991) study, arterial oxygen concentration was found to be lower in high MEI heifers. This is in contrast to Burrin et al. (1989) who reported no changes in arterial

concentrations were found in lambs fed a higher level of MEI. Reynolds et al. (1991) found that both portal-arterial and hepatic-arterial differences to be smaller in high intake heifers, but the hepatic-portal difference was not affected by MEI. Whole body, total splanchnic, PDV and liver oxygen use were all greater in high intake heifers. Relative to BW change, the liver was found to consume a greater percentage of total body oxygen in high intake heifers, indicating a disproportional increase in liver oxygen use. Burrin et al. (1989) found splanchnic oxygen consumption was 37-63% lower in lambs fed at maintenance than ad libitum fed lambs. After *ad libitum* lambs were restricted back to maintenance for a period of 21 d, splanchnic oxygen consumption decreased by 30%. In the trial done by Wood et al. (2013) on gestating cows, limited intake resulted in a decreased rate of total liver oxygen consumption and liver oxygen consumption per BW, indicating a decrease in overall metabolic rate with restricted intake. All of this data suggests that increasing MEI causes liver metabolic rate to increase, resulting in greater total oxygen consumption, creating a need for a greater flow of oxygen and blood to organs and an elevated level of heat production.

Conclusions about metabolizable energy intake

It is clear that MEI has an effect on maintenance energy requirements in terms of both fasting heat production and heat increment. Energy required for maintenance is thought to be related to the overall cellular and tissue workload. Using oxygen consumption as a representation of metabolic rate, data suggests that decreasing intake results in decreased overall metabolism. This appears to occur from the reduction in the

mass of splanchnic tissues. It appears that a realimentation period following restricted intake results in significant increases in the partial efficiency (RE/MEI) of ME use.

Ionophore introduction

One of the primary goals of ruminant nutritionists is to manipulate and improve the efficiency of ruminal fermentation. This can be done specifically by increasing ruminal propionic acid yield, decreasing methanogenesis and depressing ruminal proteolysis and deamination of dietary proteins (Bergen and Bates, 1984). There are continued attempts to manipulate the diet in order to achieve these goals, but there are also active compounds that can be added to a diet that modify fermentation and thus enhance production efficiency. Carboxylic polyether ionophore antibiotics (ionophores) are one class of these compounds. Ionophores are produced by various strains of *Streptomyces* and include monensin, lasalocid, laidlomycin, and salinomycin, all of which are labeled for use in North America. Although ionophores were originally used to control coccidiosis in poultry, they have long been fed to ruminant animals. Primary responses from feeding monensin are improved weight gains, depressed feed intake and correspondingly an enhanced feed efficiency. This is thought to be accomplished through a reduction in methane production, an increase in propionate production, a decrease in protein degradation, and decreased lactic acid production (Bell et al., 2015). Monensin is the sole ionophore approved in the United States for use beef cows, so this summary will primarily discuss the findings of monensin use.

Ionophore mode of action

Improvements in animal performance and efficiency from the inclusion of an ionophore are secondary effects caused by changes in bacterial membrane physiology (Bergen and Bates, 1984) as ionophores carry ions across membranes killing certain bacterial species within the rumen. The ruminal environment is characterized to have high Na^+ and low K^+ concentrations, with a mildly acidic pH under normal conditions. Intracellular environments of bacteria within the rumen are known to have the opposite characteristics, high K^+ and low Na^+ concentrations with a pH that is near neutral. Due to the cell membranes of bacteria being impermeable to ions, nutrient uptake is facilitated by ion gradients at a low ATP cost (Rosen, 1986), specifically Na^+ and K^+ gradients are utilized in ruminal bacteria. The differences in pH between the bacteria and the rumen also cause an inward gradient of protons. Ionophores are known to be capable of interacting with metal ions, serving as a carrier by which these ions can be transported across membranes (Ovchinnikov, 1979). Monensin is known to be an antiporter (having the ability to transport multiple cations simultaneously) that exchanges H^+ for either Na^+ or K^+ (Russell and Strobel, 1989). Monensin primarily mediates the Na^+-H^+ exchange because its affinity for Na^+ is ten times greater than its nearest competitor, K^+, and this transport cycle across membranes can reach thousands of cycles per second (Pressman, 1976). Because monensin is an antiporter, it also mediates the exchange of intracellular K^+ ions for extracellular protons (Callaway et al., 2003). Bacteria try to maintain ionic equilibrium and or pH neutrality, requiring protons to be pumped out. To pump H^+ ions back out of the cell requires active transport using ATP or an exchange of Na^+. Active

transport results in an energy expenditure that depletes the ATP pool, resulting in decreased growth and eventual death of the cell (Bell et al., 2015).

Gram-positive bacteria within the rumen are associated with producing acetate, butyrate, hydrogen and ammonia. Ionophores are generally most effective against gram-positive bacteria due to the fact that the membrane is surrounded by a porous peptidoglycan layer which allows small molecules such as ionophores to pass through and dissolve into the membrane (Supriya et al., 2012; Figure 5). Inhibition of these species by ionophores results in fewer hydrogen, ammonia and lactate producing bacteria. Gram-negative bacteria are relatively impermeable to ionophores as they are surrounded by a lipopolysaccharide layer, outer membrane, and periplasmic space (Callaway, 2003).

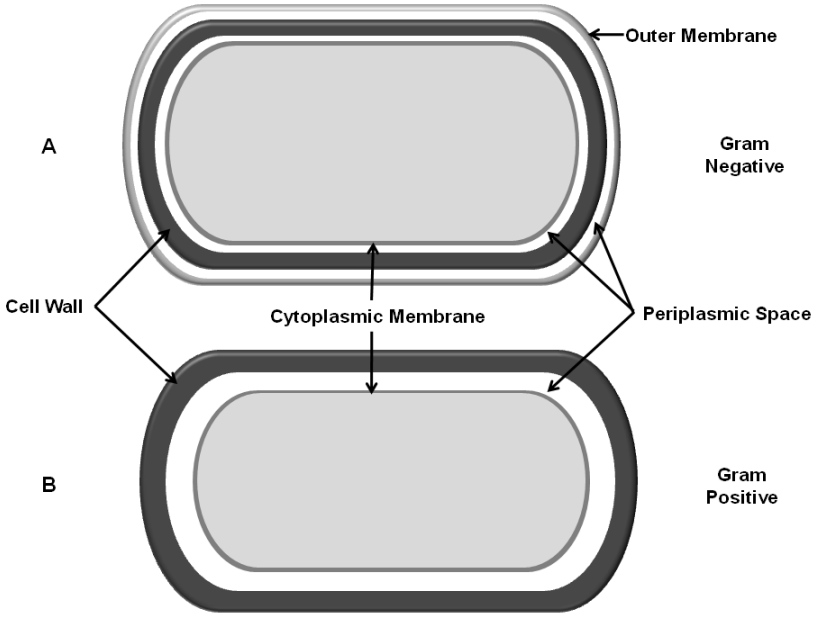

Figure 5 Simple models of Gram-positive and Gram-negative bacteria. (Supriya et al., 2012)

Ionophore effects on production, feed intake and feed efficiency

Joyner et al. (1979) found monensin decreased feed intake and increased feed efficiency in growing lambs. It was shown that this may come from the fact that monensin significantly improved the ME of the diet by decreasing urinary and methane losses. In a meta-analysis by Goodrich et al. (1984) of over 16,000 head of cattle receiving a feedlot ration, monensin was shown to increase gain (1.6%), suppress feed intake (6.4%) and improve feed efficiency (7.5%). Results on the performance of mature cows varies more significantly. Quality of forage and stage of production dictate the degree of cow weight, body condition and intake response to ionophore inclusion (Sprott et al., 1988).

In two subsequent trials Turner et al. (1977) fed gestating cows at maintenance on a low quality forage with a small (0.45 kg) grain supplement to deliver the monensin. Cows that received monensin had greater weight gain and decreased feed intake, suggesting that addition of monensin increased energy availability from the diet, and in turn, cows received energy levels above their maintenance requirement. Lemenager et al. (1978a), found similar results in grazing cows. Cows consuming 200 $mg \cdot hd^{-1} \cdot d^{-1}$ monensin reduced grazing time 14.6% and reduced intake 19.6% compared to cattle receiving no monensin. However, Burrell (1977) found contradicting results; no differences in feed consumption, body weight change or BCS were observed when cows of a low BCS were fed monensin.

In a trial to determine whether reduced amounts of hay could be fed while still meeting maintenance requirements, Turner et al. (1980) found late gestation cows

receiving 200 mg·hd^{-1}·d^{-1} of monensin were the most efficient, experiencing similar gains to cows receiving control diets but consuming 10% less hay. Following parturition, cows receiving the 200 mg treatment lost less weight and consumed 13% less hay. There were no differences among treatments in calf BW or ADG from calving until weaning. Grings and Males (1987) found monensin improved cow performance during late gestation but had no effect on cow or calf ADG after calving.

Clanton et al. (1981) restricted intake and increased the inclusion of monensin in mature cows for a period of 194 d that spanned late gestation and early lactation. Intake and monensin were fed at four different levels: 100% intake and 0 mg·hd^{-1}·day^{-1}; 95% intake and 50 mg·hd^{-1}·day^{-1}; 90% intake and 200 mg·hd^{-1}·day^{-1}; 90% intake and 300 mg·hd^{-1}·day^{-1}. It was found that no differences in BW change occurred between any of the treatments during any part of the study. This agrees with earlier work that cows are able to stay at maintenance levels when intake is reduced, but there were no additional weight gains from the inclusion of monensin. Similar to the Turner et al. (1980) study, adjusted weaning weights of calves from cows on the different treatments did not differ. There have been reports of increased birthweight in calves from cows fed monensin (Hixon et al., 1982) but this is likely due to the increased energy available to the cow during the last trimester from the inclusion of monensin.

Effect of ionophores on reproductive performance

Moseley et al. (1977) evaluated the effect of monensin on puberty and conception rates in heifers. Cattle fed 200 mg·hd^{-1}·d^{-1} reached puberty faster while there were no significant differences in conception rate. Hixon et al. (1982) found heifers fed

monensin at 200 $mg \cdot hd^{-1} \cdot d^{-1}$ during energy restriction (87% of NRC requirement) decreased postpartum interval to first estrus by 13 d. Turner et al. (1977) reported cows in moderate BCS that received monensin decreased post-partum interval by 12 days compared to cattle not fed monensin (30 vs. 42). However, when a subsequent set of cows that were carrying excessive fat cover were fed the same treatments, no differences were found in the post-partum interval, which is in agreement with the results found by Turner et al. (1980). Clanton et al. (1981) also found that there were no differences in the onset of estrus after calving, interval from calving to conception, or pregnancy rate among cows given the varying levels of monensin. In summary, feeding monensin during gestation appears to have no ill effects on reproductive performance; if cows are thin, increased energy availability due to inclusion of monensin can aid in weight and body condition score gain, both of which have been shown to improve conception rate and reduce post-partum interval.

Effect of ionophores on rumen turnover rate

Lemenager et al. (1978b) used ruminally fistulated steers to evaluate the effects of monensin on feed intake and rumen turnover rate. It was found that steers fed ad libitum harvested low quality dry winter range grass had reduced intakes of 15.6%. It was found that feeding monensin decreased rumen liquid turnover rate (30.8%) and solid rumen turnover rate (43.6%). This could be due to the decreased intake subsequently decreasing the total rumen turnover rate. However, when steers were limit-fed a high concentrate diet (thus making intake stationary), monensin still decreased rumen turnover rate. Deswysen et al. (1987) found that the inclusion of monensin decreased the

number of daily ruminal contractions in heifers fed *ad libitum* corn-silage as well as increasing the length of time to consume the feed. This suggests monensin depresses ruminal contractions and in turn rate of passage independent of its depression of intake, and that the slower turnover rate from feeding monensin is the cause for, not simply the result of, reduced intake.

Effects of ionophores on volatile fatty acid production

End products of rumen fermentation are known to affect energy utilization. Propionate is utilized through gluconeogenesis and is the main source of glucose for ruminant animals. Acetate and butyrate however are precursors for long-chain fatty acid synthesis that requires additional energy to be utilized, and thus become less efficient. Armstrong et al. (1958) used ruminally fistulated adult sheep to evaluate effects of volatile fatty acid (VFA) molar proportions on energy efficiency. It was determined that the molar concentration of acetate relative to propionate and butyrate had a negative effect on the absorption of dietary energy. It has also been shown that propionate is utilized the most efficiently by the animal (Yokoyama and Johnson, 1988). A highly documented effect of ionophores in the rumen is the decreased acetate to propionate ratio. Richardson et al. (1976) evaluated effects of monensin on rumen fermentation and the corresponding VFA profile both *in vitro* and *in vivo*. The study done *in vitro* showed that monensin included at dosage rates greater than 1 ppm decreased acetic acid, isovaleric acid and valeric acid production. Propionic acid production was increased at all monensin doses. For the *in vivo* study, both concentrate and roughage diets were evaluated. Cattle fed the concentrate ration had decreased acetic acid when monensin

was fed at a rate equal to or greater than 100 $mg \cdot hd^{-1} \cdot d^{-1}$ and the molar proportions of propionate increased from 31.9 to 41.0 and 43.5% respectively for 100 and 500 $mg \cdot hd^{-1} \cdot d^{-1}$ of monensin. Acetic acid was reduced in the pasture fed cattle at the 200 $mg \cdot hd^{-1} \cdot d^{-1}$ dosage, and the molar percentage of propionic acid was increased from 20.7 to 28.1. Turner et al. (1977) found that gestating cows on a maintenance forage diet fed monensin had increased production of propionate (31%) and decreased acetate and butyrate production (5 and 30% respectively) compared to control cows, with total VFA production remaining unchanged between treatments. Turner et al. (1980) found similar results in lactating cows as treatments receiving 200 or 300 $mg \cdot hd^{-1} \cdot d^{-1}$ had increased production of propionate and decreased acetate and butyrate as compared to control treatments or cows receiving 50 $mg \cdot hd^{-1} \cdot d^{-1}$. In changing the molar proportions of the rumen volatile acids toward more propionic and less acetic and butyric acids, monensin theoretically increases the efficiency of converting ME to RE. Ellis et al. (2012) conducted a meta-analysis study on the effects of monensin on the VFA profile. A consistent decrease in the acetate:propionate ratio was found that was in agreement with the previous individual studies discussed.

Effects of ionophores on methane production

As previously discussed the VFA profile has a large influence on the efficiency of a diet. Along with the benefits from reducing the acetate:propionate ratio from an efficiency of digestion standpoint, propionate also loses less energy via methane production than acetate or butyrate. Propionate is a hydrogen sink, whereas acetate and butyrate are hydrogen sources, and hydrogen is the major substrate for CH_4 formation

(Wolin, 1960). Ionophores also reduce methanogenesis by inhibiting hydrogen-producing bacteria and select for succinate-forming bacteria, which is eventually converted to propionate (Chen and Wolin, 1978) as well as decreasing the metabolism of formate into carbon dioxide and hydrogen, thus decreasing methane production (van Nevel and Demeyer, 1977). In the previously discussed study by Joyner et al. (1979) CH_4 production was reduced by 31%. In a comprehensive review, van Nevel and DeMeyer (1996) found that *in vitro* studies inhibited CH_4 production anywhere from 0 to 76%, with an average decrease in methanogenesis of 18%. It has been shown that when ruminal CH_4 is reduced, alternative electron sinks such as propionate must be used to dispose of the reducing equivalents, and thus the acetate:propionate ratio is decreased (Ellis et al. 2012). It can therefore be concluded that feeding of ionophores creates a dual benefit by increasing propionate production and reducing CH_4 production, all of which leads to increased energy retention in the animal (Bell et al., 2015).

Effects of ionophores on protein degradation

In vitro studies have shown that the inclusion of monensin significantly reduces the ruminal degradation of dietary protein (Schelling et al., 1977; Van Nevel and Demeyer, 1977). "Obligate amino acid fermenting" or "hyperammonia-producing" bacteria are ruminal bacteria that utilize amino acids as their sole carbon and energy source and are characterized by high specific activities of ammonia production (Bell et al., 2015). Many of these obligate amino acid fermenting bacteria are ionophore sensitive, so populations can be reduced 10-fold with an ionophore inclusion (Krause and Russell, 1996). This reduction in turn results in increased N retention and improved

feed efficiency (Potter et al., 1976). In the previously discussed Joyner et al (1979) study, including monensin at 10 ppm and 20 ppm reduced urinary nitrogen losses compared to control (11.0 and 10.4 vs. 12.0 $g \cdot d^{-1}$ respectively) which resulted in greater nitrogen retention (6.1 and 6.6 vs. 4.8 $g \cdot d^{-1}$ respectively).

Effects of ionophores on lactate production

One of the strategies for reducing maintenance energy costs in gestating cows is to limit-feed a high energy diet in an effort to reduce the costs of heat production as well as the possibility of reducing feeding costs (Loerch, 1996). However, high concentrate rations are abundant in readily available starch, and when consumed by ruminants, causes a decrease in ruminal pH, and a possibility of ruminal acidosis which can lead to a decrease in intake and lowered feed efficiency (Callaway, 2003), ulceration, founder, and in severe cases death (Russell and Strobel, 1989). Decreases in pH stem from an increase in lactate production, as lactate is a stronger acid than the typical VFA. Dennis et al. (1981) reported that the two major lactate-producing bacteria species (*S. bovis* and *Lactobacillus*) are inhibited by ionophores, reducing the occurrences of acidosis.

Conclusions about ionophores

Including ionophores into the diet of ruminant animals increases the availability of energy from the diet and improves the partial efficiency of ME (RE/MEI). This is done by reducing the amount of energy lost in heat, methane, fecal, and urine energy. Ionophores also decrease protein degradation and production of methane. The profile of the end products of fermentation are altered as the acetate:propionate ratio is decreased. Lactate production can also be decreased which decrease the occurrences of digestive

disorders. These effects increase the energy availability of the diet, and in combination with the decrease in rumen turnover rate, result in a decrease in intake. Inclusion of ionophores into the diets of gestating cows can allow for improved efficiency of ME use without any decreases in production or reproductive performance.

Diet mixing

With the potential of manipulating cow maintenance costs and in turn gaining production efficiency through intensification (Sawyer and Wickersham, 2013), the logistics of putting these theories into practice need to be considered. One issue that producers may face in limit feeding rations is the delivery of a total mixed ration (TMR) to the cowherd.

While dairy farms are known to deliver TMR to the herd on a daily basis, these diets usually consist highly of silage and concentrate ingredients and typically have less than 10% long stem forages (Heinrichs et al., 1999). Many producers wishing to feed beef cows for part of the year would not have access to these silages, and would rely on lower cost forage ingredients such as wheat straw, alfalfa, sorghum and/or grass hay. However, these long stem forages are very bulky and difficult to handle due to large pore spaces between the stems of forage (Lam et al., 2008). The low bulk-density of these ingredients also causes a concern for how much weight can be put on one load of a mixer wagon.

While there are over twenty types of mixers available on the market (Kammel, 1999), most auger type mixers can only handle 5-8% of the DM in hay (Salfer, 2001). Vertical mixers are known to be able to handle a much larger amount of hay as they can

process the long stem forages into smaller particle sizes. Length of processing time in the vertical mixer impacts particle size and corresponding bulk-density (Rippel et al., 1998). Longer processing times equate to smaller particle sizes and greater bulk-densities. However, if over-mixing occurs, particle size can be reduced to a point of being detrimental to rumen health (Woodford and Murphy, 1988) as well as being inefficient uses of machinery, fuel and labor.

There is little published information that allows prediction of bulk density of complete rations. There is a need for additional research to describe the bulk-density, mixing characteristics, and ideal processing time of common ingredients, and to develop methods to reasonably predict characteristics of their combinations. Such data will enhance optimization of formulation and logistics of delivery of lower total cost solutions for delivering TMR diets to beef cows in intensive systems.

Overall summary

Data reported in the above articles discuss some of the general concepts about ruminant bioenergetics. Altering maintenance requirements of beef cattle and reducing the amount of energy lost to heat production can greatly increase the efficiency and sustainability of the beef industry. It is clear that restricting MEI can reduce maintenance requirements of gestating cows by depressing the size and metabolic activity of splanchnic organ mass. A period of realimentation has also shown to increase efficiency of which total DMI is utilized over a long period of time.

End-products of digestion also greatly affect energy utilization of diets. By including an ionophore in diets of ruminants, the acetate:propionate ratio is consistently

decreased, while energy lost to heat production and methane is also reduced. This creates an increase in energy availability of diets for animals to utilize.

The summation of the above factors affecting energy metabolism are key in understanding what physiological events occur when diet manipulation is applied to beef cattle. It appears that limit-feeding rations that include an ionophore can increase energetic efficiency. However, more data is needed to verify these assumptions, specifically examining the effects of each factor and the interactions of the two. Data is needed in terms of understanding how these factors affect digestibility, rumen turnover rate, and end-product formation, as well as the performance of cows in productive environments

There is also a general lack of data illustrating the bulk density and mix ability of commonly used diet ingredients. If added knowledge could be gained in this regard, the TMR diets that are practical to feed to beef cattle in order to manipulate maintenance requirements could be mixed and delivered in a more efficient, cost effective manner.

CHAPTER II

EFFECTS OF MONENSIN AND DIETARY ENERGY INTAKE ON MAINTENANCE REQUIREMENTS IN BEEF COWS

Synopsis

A decrease in land availability and inventory of the cow herd has created a concern for the sustainability of beef cattle production. Intensifying production by feeding cows in a controlled environment (i.e. drylot) that allows for dietary manipulation could improve system efficiency. Two trials were designed in a 2 × 2 factorial to determine if limit-feeding an ionophore diet to cows during mid-gestation could reduce maintenance energy requirements. Both projects were designed to feed one diet at either 120% (**H**) or 80% (**L**) of NRC requirements with either **0** or **200** mg·hd^{-1}·d^{-1} of monensin. Forty cows were fed for 56 d to determine performance, while sixteen ruminally cannulated steers were used for intake and digestion. In the cow trial, a series of ultrasound and body measurements were taken to estimate total body energy. Retained energy was calculated as the difference between d 0 and 56 total body energy and HE was then calculated as the difference in MEI and RE.

Steers fed L had greater ($P < 0.01$) DM digestion, OM, ADF and GE than H, while monensin did not significantly affect digestion ($P > 0.15$). Passage rate was less for L than H ($P < 0.01$) and 200 than 0 ($P < 0.03$). Acetate:propionate was lower in 200 than 0 ($P < 0.01$) while rumen pH was increased ($P < 0.05$). Cows gained more BW when fed at H versus L ($P < 0.01$) with no effect of monensin ($P = 0.97$). Retained

energy per $EBW^{0.75}$ was greater for H than L ($P < 0.01$) although heat production was also greater ($P < 0.01$). Monensin had no effect on either RE ($P = 0.94$) or HE ($P = 0.53$). Monensin did not alter feed required for maintenance or fasting heat production. However, FHP was estimated to be 62.85 $kcal \cdot EBW^{-0.75} \cdot d^{-1}$, a decrease of 26.1% from NRC requirements. Overall, it appears limit-feeding diets can increase production efficiency of cow-calf systems, and although monensin inclusion did not decrease energy requirements or boost RE, it positively altered the rumen environment and fermentation profile.

Introduction

Despite beef cattle producers receiving high cash margins for the past several years (Trubenbach et al., 2014), the U.S. cow herd has been in decline since the late 1970's (NASS, 2015). Global population and GDP estimates suggest that there will be a spike in the demand of beef throughout the world (United Nations, 2012; PWC, 2013). However, urban sprawl, alternative land use decisions, and recent droughts have created a shortage of forage availability to graze cattle on in the United States, which has subsequently driven up land values and made it difficult for producers to expand. Intensifying production by housing mature cows in confinement (i.e. drylot) could not only reduce capital investments needed by producers, but also increase production efficiency of the animal. Other benefits to this system include ease of both data collection and use of reproductive technologies.

An estimated 50% of all feed energy consumed by beef cattle is used for cow maintenance (Ferrell and Jenkins, 1984). Limit feeding a diet containing an ionophore

has the potential to reduce maintenance requirements and increase efficiency of cow-calf systems. Continual restriction of MEI shifts maintenance production to a lower level by decreasing heat increment (Freetly and Nienaber, 1998). Inclusion of ionophores improve the VFA profile (Richardson et al., 1976) and decrease methane production (Joyner et al., 1979), theoretically increasing diet NE_m concentration. Little research has been conducted reviewing the combination of these factors. The subsequent experiments were designed to test the hypotheses that limit feeding a diet that includes an ionophore will increase dietary NE_m and decrease maintenance requirements.

Materials and methods

The experimental protocol was approved by the Agricultural Animal Care and Use Committee at Texas A&M Agrilife Research for research conducted at the McGregor Research Station in McGregor, TX and the Institutional Animal Care and Use Committee at Texas A&M University for research conducted in College Station, TX.

Experiment 1: Cow performance

Forty crossbred ($^3/_4$ *Bos taurus*, $^1/_4$ *Bos indicus*; BW 385 ± 25 kg) cows, three years of age, were used in an experiment designed to examine the effects of an ionophore (monensin; Rumensin® 90, Elanco Animal Health, Indianapolis, IN) and dietary energy intake on energy metabolism. Cows were stratified by BW and assigned to 10 pens of 4 head. Treatments were arranged as a 2 × 2 factorial, with two levels of net energy (NE) intake of a total mixed ration (TMR) containing 1.54 Mcal NE/kg: 80% NRC requirements (**L**) and 120% NRC requirements (**H**), each with two levels of

monensin inclusion: 0 (**0)** and 200 mg·hd^{-1}·d^{-1} (**200)** and were randomly assigned within pen.

Energy requirements were calculated using the mean BW of cows 7 d prior to treatment application using equations from the NRC (2000). Daily intake level was calculated per metabolic BW on an individual cow basis, with **H** receiving 76 g·kg^{-1} of MBW and **L** receiving 51 g·kg^{-1} of MBW. A supplement was made for the inclusion of monensin. Distillers' grains and Rumensin ® 90 were mixed to supply monensin at a rate of 200 mg·hd^{-1}·d^{-1} to cows when the supplement was fed at 0.5 kg per d. A control supplement of DDG was also used and added to treatment 0 diets. The 0.5 kg of DDG were removed from the TMR on a percentage basis so when the supplement was added to the daily feeding the original diet formulation was achieved (Table 1). Cows were fed individually at approximately 0730 h daily using a Calan gate system, with orts (if present) collected once per week. Cows had *ad libitum* access to fresh water throughout the experiment.

At the beginning (d 0) and end of the feeding period (d 56), animals were subjected to a series of measurements including: hip height, heart girth, body condition score (BCS) and ultrasound measurements of rib fat thickness (between 12th and 13th rib), rump fat thickness, and ribeye area. Ultrasound measurements were collected for both direct comparison and for use in select regression models to calculate body energy reserves. Body weights were collected on d 0, 14, 28, 42 and 56.

Fecal grab samples were collected and immediately frozen on d 14, 28, 42, and 56 to determine fecal production using acid detergent insoluble ash (ADIA) as an internal marker. The TMR was mixed approximately every 5 d in a Kuhn-Knight Model

Table 1 Ingredient and nutrient composition of diet

Ingredient	With Supplement	Without Supplement
	% As fed	
Wheat straw	34.52	38.11
Corn	29.46	32.52
Distillers grain	27.46	19.92
Urea	1.10	1.21
Molasses	5.00	5.52
Mineral	2.46	2.72
Diet components[a]	DM basis[b]	
Crude protein, %	16.30	
Total digestible nutrients, %	68.00	
Metabolizable energy, Mcal	2.45	
Net energy (Ne_m), Mcal	1.54	
Net energy (Ne_g), Mcal	0.95	

[a]According to NRC model estimates

[b]Dry mater contents: 89.8%

740 twin auger vertical mixer and unloaded into grain totes. Samples from each tote were taken directly from the discharge conveyer as the TMR was unloaded for subsequent analysis. Each tote of TMR was assigned to 2 pens and fed solely to those pens. To account for the possibility of diet separation varying with discharge order from

the mixer, totes were rotated between pens weekly according to how they came off the mixer (Table 2).

Table 2 Assignment of TMR totes to pens

	Bag # off of Mixer			
Pens	Week 1	Week 2	Week 3	Week 4
1-2	1	5	1	5
3-4	2	4	2	4
5-6	3	3	3	3
7-8	4	2	4	2
9-10	5	1	5	1

Experiment 2: Intake, digestion, ruminal fermentation and ruminal fill

Sixteen ruminally cannulated Angus × Hereford steers (BW 288 ± 20 kg) were used in an experiment designed to examine the effects of an ionophore (monensin; Rumensin® 90, Elanco Animal Health, Indianapolis, IN) and dietary energy intake on digestibility, ruminal pH, volatile fatty acid (VFA) concentrations and gut fill. Steers were stratified by BW and housed in individual stalls (2.1 × 1.5 m) in an enclosed, climate controlled barn. Treatments were randomly assigned using the same 2 × 2 factorial arrangement as experiment 1.

Daily intake level was set to match the average intake of the cows used in experiment 1 using individual steer BW, with H receiving 76 g/kg of MBW and L receiving 51 g/kg of MBW. A supplement was made using DDG and Rumensin® 90 to supply 200 $mg \cdot hd^{-1} \cdot d^{-1}$ to the steers in 0.5 kg package. A control supplement consisting of only DDG was added to 0 diets. The 0.5 kg of DDG were removed from the TMR on

a percentage basis for both H and L diets so when the supplement was added to the daily feeding the original diet formulation was achieved (Table 2.2). Steers were fed daily at approximately 0700 h, with orts (if present) being collected and weighed daily before feeding. Steers had a*d libitum* access to fresh water throughout the experiment.

The first 14 days of the experiment served as an adaptation to treatments. Feed and ort samples were collected on d 14 through 17 to correspond with fecal samples collected on d 15 through 18. Fecal grab samples were collected and composited every 8 h in a staggered pattern across the 4-d period, then frozen at -20°C. Collection procedures were arranged to give representative samples of every second hour of the 24 h day.

Ruminal pH level and VFA concentration were measured on d 19. One rumen fluid sample was collected immediately before feeding (0 h) while the others were collected at 2, 4, 6, 9, 12 and 16 h after feeding, using a suction strainer (Raun and Burroughs, 1962; 19 mm diameter, 1.5 mm mesh). Immediately following sample collection, pH of each sample was determined using a portable pH meter with a combined electrode (VWR SympHony). Eight ml of rumen fluid was combined with 2 mL of 25% *m*-phosphoric acid for future VFA analysis and were immediately frozen at -20°C.

Rumen evacuations were performed on d 20. Total weight of the rumen contents were determined by manually emptying the rumen of each animal 0.5 h before feeding and 4 h after feeding. Rumen contents were collected into barrels and at each evacuation

time three samples were collected per steer. Rumen contents were returned immediately following sampling.

Laboratory analysis

Feed, rumen, and fecal samples were processed and analyzed using the same techniques. Samples were dried in a forced-air oven for at least 96 h at 55°C and allowed to air equilibrate for determination of partial dry matter (DM). Samples were then ground (No. 4 Wiley Mill, Thomas Scientific, Swedesboro NJ) to pass through a 1-mm screen, with all feed samples being previously ground to pass through a 4-mm screen. Dry matter was calculated by placing samples in a 105°C oven for 24 h. Dry matter samples were combusted in a muffle furnace for a minimum of 8 h at 450°C and organic matter was determined by the loss in DM.

Acid detergent fiber (ADF) analysis was performed using an Ankom Fiber Analyzer (Ankom Technology Corp., Macedon, NY) with sodium sulfite and amylase omitted and without correction for residual ash. ADF samples were combusted in a muffle furnace for a minimum of 8 h at 450°C and acid detergent insoluble ash (ADIA) was determined by loss in ADF DM. Gross Energy (GE; Mcal/kg DM) was determined by direct calorimetry using a Parr 6300 Calorimeter (Parr Instrument Company, Moline, IL).

Rumen fluid samples were thawed and centrifuged at 20,000 × g for 20 min. Volatile fatty acid concentrations were measured using a gas chromatograph with methods described by Vanzant and Cochran (1994).

Calculations

Fecal production was calculated by dividing ADIA consumption by fecal ADIA concentration:

$$\text{Fecal production, kg} = \frac{DMI \times ADIA_d}{ADIA_f}$$

where:

DMI, kg

$ADIA_d$ = Dietary ADIA concentration (%DM)

$ADIA_f$ = Fecal ADIA concentration (%DM)

Digestibility of DM, OM, ADF and GE were all calculated using:

$$\text{Digestibility}_x, \% = \frac{Intake_x - Fecal_x}{Intake_x} \times 100\%$$

where:

$Intake_x$ = DMI (kg) × dietary nutrient concentration (%DM)

$Fecal_x$ = Fecal production (kg) × fecal nutrient concentration (%DM)

Measures of digestible energy (DE) and metabolizable energy (ME) were calculated by the following equations:

DE (Mcal/kg DM) = GE × $\text{Digestibility}_{GE}$

ME (Mcal/kg DM) = DE × 0.82 per NRC (2000).

Maintenance requirement for metabolizable energy (ME_m) was calculated for the diet using a linear regression of the means of RE on MEI. The linear function was solved for RE = zero; the solution of which represented the ME_m value.

Fasting heat production was estimated using the linear regression of the means of log (HE) on MEI. The linear functions representing each diet were solved for MEI = zero; the solution of which represented the estimate of FHP.

Body condition score (BCS) was calculated at both the beginning and end of the trial using the regression equation (Figure 6) presented by Herd and Sprott (1998).

$$BCS = -1.2927x^2 + 6.0916x + 2.2114$$

where:

x, cm = Rib fat

Equations published in Nutrient Requirements of Beef Cattle (2000; NRC) were used to calculate empty body energy.

1. Body composition was estimated using the following equations:

$$AF = 3.768 \times CS$$

$$AP = 20.09 - 0.668 \times CS$$

where:

AF = proportion of empty body fat

AP = proportion of empty body protein

CS = body condition score

2. Body components were calculated as:

$$TF = AF \times EBW$$

$$TP = AP \times EBW$$

$$EBW = SBW - FL$$

$$FL = SBW * \alpha$$

$$SBW = BW \times 0.96$$

where:

TF = total fat, kg

TP = total protein, kg

FL = fill, kg

α (% SBW) was estimated for each treatment using unpublished data in which ruminal contents were measured from cannulated steers fed the diets used in this study at equivalent rates (g/kg EBW^0.75) via rumen evacuation.

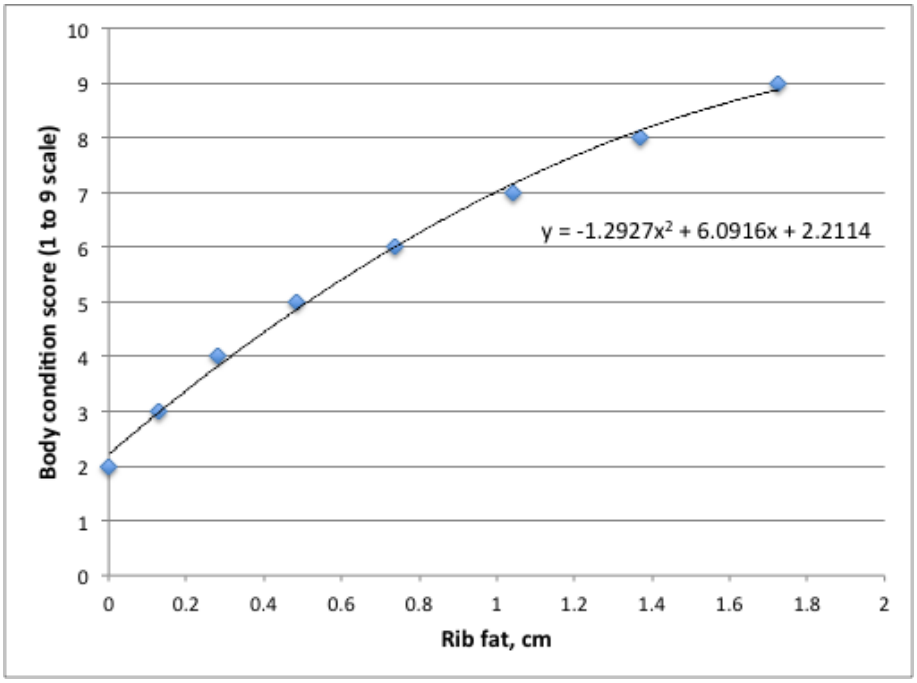

Figure 6 Direct measurements of rib fat thickness used to estimate the body condition score of treatment cows (Adapted from Herd and Sprott, 1998)

3. Total body energy (TBE) was calculated as:

TBE (Mcal) = 9.4 × TF + 5.7 × TP

4. RE and HE were calculated as:

$RE = TBE_f - TBE_i$

HE = ME - RE

where:

RE = retained energy, Mcal

TBE_i = total body energy on d 0, Mcal

TBE_f = total body energy on d 56, Mcal

HE = heat energy, Mcal

ME = metabolizable energy, Mcal.

Ruminal DM fill was calculated using:

$$\text{DM fill, kg} = \frac{DM\ Fill_0 + DM\ Fill_4}{2}$$

where:

$DM\ Fill_0$ = Rumen evacuation dry matter contents before feeding

$DM\ Fill_4$ = Rumen evacuation dry matter contents 4 h after feeding

Molar proportions of VFA's were calculated using:

$$\text{Molar proportion}_x, \% = \frac{Concentration_x}{VFA\ Concentration} \times 100\%$$

where:

$Concentration_x$ = Individual VFA concentration (m*M*)

VFA Concentration = Sum of all $Concentration_x$ (m*M*)

Total ruminal VFA's were calculated using:

Total VFA_x, mol = $Concentration_x$ × total ruminal liquid contents

where:

Total ruminal liquid contents = Average rumen contents (kg) – DM fill (kg)

In addition to NRC estimates of body energy, published regression equations (Table 3) were used to estimate body energy for calculation of RE and ME. An equation presented by Ferrell and Jenkins (1984) was used to estimate energy content of the empty body of mature beef cows. Equations from articles by Gresham et al. (1986) and Wagner et al. (1988) were used to estimate energy in the carcass of mature beef cows. This paper will discuss empty body energy considering calculations for empty body and carcass as synonymous.

Statistical analysis

Data for measures of digestibility, scan measurements, RE and HE were all analyzed using PROC MIXED procedures in SAS 9.3 (SAS Inst. Inc., Cary, NC). The model effects included diet, intake and diet × intake. Data for cow BW over time, VFA concentrations and rumen pH were all analyzed using PROC MIXED procedures in SAS 9.3. The model effects included diet, intake and time, with interactions of diet × intake, diet × time, intake × time and diet × intake × time.

Table 3 Multiple regression coefficients of selected models used for estimating energy[1] contained in the empty body or carcass of beef cows.

		Independent variables[b]										
Model	Type	β_0	BW	BF_c	BF_m	BF_m^2	HH	WH	WT:HH	BCS	EBW	R^2
Ferrell and Jenkins (1984, 1)	Empty Body	73.3	2.9	422.0			-2.7					0.87
Ferrell and Jenkins (1984, 2)	Empty Body	-333.0									4.6	0.69
Gresham et al. (1986)	Carcass	-733.7	1.8		77.7	-1.8		2.5				0.87
Wagner et al. (1988, 1)	Carcass	-487.2	1.3							78.4		0.90
Wagner et al. (1988, 2)	Carcass	-661.5	2.7									0.81
Wagner et al. (1988, 3)	Carcass	-756.7							361.5			0.83
Wagner et al. (1988, 4)	Carcass	-221.5								128.2		0.85

[a]Mcal

[b]BW = live body weight (kg); BF_c = back fat (cm); BF_m = back fat (mm); HH = hip height (cm); WH = wither height (cm, estimated as HH - 5); BCS = body condition score (1 to 9 scale, 1 = emaciated and 9 = very obese); WT:HH = ratio of WT:HH, kg:cm; EBW = empty body weight (kg)

Results

Experiment 1

One cow from L0 was removed from the experiment and subsequent statistical analysis due to failure to accept training to the Calan gate system.

There were no interactions between intake level and monensin inclusion ($P > 0.18$) for estimates of digestibility, dietary energy availability or energy intakes (Table 4). By design, DMI, digestible OM intake, GE intake, DE intake and MEI were greater ($P < 0.01$) in H than L. Also by design, DMI and GE intake did not significantly differ between 0 and 200 ($P = 0.75$). Monensin inclusion did not significantly affect digestible OM intake, DE intake or MEI ($P > 0.44$). Digestibility of DM was greater ($P < 0.01$) for L than H (67.9 vs. 65.7%, respectively) with OM and GE digestibility following a similar pattern; however, ADF digestibility did not differ significantly between intake levels ($P = 0.66$). There were no significant differences in the digestibility of DM, OM, ADF, or GE ($P > 0.18$) due to monensin inclusion. Observed values of DE and ME per unit of feed DM were both greater ($P < 0.01$) for L than H (2.92 vs. 2.80 and 2.39 vs. 2.30 Mcal/kg, respectively), but were not significantly affected ($P = 0.37$) by monensin inclusion.

Body weight (Table 5) did not differ significantly ($P > 0.77$) for intake level or monensin inclusion before treatments were applied. Cows on H (448.0 kg) had greater BW ($P <0.01$) on d 56 than L (419.7 kg) and greater BW gain ($P <0.01$) over the 56 d period (18.0 vs. -4.7 kg, respectively). Neither final BW nor BW gain differed significantly ($P > 0.36$) due to monensin inclusion. However, a monensin × time ($P =$

0.03) and intake × time ($P < 0.01$) interaction was observed for changes in BW (Figure 7).

Body weight for both H0 and H200 increased over the 56 d period. Both L0 and L200 maintained ($P > 0.57$) body weight for the first 14 d. Cows on L0 then lost weight ($P < 0.01$) from d 14 to 28 whereas L200 continued to maintain BW ($P = 0.49$). From d 28 to 42, L0 cows were able to maintain weight while L200 lost BW ($P = 0.09$). From d 42 to 56 L0 began to numerically increase ($P = 0.13$) BW and L200 BW did not change ($P = 0.88$).

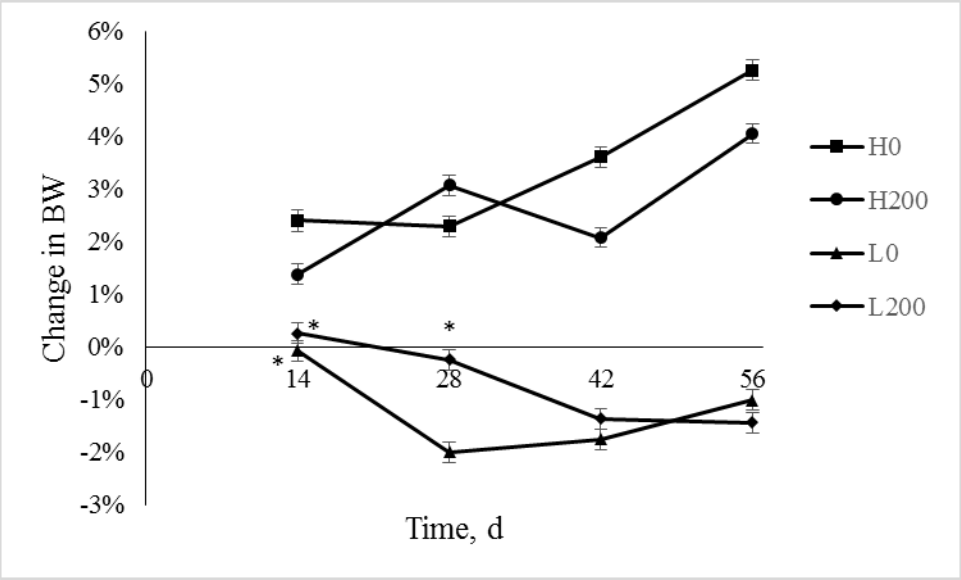

Figure 7 Body weight changes over time of cows fed high and low intakes with two levels of monensin inclusion. H0 = received 120% NRC requirements and 0 mg·hd^{-1}·d^{-1}; H200 = received 120% NRC requirements and 200 mg·hd^{-1}·d^{-1}; L0 = received 80% NRC requirements and 0 mg·hd^{-1}·d^{-1}; L200 = received 80% NRC requirements and 200 mg·hd^{-1}·d^{-1}. Significant effects of intake ($P < 0.01$), time ($P = 0.02$) and monensin × intake interaction ($P = 0.02$); no other significant effects ($P > 0.21$). *not significantly different from 0.

Table 4 Observed intakes, nutrient digestibility and energy availability in cows fed high and low intakes with two levels of monensin inclusion

	Low[1]		High			Probability[2]	
Item	0	200	0	200	SEM[3]	Monensin	Intake
Number of observations	9	10	10	10			
Intake, kg/d							
DMI	3.54	3.49	5.12	5.22	0.081	0.75	<0.01
DOMI	2.24	2.21	3.10	3.23	0.064	0.45	<0.01
Digestibility, %							
DM	68.0	67.8	65.1	66.4	0.72	0.43	<0.01
OM	69.2	69.0	66.1	67.5	0.78	0.41	<0.01
ADF	53.8	51.2	52.2	51.7	1.20	0.18	0.66
GE	66.9	66.6	63.5	65.2	0.80	0.37	<0.01
Energy availability, Mcal/kg DM							
DE	2.92	2.91	2.77	2.84	0.040	0.44	<0.01
ME	2.40	2.39	2.27	2.33	0.033	0.44	<0.01
Energy Intake, Mcal/d							
GE	15.55	15.33	22.41	22.85	0.370	0.75	<0.01
DE	10.40	10.22	14.24	14.91	0.319	0.44	<0.01
ME	8.53	8.38	11.68	12.23	0.262	0.44	<0.01

[1]Low = received 80% NRC requirements; High = received 120% NRC requirements; 0 = 0 mg·hd^{-1}·d^{-1} monensin inclusion; 200 = 200 mg·hd^{-1}·d^{-1} monensin inclusion

[2]Monensin = effect of 0 vs. 200; Intake = effect of Low vs. High; no treatment interactions ($P > 0.18$)

[3]SEM = standard error of mean

No interactions between level of intake and monensin inclusion ($P > 0.24$) were observed for ultrasound measurements (Table 5) collected on d 0 or 56. Likewise, no interactions were detected for changes in ultrasound measurements between d 0 and 56. Back fat was greater in L than H on d 0 ($P = 0.04$), but no other differences in ultrasound measurements were detected on d 0 and 56 between L and H. No differences in back fat, hip fat, or REA were detected between 0 and 200 at the beginning of the trial. No differences were detected in hip fat or rib fat ($P > 0.76$) between 0 and 200 although REA tended ($P = 0.08$) to be larger in 0 than 200 at the end of the trial. Change in hip fat was greater ($P = 0.01$) and change in back fat tended to be greater ($P = 0.09$) in H than L

(0.87 vs. -0.17 and 0.60 vs. 0.01 mm, respectively). Changes in hip fat and back fat for L were not different than zero. Ribeye area was increased in both L and H ($P < 0.05$) over the 56 d period, but no differences in REA change were observed due to level of intake ($P = 0.19$). No change ($P > 0.77$) in back fat or hip fat was detected between 0 and 200, and neither change was different than zero. Change in REA was greater ($P < 0.01$) in 0 than 200.

Table 5 Body weight and ultrasound measurements of cows fed high and low intakes with two levels of monensin inclusion

	Low[1]		High			Probability[2]	
Item	0	200	0	200	SEM[3]	Monensin	Intake
Number of observations	9	10	10	10			
Initial measurements							
Body weight, kg	430.6	419.4	422.4	433.3	9.79	0.99	0.77
Metabolic body weight, kg	86.66	84.94	85.41	87.07	1.477	0.98	0.76
Hip fat, mm	2.46	2.79	2.09	1.83	0.427	0.93	0.11
Back fat, mm	2.57	2.34	1.75	1.68	0.357	0.66	0.04
Ribeye area, cm^2	58.19	56.13	56.27	58.97	2.286	0.89	0.84
Final measurements							
Body weight, kg	426.2	413.3	445.0	451.1	10.48	0.74	<0.01
Metabolic body weight, kg	86.00	84.01	88.81	89.73	1.578	0.73	<0.01
Hip fat, mm	2.24	2.69	2.91	2.74	0.489	0.76	0.45
Back fat, mm	2.67	2.26	2.23	2.39	0.461	0.78	0.73
Ribeye area, cm^2	63.10	56.63	63.71	62.06	2.388	0.08	0.18
Change in measurements							
Body weight, kg	-3.9	-5.4	20.1	15.9	3.21	0.36	<0.01
Metabolic body weight, kg	-0.65	-0.93	3.38	2.66	0.537	0.34	<0.01
Hip fat, mm	-0.23	-0.10	0.82	0.91	0.406	0.77	0.01
Back fat, mm	0.10	-0.08	0.48	0.71	0.350	0.94	0.09
Ribeye area, cm^2	4.90	0.29	6.94	3.10	1.950	0.03	0.19

[1]Low = received 80% NRC requirements; High = received 120% NRC requirements; 0 = 0 $mg \cdot hd^{-1} \cdot d^{-1}$ monensin inclusion; 200 = 200 $mg \cdot hd^{-1} \cdot d^{-1}$ monensin inclusion

[2]Monensin = effect of 0 vs. 200; Intake = effect of Low vs. High; no treatment interactions ($P > 0.24$)

[3]SEM = standard error of mean

No interactions were observed ($P > 0.65$) between level of intake and monensin inclusion for RE ($kcal \cdot d^{-1} \cdot EBW^{-0.75}$) for any of the equations used to estimate RE. The NRC equation predicted greater ($P < 0.01$) RE estimates (Table 2.6) for H compared to L (16.57 vs. -2.48 $kcal \cdot d^{-1} \cdot EBW^{-0.75}$, respectively). Similarly, equations from Ferrell and Jenkins (1984), Gresham et al. (1986), and Wagner et al. (1988) estimated RE to be greater in H than L, except for Wagner et al. (1988, Equation 4) which resulted in a tendency for H be greater ($P = 0.07$) than L. None of the equations estimated differences ($P > 0.23$) in RE due to monensin inclusion.

No significant ($P > 0.23$) interactions between level of intake and monensin inclusion were detected in the equations used to estimate HE ($kcal \cdot d^{-1} \cdot EBW^{-0.75}$). Heat energy estimates (Table 7) derived from RE estimates were greater ($P < 0.01$) for H than L (127.0 vs. 104.6 $kcal \cdot d^{-1} \cdot EBW^{-0.75}$, respective averages) for all the previously discussed equations. Heat energy was estimated to be greater for 200 than 0 in Wagner et al. (1988, 2 and 3; $P < 0.05$) and tended to be greater ($P = 0.08$) for Ferrell and Jenkins (1984, 2). No differences in heat energy estimates in response to monensin were detected using the NRC equation or the Ferrell and Jenkins (1984, 1), Gresham et al. (1986), or Wagner et al. (1988, 1 and 4) equations.

Table 6 Estimates of retained energy[1] in cows fed high and low intakes with two levels of monensin inclusion

	Low[2]		High			Probability[3]	
	0	200	0	200	SEM[4]	Monensin	Intake
Number of observations	9	10	10	10			
Model							
NRC	-1.7	-3.2	16.1	17.0	4.61	0.94	<0.01
Ferrell and Jenkins (1984, 1)	-2.8	-5.6	16.9	15.8	3.64	0.57	<0.01
Ferrell and Jenkins (1984, 2)	-3.6	-5.2	18.4	14.2	2.90	0.31	<0.01
Gresham et al. (1986)	-0.5	-1.2	16.6	17.6	4.75	0.98	<0.01
Wagner et al. (1988, 1)	-0.9	-1.8	10.5	11.0	3.03	0.95	<0.01
Wagner et al. (1988, 2)	-2.5	-3.6	12.8	9.9	2.02	0.31	<0.01
Wagner et al. (1988, 3)	-5.3	-7.3	8.9	6.0	2.05	0.23	<0.01
Wagner et al. (1988, 4)	0.4	-0.2	7.2	10.2	4.71	0.78	0.07

[1]$kcal \cdot d^{-1} \cdot EBW^{-0.75}$, Calculated as $RE \cdot d^{-1} \cdot EBW^{-0.75}$, where d = 56 days

[2]Low = received 80% NRC requirements; High = received 120% NRC requirements; 0 = 0 $mg \cdot hd^{-1} \cdot d^{-1}$ monensin inclusion; 200 = 200 $mg \cdot hd^{-1} \cdot d^{-1}$ monensin inclusion

[3]Monensin = effect of 0 vs. 200; Intake = effect of Low vs. High; no treatment interactions ($P > 0.65$)

[4]SEM = standard error of mean

Table 7 Estimates of heat energy[1] in cows fed high and low intakes with two levels of monensin inclusion

	Low[2]		High			Probability[3]	
	0	200	0	200	SEM[4]	Monensin	Intake
Number of observations	9	10	10	10			
Model							
NRC	103.2	105.5	121.2	125.4	4.86	0.49	<0.01
Ferrell and Jenkins (1984, 1)	104.2	107.8	120.6	126.9	3.86	0.19	<0.01
Ferrell and Jenkins (1984, 2)	104.9	107.3	119.1	128.5	3.32	0.08	<0.01
Gresham et al. (1986)	101.9	103.4	120.9	125.0	4.89	0.55	<0.01
Wagner et al. (1988, 1)	102.4	104.0	127.0	131.6	3.20	0.31	<0.01
Wagner et al. (1988, 2)	103.9	105.8	124.7	132.8	2.47	0.04	<0.01
Wagner et al. (1988, 3)	106.8	109.4	128.6	136.7	2.37	0.02	<0.01
Wagner et al. (1988, 4)	101.0	102.3	130.3	132.4	4.74	0.72	<0.01

[1]$kcal \cdot d^{-1} \cdot EBW^{-0.75}$, Calculated as $(ME - RE) \cdot d^{-1} \cdot EBW^{-0.75}$, where d = 56 days

[2]Low = received 80% NRC requirements; High = received 120% NRC requirements; 0 = 0 $mg \cdot hd^{-1} \cdot d^{-1}$ monensin inclusion; 200 = 200 $mg \cdot hd^{-1} \cdot d^{-1}$ monensin inclusion

[3]Monensin = effect of 0 vs. 200; Intake = effect of Low vs. High; no treatment interactions ($P > 0.23$)

[4]SEM = standard error of mean

Experiment 2

There were no interactions between intake level and monensin inclusion ($P > 0.22$) for estimates of digestibility, dietary energy availability, energy intakes, passage rate, or ruminal fill (Table 8). By design, DMI (4.35 vs. 2.92 kg), digestible OM intake (2.75 vs. 2.00 kg), GE intake (17.17 vs. 11.65 Mcal), DE intake (11.56 vs. 8.49 Mcal) and MEI (9.48 vs. 6.96 Mcal) were greater ($P < 0.01$) in H than L. Also by design, DMI and GE did not differ ($P > 0.96$) between 0 and 200. No significant differences in digestible OM intake, DE intake or MEI were observed between 0 and 200 ($P > 0.80$). Passage rate was slower ($P < 0.01$) for L (1.70% / hr) compared to H (2.37% / hr) and for 200 compared to 0 (1.90 vs. 2.16% / hr, respectively; $P = 0.03$). Total DM in the rumen (expressed as both total kg and as a percentage of BW) was greater in H ($P < 0.01$) compared to L and for 200 compared to 0 ($P < 0.05$). Digestibility of DM, OM, ADF and GE was greater ($P < 0.01$) in L than H. There were no significant differences in the digestibility of DM, OM, or GE ($P > 0.64$) due to monensin inclusion. Digestibility of ADF was numerically higher ($P = 0.16$) for 0 than 200. Observed values of DE and ME per unit of feed DM were both greater ($P < 0.01$) for L than H, but were not affected ($P = 0.74$) by monensin inclusion.

There was a monensin × time ($P < 0.03$) interaction for the molar proportion of acetate, propionate, butyrate, isobutyrate, isovalerate, and valerate as well as the acetate to propionate ratio and ruminal pH that resulted from differences between treatments at different times rather than a re-ranking of treatments (data not shown). An intake × monensin × time ($P = 0.03$) interaction was observed for acetate as well as a tendency (P

= 0.07) for a monensin × intake interaction (Figure 8). For 200 treatments, H had a lower acetate molar proportion than L. However, for 0 treatments, L had a lower acetate molar proportion than H. Monensin inclusion decreased ($P < 0.01$) the molar proportion of acetate and increased ($P < 0.01$) the molar proportion of propionate (Table 9). The acetate:propionate ratio was therefore lower ($P < 0.01$) for 200 compared to 0. Rumen pH over all time periods was higher ($P = 0.01$) for L than H (6.49 vs. 6.33 respectively) and for 200 compared to 0 (6.49 vs. 6.34 respectively; $P = 0.02$).

There were monensin × time and intake × time ($P < 0.01$) interactions for acetate, propionate and total VFA concentrations which resulted from differences between treatments at different times rather than a re-ranking of treatments (data not shown). Acetate concentration was lower ($P = 0.03$) for L compared to H and lower ($P < 0.01$) for 200 compared to 0. Propionate concentration was lower ($P = 0.05$) for L compared to H, but was unaffected ($P = 0.45$) by monensin inclusion. Total VFA concentration was lower ($P = 0.03$) for L than H and lower ($P <0.01$) for 200 than 0.

Total VFA contents (m*M*) in the rumen were calculated by multiplying the concentration (m*M*) of the VFA by the total liquid (liters) in the rumen. Total ruminal acetate, propionate, and total VFA's in rumen were all lower ($P < 0.02$) for L compared to H. Total ruminal acetate was lower ($P = 0.02$) for 200 compared to 0, but changes in total ruminal propionate ($P = 0.20$) and total VFA's in rumen ($P = 0.20$) due to the inclusion of monensin were not detected.

Table 8 Observed intakes, nutrient digestibility, energy availability, passage rate and ruminal fill of steers fed high and low intakes with two levels of monensin inclusion

	Low[1]		High			Probability[2]	
Item	0	200	0	200	SEM[3]	Monensin	Intake
Intake, kg/d							
DMI	2.92	2.91	4.34	4.36	0.112	0.98	<0.01
DOMI	2.00	2.00	2.77	2.73	0.094	0.80	<0.01
Digestibility, %							
DM	74.2	74.4	69.7	68.5	1.18	0.64	<0.01
OM	76.7	76.9	71.9	70.8	1.11	0.69	<0.01
ADF	59.4	58.1	53.8	51.2	1.30	0.16	<0.01
GE	75.2	75.4	70.7	69.8	1.19	0.74	<0.01
Energy availability, Mcal/kg DM							
DE	2.90	2.90	2.70	2.66	0.052	0.74	<0.01
ME	2.38	2.38	2.21	2.18	0.043	0.74	<0.01
Energy Intake, Mcal/d							
GE	11.66	11.64	17.14	17.21	0.438	0.96	<0.01
DE	8.49	8.49	11.63	11.49	0.408	0.86	<0.01
ME	6.96	6.96	9.54	9.42	0.335	0.86	<0.01
Passage Rate, % / hr	1.88	1.51	2.44	2.29	0.107	0.03	<0.01
Ruminal DM fill, kg	3.51	4.18	4.54	4.90	0.236	0.05	<0.01
Ruminal DM fill, % of BW	1.15	1.39	1.54	1.64	0.053	<0.01	<0.01

[1]Low = received 80% NRC requirements; High = received 120% NRC requirements; 0 = 0 mg·hd^{-1}·d^{-1} monensin inclusion; 200 = 200 mg·hd^{-1}·d^{-1} monensin inclusion

[2]Monensin = effect of 0 vs. 200; Intake = effect of Low vs. High; no treatment interactions ($P > 0.22$)

[3]SEM = standard error of mean, for n = 4

Table 9 Rumen pH and volatile fatty acid profile of steers fed high and low intakes with two levels of monensin inclusion

	Low[1]		High			Probability[2]					
Item	0	200	0	200	SEM[3]	Monensin	Intake	Time	M × I	M × T	I × T
Rumen pH	6.4	6.58	6.27	6.39	0.054	0.02	0.01	<0.01	0.62	0.13	<0.01
Molar percent											
Acetate	63.87	59.74	65.66	58.01	0.863	<0.01	0.94	<0.01	0.07	0.03	0.07
Propionate	21.20	24.02	21.02	26.05	0.921	<0.01	0.33	<0.01	0.25	<0.01	0.14
Butyrate	10.84	11.09	9.62	11.31	0.653	0.16	0.46	<0.01	0.29	0.01	0.24
Isobutyrate	1.22	1.54	1.08	1.38	0.036	<0.01	<0.01	<0.01	0.70	<0.01	0.01
Isovalerate	1.88	2.64	1.64	2.13	0.183	<0.01	0.06	<0.01	0.48	<0.01	<0.01
Valerate	0.99	0.96	0.98	1.04	0.047	0.76	0.49	<0.01	0.36	<0.01	0.07
Acetate:Propionate	3.04	2.51	3.16	2.28	0.136	<0.01	0.71	<0.01	0.21	<0.01	0.04
Concentration, m*M*											
Acetate	52.07	41.89	57.01	44.93	1.589	<0.01	0.03	<0.01	0.56	<0.01	<0.01
Propionate	17.32	16.82	18.28	20.38	1.019	0.45	0.05	<0.01	0.23	<0.01	<0.01
Total VFA	81.67	69.98	86.79	77.54	2.595	<0.01	0.03	<0.01	0.65	<0.01	<0.01

[1]Low = received 80% NRC requirements; High = received 120% NRC requirements; 0 = 0 mg·hd^{-1}·d^{-1} monensin inclusion; 200 = 200 mg·hd^{-1}·d^{-1} monensin inclusion

[2]Monensin = effect of 0 vs. 200; Intake = effect of Low vs. High; M × I × T interaction for acetate proportion (P = 0.03); all others (P > 0.10)

[3]SEM = standard error of mean, for n = 4

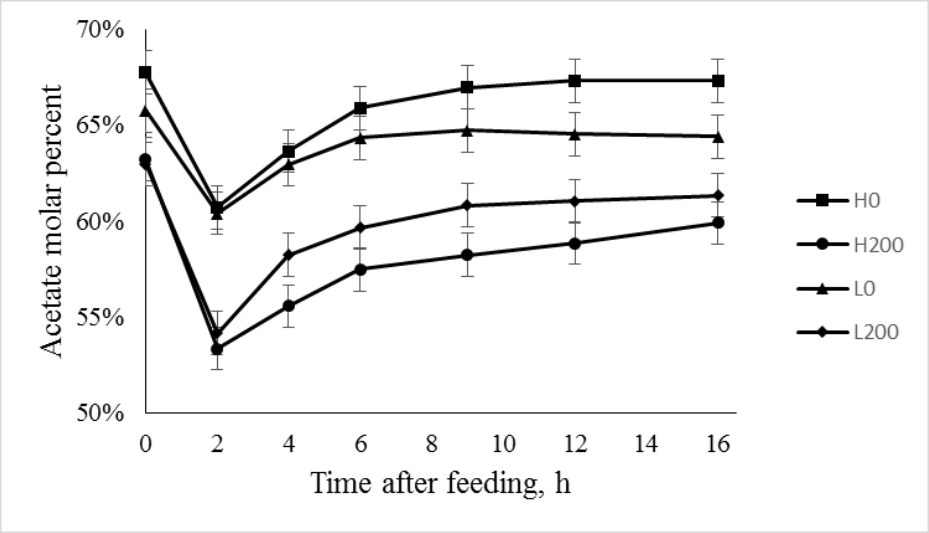

Figure 8 Molar percentage of acetate over time in steers fed high and low intakes with two levels of monensin inclusion. H0 = received 120% NRC requirements and 0 mg·hd^{-1}·d^{-1}; H200 = received 120% NRC requirements and 200 mg·hd^{-1}·d^{-1}; L0 = received 80% NRC requirements and 0 mg·hd^{-1}·d^{-1}; L200 = received 80% NRC requirements and 200 mg·hd^{-1}·d^{-1}. Significant effects of monensin (P < 0.01), time (P < 0.01) and treatment × time interactions (P < 0.05).

Table 10 Total VFA contents[1] in the rumen of steers fed high and low intakes with two levels of monensin inclusion

	Low[2]		High			Probability[3]		
Item	0	200	0	200	SEM[4]	Monensin	Intake	M × I
Acetate	1616.81	1521.17	2147.35	1610.24	115.87	0.02	0.02	0.08
Propionate	533.66	610.18	685.95	726.52	43.089	0.2	<0.01	0.68
Total VFA	2530.7	2538.71	3266.58	2778.5	177.29	0.2	0.02	0.19

[1]Calculated as VFA concentration × liquid content of rumen; m*M*

[2]Low = received 80% NRC requirements; High = received 120% NRC requirements; 0 = 0 mg·hd^{-1}·d^{-1} monensin inclusion; 200 = 200 mg·hd^{-1}·d^{-1} monensin inclusion

[3]Monensin = effect of 0 vs. 200; Intake = effect of Low vs. High

[4]SEM = standard error of mean, for n = 4

Discussion

The objective of this study was to quantify the effects of monensin inclusion and differing MEI on digestion and energy utilization in beef cows and their effects on maintenance energy requirements.

Effects of MEI

Reducing MEI increased digestion of DM, OM, and GE, which was expected as passage rate was slower in L than H and a slower rate of passage is known to increase digestion (Baldwin et al., 1977; Bull et al., 1979). Both DE and ME of the diet were calculated from GE digestibility and accordingly were greater for L than H (2.39 vs. 2.30 Mcal·kg^{-1} DM respectively). These are slightly higher than observed by Trubenbach (2014) for a similar diet (2.32 and 2.31 Mcal·kg^{-1} DM respectively), which is due to a higher observed GE digestion in the current study. However, these ME values are still lower than the 2.45 Mcal·kg^{-1} DM estimated by the NRC (2000). Increases in cow BW and ultrasound measurements of fat observed in H versus L were expected, as the increase in total MEI of H should increase RE and subsequent fat deposition and weight gain. Although cows on L in our study lost weight, ultrasound measurements in L were not different than zero suggesting that a new maintenance equilibrium may have been reached in the L treatment similar to previous reports (Trubenbach, 2014; Freetly and Nienaber 1998). However, due to the small amount of fat detected in the cows throughout the trial and the inevitable variance from collecting the data, the ability to detect differences within the specific treatments was not the primary goal of the

ultrasound. Rather, the data were collected to be used in regression equations to predict RE (Ferrell and Jenkins, 1984; Gresham et al., 1986; Wagner et al., 1988).

Similar to BW, increased RE was expected in H compared to L as increasing MEI results in increased nutrient balance and positive energy balances were achieved. Although L was designed to supply NE at 80% of NRC (2000) requirements, RE predicted by inputting observed body composition values into the NRC (2000) equation was not different from 0, whereas the NRC model predicted a loss of 22 $kcal \cdot EBW^{-0.75} \cdot d^{-1}$ when simulating consumption of these diets at the L intake level. This suggests that there were decreases in FHP and HI compared to NRC (2000) model predictions that most likely came from decreases in splanchnic tissue mass (Camacho et al., 2014) which leads to reduced heat production (Reynolds et al., 1991) and thus greater RE for a given MEI. The fact that calculated ME values of L were lower than the NRC predicted, and L cows were fed at only 80% of NRC (2000) values, shows that cows were able to reach a new maintenance equilibrium that was much lower than predicted by the NRC.

Percentage change in heat production between treatments is shown in Table 10. Because cows differ in energy requirements (Jenkins and Ferrell, 1997) expressing energetic savings as a percentage rather than in Mcal allows for more accurate comparison across breed types. It has consistently been shown that reducing intake reduces heat production (Trubenbach, 2014; Freetly et al., 2006; Freetly and Nienaber, 1998; and Ortigues et al., 1993) so it was expected that L would have reduced HE compared to H. The reduction of 21% in L compared to H is less than the 28% savings Trubenbach (2014) reported using similar diets, but the difference is most likely due to

our study reporting a greater increase in GE digestibility of L, which led to calculated MEI to be greater per metabolic BW.

Table 11 Changes in daily heat production in cows fed high and low intakes with two levels of monensin inclusion

	Factor Means[1]				Difference	
	H	L	0	200	Intake[2]	Monensin[3]
Number of observations	20	19	19	20		
Model						
NRC	123.3	104.4	103.2	105.5	-18%	2%
Ferrell and Jenkins (1984, 1)	123.8	106.0	112.4	117.3	-17%	4%
Ferrell and Jenkins (1984, 2)	123.8	106.2	112.1	117.9	-17%	5%
Gresham et al. (1986)	123.0	102.6	111.4	114.2	-20%	2%
Wagner et al. (1988, 1)	129.3	103.2	114.7	117.8	-25%	3%
Wagner et al. (1988, 2)	128.7	104.8	114.3	119.3	-23%	4%
Wagner et al. (1988, 3)	132.7	108.1	117.7	123.1	-23%	4%
Wagner et al. (1988, 4)	131.4	101.7	115.7	117.4	-29%	1%
Means	127.0	104.6	112.7	116.6	-21%	3%

[1] $kcal \cdot d^{-1} \cdot EBW^{-0.75}$

[2] Calculated as 100% × [(L - H) / L]

[3] Calculated as 100% × [(200 - 0) / 200]

Effects of monensin

Ionophores are known to alter the VFA profile and improve the capture of feed energy during ruminal fermentation. Accordingly, the NRC (2000) recommends increasing NE_m values by 12% with the inclusion of an ionophore. Based on this assumption, it was thought that 200 cows would have greater ultrasound measurements and RE than 0, which was not observed in the current study. Observed reductions in REA found in our study have not been previously reported. A tendency for the inclusion of monensin to decrease REA has been reported in finishing cattle (Boling et al., 1977)

but no significant changes have ever been reported and many show no differences at all (Pendlum et al., 1978 and Steen et al., 1978). Similar to the BF data previously discussed, changes in REA were not of specific interest, rather using them in the RE equations was the primary purpose of collection. Although we did expect increased RE in 200 compared to 0, the fact our cows were in a poor BCS based on BF measurements and did not show gains in energetic efficiency is consistent with Burrell (1977). However, our calculations were only based off of beginning and ending data. Cows on H increased in BW over the 56 d period regardless of monensin inclusion. However, if we evaluate BW changes of cows on L treatments (Figure 7), cows receiving 200 took longer to lose weight than cows receiving 0. Assuming that monensin did increase NE_m by 12%, cows on L200 would have theoretically been receiving 89.6% of maintenance requirements rather than the 80% that L0 received. This could explain the slower loss in BW in L200 compared to L0. However, it would also mean that these cows had a greater BW to maintain and it appears as though it took them between 42 and 56 d to reach a new equilibrium whereas cows on L0 appear to have reached a new equilibrium by d 28 and even began to regain BW for the rest of the trial. A longer trial period is needed to determine if L200 cows were able to achieve a new maintenance equilibrium and begin to regain weight as the L0 cows did. However, by limit feeding a high energy diet, the full 12% increase in NE_m may not been achieved due to overlapping benefits of the two factors. More research is needed in this area to fully define effects of using ionophores in limit-fed gestating cows.

Shifting the VFA profile is a well-documented effect to monensin inclusion (Lemenager et al. 1978; Richardson et al., 1976). Our results are consistent with these observations; monensin reduced molar percentage of acetate, increased propionate and reduced acetate:propionate ratio. Lemenager et al. (1978) also reported similar results to our study in that total VFA concentrations were decreased with inclusion of 200 $mg \cdot hd^{-1} \cdot d^{-1}$, but others have shown no decrease in total VFA concentrations (Dinius et al. 1976). Propionate concentrations were not significantly different between 200 and 0. Accordingly, changes in the molar proportions of the two VFA's and the acetate:propionate ratio can be attributed to the decreased concentration of acetate. To determine if total VFA's in the rumen were reduced (m*M*), average liquid content in the rumen (obtained from rumen evacuations) was multiplied by VFA concentrations. It is not surprising that increasing intake increased the total VFA content. Also not surprising is the fact monensin decreased total acetate content. However, total VFA content was not significantly affected by adding monensin, suggesting that no decrease in total VFA availability occurred, despite the apparent decrease in total VFA concentration that was previously discussed.

The increased NE_m of 12% is primarily contributed to the VFA profile alteration rather than changing digestibility due to monensin. This is consistent with our data which showed no significant increases in any digestibility measures resulting from monensin inclusion. Rate of passage was decreased in 200 compared to 0, which has previously been reported in steers limit-fed a high concentrate diet by Lemenager et al. (1978b), perhaps due to a decrease in the number of daily ruminal contractions

(Deswysen et al., 1987). Monensin has previously been shown not to affect ADF digestion (Dinius et al., 1976; Benz and Johnson, 1982), but varying results have been observed for DM digestion. Poos et al. (1979) reported that monensin decreased DM digestion when there was no adaptation period, but had no effect after a 29 d adaptation period. Monensin increased DM digestion in both grain-fed (Dinius et al., 1976) and grazing cattle (Pond and Ellis, 1981). One reason for the lack of differences in DM digestion observed in the current study may be that the cattle were limit-fed. Cattle on both the Dinius et al. (1976) and Pond and Ellis (1981) studies were fed *ad libitum* and DMI was decreased with monensin; this could have led to increased DM digestibility. Again, both DE and ME were calculated based off of GE digestibility and accordingly did not significantly change with inclusion of monensin. However, calculated ME ($Mcal \cdot kg^{-1}$ DM) was lower than the NRC (2000) predicted for both 0 and 200 (2.33 and 2.36 vs. 2.45 respectively).

Using mean MEI and RE data, estimated ME_m values were calculated by regressing RE on MEI and solving for RE=0 (Figure 9). The resulting ME_m values were estimated to be 102 and 105 $kcal \cdot EBW^{-0.75} \cdot d^{-1}$ respectively for 0 and 200. These values are very similar to the 104 ME_m $kcal \cdot EBW^{-0.75} \cdot d^{-1}$ reported by Freetly and Nienaber (1998) when intake was restricted to 65% of maintenance requirements. Although values from the current study are greater than the 93 $kcal \cdot EBW^{-0.75} \cdot d^{-1}$ reported by Trubenbach (2014) in a similar study (likely due to our higher digestion estimates), they are still 35.1% lower on average than 160 $kcal \cdot EBW^{-0.75} \cdot d^{-1}$ calculated from the NRC (2000),

suggesting that the NRC significantly overestimates ME_m values of cows limit-fed a high concentrate diet.

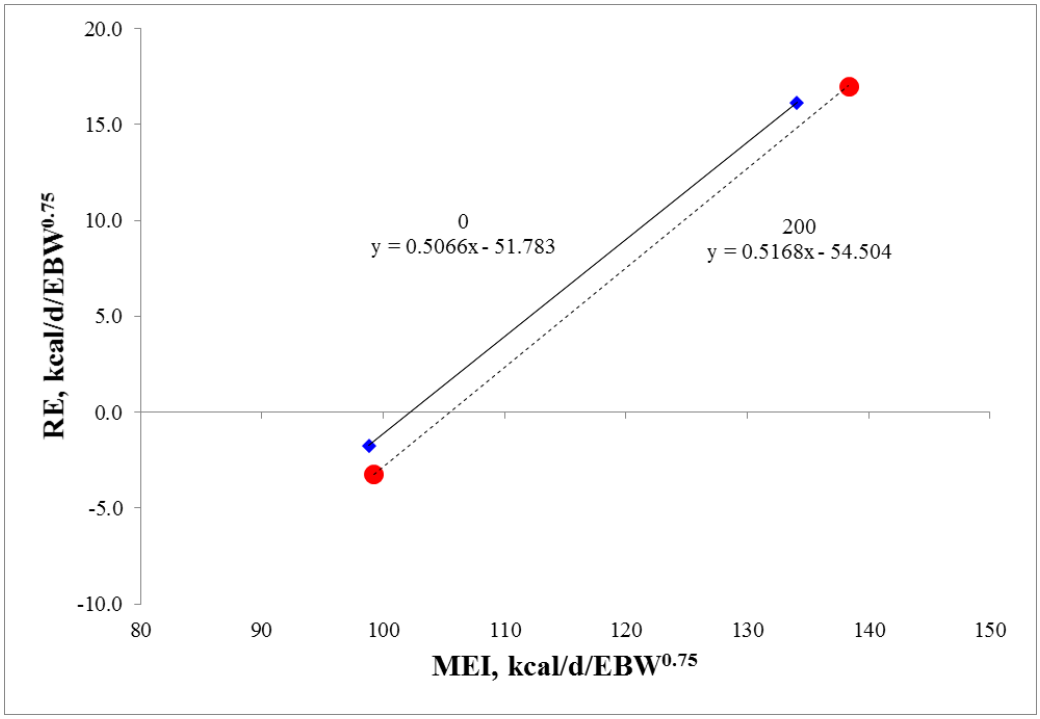

Figure 9 The effect of MEI on RE in cows fed two levels of monensin. 0 = received 0 mg·hd^{-1}·d^{-1} monensin; 200 = received 200 mg·hd^{-1}·d^{-1} monensin.

An observed numerical increase in heat production from the inclusion of monensin observed in our study agrees with previous reports in finishing steers (Wedegaertner and Johnson, 1983) and growing lambs (Joyner et al., 1979), but is contradictory to Thornton and Owens (1981) who reported no significant differences in heat production from the inclusion of monensin in finishing steers. Similar to the BW

discussion earlier, the increase in HE observed in our study most likely comes the L200 cows taking longer to reach the new equilibrium, and showing a lower RE on d 56. It should also be noted that changes in heat production were consistent across all equations used to predict RE, suggesting that use of a specific equation isn't important, and that the NRC (2000) equations which uses only BW and BCS is sufficient.

To account for the non-linearity of heat production as MEI increases infinitely, fasting heat production was estimated by regressing log (HE) on MEI (Figure 10). The y-intercept of these equations represents log(FHP) and by taking the inverse (inverse log, 10^{x}), FHP can be derived. Estimates for 0 and 200 were 62 and 64 kcal·EBW$^{-0.75}$·d^{-1} respectively, which on average is an 18.4% reduction from the 77 kcal·EBW$^{-0.75}$·d^{-1} that the NRC (2000) estimates for dry cows and a 26.1% reduction from the 85 kcal·EBW$^{-0.75}$·d^{-1} the NRC estimates for cows 8 months past calving, which is similar to cows in our study. The numerically higher FHP in 200 compared to 0 is contradictory to the reports of Garrett et al. (1980), but it was not expected that monensin would decrease FHP. Numerical increases in FHP make sense for how we calculated HE as ME between 0 and 200 did not change and 0 had numerically higher RE figures. This once again could be due to the 200 cows reaching a new equilibrium later than the 0 treatment.

The data reported from these experiments support findings from Trubenbach (2014) in suggesting NRC (2000) extremely overestimates ME_m and FHP in cows limit-fed a high concentrate diet. Although RE was not increased with the inclusion of monensin, the fact it altered the VFA profile in favor of propionate rather

than acetate and delayed BW loss in cows fed below maintenance, suggests there still may be energetic gains achieved by adding monensin to diets fed to gestating cows.

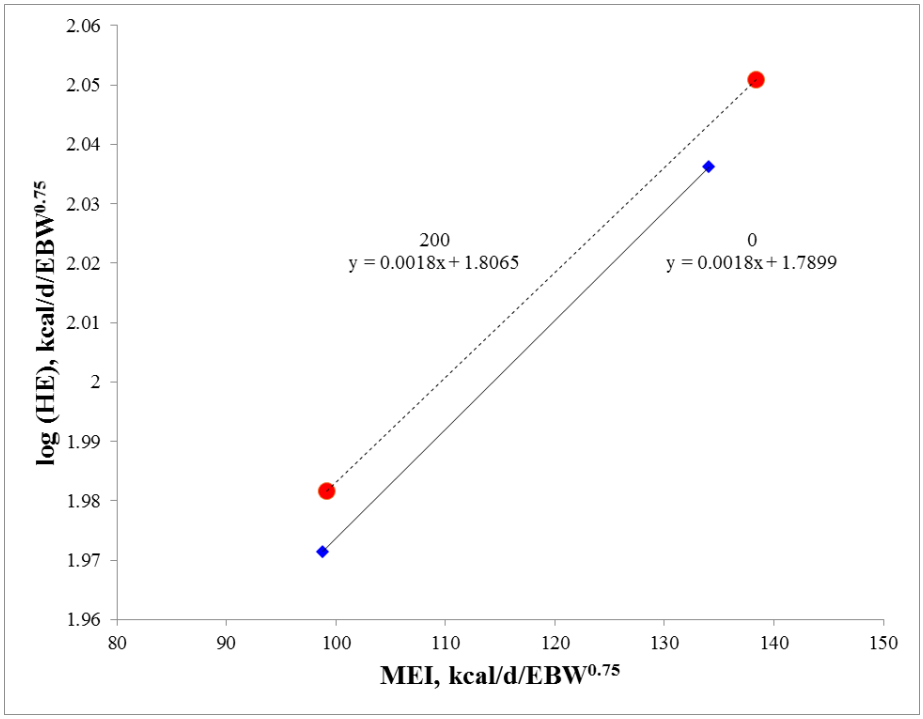

Figure 10 Logarithmic transformation of the effect of MEI on HE in control cows or fed monensin. 0 = received 0 mg·hd^{-1}·d^{-1} monensin; 200 = received 200 mg·hd^{-1}·d^{-1} monensin.

CHAPTER III

METHODOLOGY TO MEASURE VOID SPACE AND BULK DENSITY OF FEED INGREDIENTS

Synopsis

Feeding bulky rations containing large amounts of forage to cattle in confinement creates logistical challenges and reduces the efficiency of feed delivery. Describing void space and bulk density of feed ingredients may improve feeding logistics by allowing formulation to optimize the amount of feed delivered per load with efficient ingredient combinations. Bulk density was similar for wheat straw (18 $kg \cdot m^{-3}$) and sorghum × sudangrass (33 $kg \cdot m^{-3}$; $P = 0.52$) and greater ($P < 0.01$) for alfalfa (89 $kg \cdot m^{-3}$). The void space of wheat straw (66.4%), hay grazer (62.9%), and alfalfa (28.1%) all differed ($P < 0.04$). Rolled corn and DDG differed in bulk density (657 $kg \cdot m^{-3}$ vs. 581 $kg \cdot m^{-3}$; $P < 0.05$), but had a similar void space (1.8 vs. 0.4% $P = 0.32$). Concentrates differed from roughages ($P < 0.01$) in both bulk density and void space. Calculations were then made to predict how much concentrate could be mixed with a given roughage in a fixed volume container. By knowing the bulk density and void space, total feed amounts could be mixed together and maximum payload within a fixed volume were accurately predicted.

In a separate evaluation, sorghum × sudangrass was chopped for 5, 10, 15, 30, and 60 min in a twin-auger vertical mixer to evaluate processing time effects on bulk density and void space. Bulk density increased between 5 min (17.2 $kg \cdot m^{-3}$) and 15 min

(24.5 kg·m^{-3}; $P < 0.05$) and again from 30 min and 60 min (27.0 kg·m^{-3} to 54.2 kg·m^{-3}; $P < 0.01$). Void space did not change ($P = 0.41$) between 5 min and 30 min, but decreased ($P < 0.01$) from 60.7 to 36.1 % when chop time changed from 30 min to 60 min. Overall, a quick method of measuring bulk density and void space was developed and the use of these two feed characteristics may allow optimization of mixing and reduce delivery costs of high-roughage diets to large numbers of cattle in confinement systems.

Introduction

Intensifying cow-calf production appears to be a viable option for producers to reduce capital investment costs and increase production efficiency (Sawyer and Wickersham, 2013). In these types of systems, labor and feed would be increased compared to more traditional extensive operations as feed would need to be delivered every day. While dairy farms have long fed TMR rations to their herds, these diets typically still have less than 10% long stem forages (Heinrichs et al., 1999). The primary goal in dairies is also similar to feed yards and are more focused on maximizing performance than minimizing costs. To decrease costs and maintain rumen health, diets of mature cows typically contain much higher percentages of roughage than that of feedlot or dairy diets. However, roughages have a much lower bulk density and are more difficult to handle (Lam et al., 2008) which limits the amount of feed that can be delivered in one load. These forages also have large pore spaces between them, (Lam et al., 2008) creating space for ingredients of small particle size. Vertical mixers have the ability to process the forages into smaller particles, and thus can handle a larger amount of hay. Length of processing time is known to affect bulk density (Rippel et al., 1998),

but over processing creates too small of a particle size and wastes resources of time and fuel. If additional characteristics of the feed could be quickly and accurately described, rations could be mixed and delivered in a more time and cost efficient manner. The following described experiments were designed to test the hypothesis that void space and bulk density could be measured quickly, and by knowing these characteristics, predictions could be made for maximum payload and ingredient inclusion within a fixed volume container.

Materials and methods

Five commonly used feed ingredients were used to determine void space percentage based on compressibility and bulk density and determine if the maximum quantities of ingredients mixed in one batch of feed could be predicted based off the corresponding void space. Feed ingredients consisted of two concentrates that were tested as received; rolled corn and dried distillers' grain (DDG), and three roughages processed through a tub grinder equipped with a 5 cm screen; alfalfa hay, wheat straw and sorghum × sudangrass.

To determine how processing time affected void space and bulk density, sorghum × sudangrass was chopped in a Kuhn Knight VT180 twin-screw vertical mixer. Samples were collected from the vertical mixer after 5, 10, 15, 30, and 60 min.

All samples were individually poured into a fixed volume (168 cm^3) container and compressed by letting a constant mass (8.639 kg) plate drop down the container. Compression distance was recorded from top of cylinder to where the mass plate rested.

Samples were then emptied out of the cylinder and sample weight was recorded to calculate bulk density.

Maximum amounts of two ingredients that could be mixed together in a fixed volume container was then predicted based off of bulk density and void space of the two ingredients. The ingredient with the higher void space was considered the base ingredient, and the second ingredient was added according to void space of the first ingredient multiplied by the volume of the container.

Calculations

$$\text{Bulk density, kg·m}^{-3} = \frac{Sample\ Mass}{Cylinder\ Volume}$$

$$\text{Void space, \%} = \frac{Cylinder\ Volume - Compressed\ Volume}{Cylinder\ Volume}$$

Results

Bulk density (Table 12) was similar for wheat straw (18 kg·m^{-3}) and sorghum × sudangrass (33 kg·m^{-3}; P = 0.52) and greater (P < 0.01) for alfalfa (89 kg·m^{-3}). The void space of wheat straw (66.4%), hay grazer (62.9%), and alfalfa (28.1%) all differed (P < 0.04). Rolled corn and DDG differed in bulk density (657 kg·m^{-3} vs. 581 kg·m^{-3}; P < 0.05), but had a similar void space (1.8 vs. 0.4% P = 0.32). Concentrates differed from roughages (P < 0.01) in both bulk density and void space.

Processing time increased bulk density between 5 min (17.2 kg·m-3) and 15 min (24.5 kg·m-3; P < 0.05) and again from 30 min and 60 min (27.0 kg·m-3 to 54.2 kg·m-3; P < 0.01). Void space did not change (P = 0.41) between 5 min and 30 min, but

decreased ($P < 0.01$) from 60.7 to 36.1 % when chop time changed from 30 min to 60 min.

Table 12 Bulk density and void space of common feed ingredients

	Bulk Density[1,2]	Void Space[3,4]
Ingredient		
Wheat Straw	18.18[a]	66.40[w]
Sorgum × sudangrass	33.39[a]	62.91[x]
Alfalfa	88.91[b]	28.12[y]
Rolled Corn	656.7[c]	1.82[z]
DDG	580.56[d]	0.36[z]

[1]$kg \cdot m^{-3}$; calculated as mass / volume;

[2]Standard error of mean = 15.73

[3]%; calculated as (volume - compressed volume) / volume;

[4]standard error of mean = 0.93

[a-d]Means lacking common superscript differ ($P < 0.05$)

[w-z]Means lacking common superscript differ ($P < 0.05$)

Discussion

It is well known that the bulk density of concentrate ingredients is greater than roughages, and that particle size is correlated to bulk density. However, finding the exact bulk densities of the feed ingredients was not the primary objective, and because the bulk densities we calculated are similar to previous reports (Lam et al., 2008) indicates

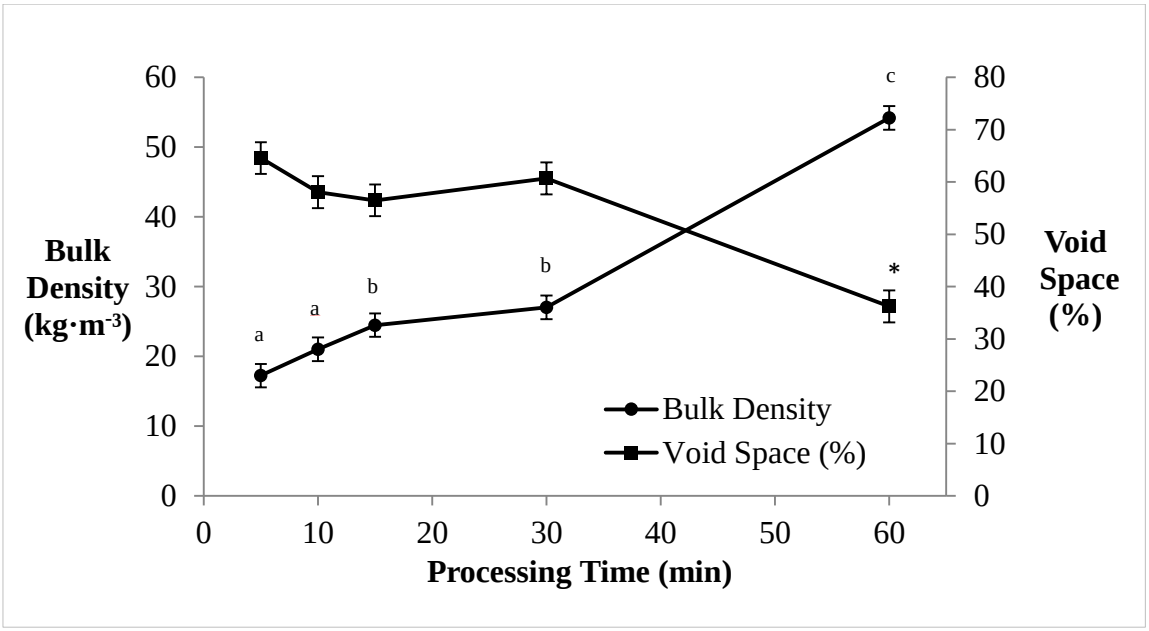

Figure 11 Effects of processing time on bulk density and void space percentage of sorghum × sudangrass. [a-c] = means lacking common superscript differ ($P < 0.03$) in bulk density; * = means differ ($P < 0.05$) in void space percentage.

that the method of collection is capable of measuring accurate figures and provides a rapid method for field use. Based off of the calculated void spaces of each ingredient, predictions were then made for maximum amounts of two different ingredients that could be mixed in a fixed-volume container. Our predictions were accurate as the container was completely filled with the predicted amounts with only void space similar to that of the concentrate ingredients. These findings show that void space is a viable measurement to collect when mixing multiple ingredients of feed together. From these predictions, maximum payload (Figure 12) of cracked corn mixed with either alfalfa or wheat straw was then calculated based off of bulk density and void space of the ingredients, depending on desired roughage level inclusion in the diet. As expected, the

greater bulk-density of alfalfa allowed for greater maximum payloads to be achieved at the same roughage inclusion as wheat straw. By acquiring bulk-density and void-space measurements, least cost rations accounting for feed-delivery costs could easily be achieved. Developing a decision support tool to calculate these costs would be the next required step in this research.

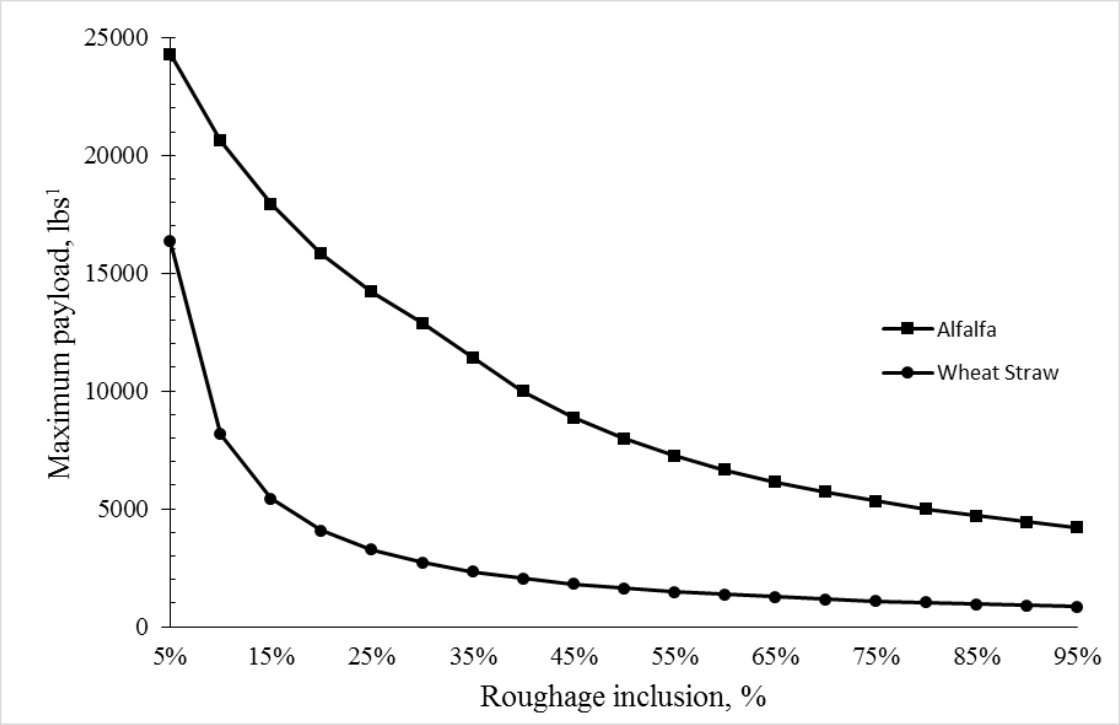

Figure 12 Maximum payload of either alfalfa or wheat straw mixed with cracked corn based on varying levels of roughage inclusion. [1]Calculated for a mixer with book capacity of 800 ft^3, assuming 90% of book value is actual capacity.

CHAPTER IV

SUMMARY

The results from these studies successfully displayed the energetic savings by limiting MEI in gestating beef cows. This data suggests confirms previous work in that the NRC vastly overestimates energy requirements in limit fed, high-energy diets. In addition, these experiments provide additional evidence towards previous reports that intake restriction shifts maintenance equilibriums to a lower level. Although no energetic efficiencies were observed by the inclusion of monensin, we still observed positive effects that suggest more research is needed on this topic matter. Furthermore, data were acquired that may help solve the logistical issues of feed-delivery in intensive systems.

Through nutritional manipulation, it appears that gains in production efficiency can be gained through intensifying beef cattle production. These opportunities not only provide opportunities for producers to dilute land investment costs, but could help with the sustainability of the industry. Further research is needed to confirm that a lower equilibrium is truly achieved, as well as gaining a better understanding on the positive effects monensin could have in intensified systems. Finally, work needs to be done in determining how much of the energetic savings is achieved from limit-feeding and how much is derived from energetic savings associated with lower activity levels.

LITERATURE CITED

Armsby, H. P., and J. A. Fries. 1919. Net energy values and starch values. J. Agr. Sci. 9:182-187.

Armstrong, D. G., K. L. Blaxter, N. M. Graham and F. W. Wainman. 1958. The utilization of the energy of two mixtures of steam-volatile fatty acids by fattening sheep. Br. J. Nut. 12:177-188.

Baldwin, R. L., L. J. Koong and M. J. Ulyatt. 1977. A dynamic model of ruminant digestion for evaluation of factors affecting nutritive value. Agr. Syst. 2:255-288.

Bell, N. L., T. A. Wickersham, V. Sharma, T. Edrington, and T. R. Callaway. 2015. Ionophores: a tool for improving ruminant production and reducing environmental impact. In: Livestock Production and Climate Change. Eds. P. K. Malik, R. Bhatta, J. Takahashi, R. Kohn, and C. S. Prasad. CABI Press, Oxfordshire, UK.

Bergen, W. G., and D. B. Bates. 1984. Ionophores: Their effect on production efficiency and mode of action. J. Anim. Sci. 58:1465-1483.

Benz, D. A., and D. E. Johnson. 1982. The effect of monensin on energy partitioning by forage-fed steers. J. Anim. Sci. 55:491-495.

Blaxter, K. L., J. L. Clapperton, and F. W. Wainman. 1966. Utilization of energy and protein of the same diet by cattle of different ages. J. Agric. Sci. Camb. 67:67–73.

Blaxter, K. L., and F. W. Wainman. 1961. The utilization of food by sheep and cattle. J. Agric. Sci. Camb. 57:419–425.

Boling, J. A., N. W. Bradley and L. D. Campbell. 1977. Monensin levels for growing and finishing steers. J. Anim. Sci. 44:867-871.

Bull, L. S., W. V. Rumpler, T. F. Sweeney and R. A. Zinn. 1979. Influence of ruminal turnover on site and extent of digestion. Fed. Proc. 38:2713-2719.

Burrell W. C. 1977. The effect of monensin in lactating beef cows in poor body condition receiving low levels of energy. Ph.D. Disseration. Texas A&M Univ., College Station, TX.

Burrin, D. G., C. L. Ferrell, J. H. Eisemann, R. A. Britton, and J. A. Nienaber. 1989. Effect of level of nutrition on splanchnic blood flow and oxygen consumption in sheep. Br. J. Nut. 62:23-34.

Burrin, D. G., C.L. Ferrell, R. A. Britton, and M. Bauer. 1990. Level of nutrition and visceral organ size and metabolic activity in sheep. Br. J. Nut. 64:439-448.

Camacho, L. E., C. O. Lemley, M. L. Van Emon, J. S. Caton, K. C. Swanson, and K. A. Vonnahme. 2014. Effects of maternal nutrient restriction followed by realimentation during early and midgestation on beef cows. I. Maternal performance and organ weights at different stages of gestation. J. Anim. Sci. 92:520-529.

Callaway, T. R., T. S. Edrington, J. L. Rychlik, K. J. Genovese, T. L. Poole, Y. S. Yung, K. M. Bischoff, R. C. Anderson, and D. J. Nisbet. 2003. Ionophores: their use as

ruminant growth promotants and impact on food safety. Curr. Issues Intest. Microbiol. 2003 4:43-51.

Capper, J. L., and D. J. Hayes. 2012. The environmental and economic impact of removing growth-enhancing technologies from U.S. beef production. J. Anim. Sci. 90:3527–3537.

Carlson, D. B., J. J. Reed, P. P. Borowicz, J. B. Taylor, L. P. Reynolds, T. L. Neville, D. A. Redmer, K. A. Vonnahme, and J. S. Caton. 2009. Effects of dietary selenium supply and timing of nutrient restriction during gestation on maternal growth and body composition of pregnant adolescent ewes. J. Anim. Sci. 87:669–680.

Chen, M. and M. J. Wolin. 1979. Effect of monensin and lasalocid-sodium on the growth of methanogenic and rumen saccharolytic bacteria. Appl. Enviro. Microbiol. 38:72-77.

Clanton, D. C., M. E. England, and J. C. Parrott III. 1981. Effect of monensin on efficiency of production in beef cows. J. Anim. Sci. 53:873-880.

Dennis, S. M., T. G. Nagaraja, and E. E. Bartley. 1981. Effects of lasalocid or monensin on lactate-producing or -using bacteria. J. Anim. Sci. 52:418-426.

Deswysen, A. G., W. C. Ellis, K. R. Pond, W. L. Jenkins, and J. Connelly. 1987. Effects of monensin on voluntary intake, eating and ruminating behavior, and rumen motility in heifers fed corn-silage. J. Anim. Sci. 67:827-834.

Dinius, D. A., M. S. Simpson and P. B. Marsh. 1976. Effect of monensin fed with forage on digestion and the ruminal ecosystem of steers. J. Anim. Sci. 42:229-234.

Ellis, J. L., J. Dijkstra, A. Bannink, E. Kebreab, S. E. Hook, S. Archibeque, and J. France. 2012. Quantifying the effect of monensin dose on the rumen volatile fatty acid profile in high-grain-fed beef cattle. J. Anim. Sci. 90:2717-2726.

Ferrell, C. L., and T. G. Jenkins. 1984. Relationships among various body components of mature cows. J. Anim. Sci. 58:222-233.

Ferrell, C. L., and T. G. Jenkins. 1985. Cow type and the nutritional environment: nutritional aspects. J. Anim. Sci. 61:725-741.

Ferrell, C. L., and J. W. Oltjen. 2008. ASAS Centennial Paper: Net energy systems for beef cattle- Concepts, application, and future models. J. Anim. Sci. 86:2779-2794.

Freetly, H. C., C. L. Ferrell, and T. G. Jenkins. 2000. Timing of realimentation of mature cows that were feed-restricted during pregnancy influences calf birth weights and growth rates. J. Anim. Sci. 38:2790-2796.

Freetly, H. C., and J. A. Nienaber. 1998. Efficiency of energy and nitrogen loss and gain in mature cows. J. Anim. Sci. 76:896-905.

Freetly, H. C., J. A. Nienaber, and T. Brown-Brandl. 2006. Changes in heat production by mature cows after changes in feeding level. J. Anim. Sci. 84:1429-1438.

Garrett, W. N., N. Hinman and G. A. Nader. 1980. Net energy of alfalfa as influenced by monensin. J. Anim. Sci. 51:361.

Garrett, W. N., and D. E. Johnson. 1983. Nutritional energetics of ruminants. J. Anim. Sci. 57:478-497.

Goodrich R. D., J. E. Garrett, D. R. Gast, M. A. Kirick, D.A. Larson, and J. C. Meiske. 1984. Influence of monensin on the performance of cattle. J. Anim. Sci. 58:1484-1498.

Gregory, K. E. 1972. Beef cattle type for maximum efficiency "Putting it all together." J. Anim. Sci. 34: 881.

Gresham, J. D., J. W. Holloway, W. T. Butts and J. R. McCurley. 1986. Prediction of mature cow carcass composition from live animal measurements. J. Anim. Sci. 63:1041-1048.

Grings E. E. and J. R. Males. 1988. Performance, blood and ruminal characteristics of cows receiving monensin and a magnesium supplement. J. Anim. Sci. 66:566-573.

Haaland, G. L., H. F. Tyrrell, P. W. Moe and W. E. Wheeler. 1982. Effect of crude protein level and limestone buffer in diets fed at two levels of intake on rumen pH Ammonia-nitrogen, buffering capacity and volatile fatty acid concentration of cattle. J. Anim. Sci. 55:943-950.

Heinrichs A. J., D. R. Buckmaster, and B. P. Lammers. 1999. Processing, mixing, and particle size reduction of forages for dairy cattle. J. Anim. Sci. 77:180-186.

Herd, D. B., and L. R. Sprott. 1998. Body condition, nutrition and reproduction of beef cows. Texas Agrilife Extension Service, College Station, TX. Retrieved from: http://animalscience-old.tamu.edu/beef-skillathon/pdf/nutrition-body-condition-nutrition.pdf. p. 4.

Hixon, D. L., G. C. Fahey, Jr., D. J. Kesler and A. L. Neumann. 1982. Effects of creep feeding and monensin on reproductive performance and lactation of beef heifers. J. Anim. Sci. 55:467-474.

Jenkins, T.G., and C.L. Ferrell. 1997. Changes in proportions of empty body depots and constituents for nine breeds of cattle under various feed availabilities. J. Anim. Sci. 75:95-104.

Joyner, A. E., L. J. Brown, T. J. Fogg, and R. T. Rossi. 1979. Effect of monensin on growth, feed efficiency and energy metabolism of lambs. J. Anim. Sci. 48:1065-1069.

Kammel, D.W. 1999. Design, selection, and use of TMR mixers. Proceedings of 10th Annual Florida Ruminant Nutrition Symposium. Gainesville, FL.

Kleiber, M. 1975. The Fire of Life and Introduction to Animal Energetics. Robert E. Krieger Publishing, Huntington, NY.

Klosterman, E. W., and C. F. Parker. 1976. Effect of size, breed and sex upon feed efficiency in beef cattle. Ohio Agr. Res. And Dev. Center Res. Bull. 1088, July.

Krause, D. O. and J. B. Russell. 1996. An rRNA approach for assessing the role of obligate amino acid-fermenting bacteria in ruminal amino acid deamination. Appl. Environ. Microbiol. 62:815-821.

Lam, P. S., S. Sokhansanj, X. Bi, C. J. Lim, L. J. Naimi, M. Hoque, S. Mani, A. R. Womac, X. P. Ye, and S. Narayan. 2008. Bulk density of wet and dry wheat straw and switchgrass particles. App. Eng. Agr. 24:351-358.

Lemenager R. P., F. N. Owens, K. S. Lusby, and R. Totusek. 1978a. Monensin, forage intake and lactation of range beef cows. J Anim. Sci. 47:247-254.

Lemenager R. P., F. N. Owens, B. J. Shockey, K. S. Lusby, and R. Totusek. 1978b. Monensin effects on rumen turnover rate, twenty-four hour VFA pattern, nitrogen components and cellulose disappearance. J Anim. Sci. 47:255-261.

Loerch, S. C. 1996. Limit-feeding corn as an alternative to hay for gestating beef cows. J. Anim. Sci. 74:1211-1216.

McLeod, K.R., and R. L. Baldwin. 2000. Effects of diet forage:concentrate ratio and metabolizable energy intake on visceral organ growth and in vitro oxidative capacity of gut tissues in sheep. J. Anim. Sci. 78:760-770.

Meyer, A. M., J. J. Reed, K. A. Vonnahme, S. A. Soto-Navarro, L. P. Reynolds, S. P. Ford, B. W. Hess, and J. S. Caton. 2010. Effects of stage of gestation and nutrient restriction during early to mid-gestation on maternal and fetal visceral organ mass and indices of jejunal growth and vascularity in beef cows. J. Anim. Sci. 88:2410-2424.

Moseley, W. M., M. M. McCartor and R. D. Randel. 1977. Effects of monensin on growth and reproductive performance of beef heifers. J. Anim. Sci. 45:961-968.

National Agricultural Statistics Service. 2014. United States Department of Agriculture Economics, Statistics, and Market Information System. Cornell University, Ithica, NY. Retrieved from: http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1017.

National Agricultural Statistics Service. 2015. United States Department of Agriculture Economics, Statistics, and Market Information System. Cornell University, Ithica, NY. Retrieved from: http://www.nass.usda.gov/Charts_and_Maps/Cattle/bcow.asp

NRC. 1981. Nutritional Energetics of Domestic Animals & Glossary of Energy Terms. Natl. Acad. Press, Washington, DC.

NRC. 2000. Nutrient Requirements of Beef Cattle. 7th rev. ed. Update. Natl. Acad. Press, Washington, DC.

Ortigues, I., M. Petit, J. Agabriel, and M. Vermorel. 1993. Maintenance requirements in metabolizable energy of adult, nonpregnant, nonlactating Charolais cows. J. Anim. Sci. 71: 1947−1956.

Ovchinnikov, Y. A. 1979. Physico-chemical basis of ion transport through biological membranes: ionophores and ion channels. Eur. J. Biochem. 94:321-336.

Pendlum, L. C., J. A. Boling, and N. W. Bradley. 1978. Levels of monensin with and without tylosin for growing-finishing steers. J. Anim. Sci. 47:1-5.

Pond, K. P. and W. C. Ellis. Effects of monensin on fecal output and voluntary intake of grazed coastal Bermudagrass. 1981. Beef Cattle Research in Texas, Texas Agr. Exp. Sta. p. 31.

Poos, M. I., T. L. Hanson and T. J. Klopfenstein. 1979. Monensin effects on diet digestibility, ruminal protein bypass and microbial protein synthesis. J. Anim. Sci. 48:1516-1524.

Potter, E. L., C. O. Cooley, L. F. Richardson, A. P. Raun, and R. P. Rathmacher. 1976. Effect of monensin on performance of cattle fed forage. J. Anim. Sci. 43:665-669.

Pressman, B. C. 1976. Biological application of ionophores. Ann. Rev. Biochem. 45:501-530.

Price Waterhouse Coopers Economics. 2013. World in 2050: The BRICs and beyond: prospects, challenges and opportunities. Accessed from http://www.pwc.com/gx/en/world-2050/assets/pwc-world-in-2050-report-january-2013.pdf.

Reynolds, C.K., H. F. Tyrell and P. J. Reynolds. 1991. Effects of diet forage-to-concentrate ration and intake on energy metabolism in growing beef heifers: whole body energy and nitrogen balance and visceral heat production. J. Nutr. 121:994-1003.

Richardson, L. F., A. P. Raun, E. L. Potter and C. O. Cooley. 1976. Effect of monensin in rumen fermentation *in vitro* and *in vivo.* J. Anim. Sci. 43:657-664.

Rosen, B. P. 1986. Recent advances in bacterial ion transport. Annu. Rev. Microbiol. 40:263-286.

Russell, J. B. and H. J. Strobel. 1989. Effect of ionophores on ruminal fermentation. Appl. Environ. Microbiol. 55:1-6.

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

Salfer, J. 2001. Mixer match. Choose the right TMR mixer based on feed, batch size, and management. In: Dairy Today, June/July, 2001. Pg. 8.

Sawyer, J. E., and T. A. Wickersham. 2013. Defining value and requirements in cow rations: What is a calorie worth? Dr. Kenneth S. and Caroline McDonald Eng Foundation Symposium, Lincoln, NE. p 31-36.

Schelling, G. T., H. R. Spires, G. E. Mitchell, Jr. and R. E. Tucker, 1977. The effect of various anti-microbials on amino acid degradation rates by rumen microbes. Fed. Proc. 37:411.

Seal, C. J., and C. K. Reynolds. 1993. Nutritional implications of gastrointestinal and liver metabolism in ruminants. Nutr. Res. Rev. 6:185-208.

Sprott, L. R., T. B. Goehring, J. R. Beverly and L. R. Corah. 1988. Effects of ionophores on cow herd production: A Review. J. Anim. Sci. 66:1340-1346.

Steen W. W., N. Gay, J. A. Boling, N. W. Bradley, J. W. McCormick and L. C. Pendlum. 1978. Effect of monensin on performance and plasma metabolites in growing-finishing steers. J. Anim. Sci. 46:350-355.

Supriya, B., J. Dong, P. C. Biplab, and T. E. S Dahms. 2012. Viscoelasticity in Biological Systems: A Special Focus on Microbes. In: Viscoelasticity - From Theory to Biological Applications. Ed. J. De Vicente. ISBN: 978-953-51-0841-2, InTech. Accessed at: http://www.intechopen.com/books/viscoelasticity-from-theory-to-biological-applications/viscoelasticity-in-biological-systems-a-special-focus-on-microbes.

Thornton, J. H., and F. N. Owens. 1981. Monensin supplementation and *in vivo* methane production by steers. J. Anim. Sci. 52:628-634.

Trubenbach, L. A. 2014. Effects of energy density and intake on maintenance requirements in beef cows. M.S. Thesis. Texas A&M Univ., College Station, TX.

Turner, H. A., R. J. Raleigh, and D. C. Young. 1977. Effect of monensin on feed efficiency for maintaining gestating mature cows wintered on meadow hay. J Anim. Sci. 44:338-342.

Turner, H. A., D. C. Young R. J. Raleigh, and D. ZoBell. 1980. Effect of various levels of monensin on efficiency and production of beef cows. J. Anim. Sci. 50:385-390.

United Nations Department of Economics and Social Affairs. 2012. The 2012 revision of the world population prospects. Accessed from http://esa.un.org/wpp/.

United States Department of Agriculture - Agricultural Marketing Service. 2014. Compiled by the Livestock Marketing Information Center. Accessed from http://www.extension.iastate.edu/AGDm/livestock/pdf/b2-12.pdf

United States Meat Export Federation. 2013. Total U.S. Beef Exports. Accessed from https://www.usmef.org/downloads/Beef-2004-to-2013.pdf.

van Nevel, C. J., and D. I. Demeyer. 1977. Effect of monensin on rumen metabolism *in vitro.* Appl. Enviro. Microbiol. 34:251-257.

van Nevel, C. J., and D. I. Demeyer. 1996. Control of rumen methanogenesis. Environmental Monitoring and Assessment. 42:73-97.

Van Soest, P. J. (1967). Development of a Comprehensive System of Feed Analyses and its Application to Forages. J. Anim. Sci. 26:119-128.

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

Webster, J. F., P. O. Osuji, F. White, and J. F. Ingram. 1975. The influence of food intake on portal blood flow and heat production in the digestive tract of sheep. Br. J. Nut. 34:125-139.

Wedegaertner T. C. and D. E. Johnson. 1983. Monensin effects on digestibility, methanogenesis and heat increment of a cracked corn-silage diet fed to steers. J. Anim Sci. 57:168-177.

Wolin, M. J. 1960. A theoretical rumen fermentation balance. J. Dairy Sci. 43:1452-1459.

Wood, K. M., B. J. Awda, C. Fitzsimmons, S. P. Miller, B. W. McBride, B. W. and K. C. Swanson. 2013. Influence of pregnancy in mid-to-late gestation on circulating metabolites, visceral organ mass, and abundance of proteins relating to energy metabolism in mature beef cows. J. Anim. Sci. 91:5775-5784.

Yokoyama, M. G. and K. A. Johnson. 1988. Microbiology of the rumen and intestine. In *The Ruminant Animal: Digestive Physiology and Nutrition.* Church, D. C. ed. Englewood Cliffs, NJ: Waveland Press, 1988, pp 125-144.