AN EVALUATION OF FEEDYARD MANAGEMENT STRATEGIES TO OPTIMIZE

CATTLE FEEDING PERFORMANCE AND ANIMAL HEALTH

A Dissertation

by

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

DOCTOR OF PHILOSOPHY

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August 2019

Major Subject: Animal Science

ABSTRACT

End products of ruminal fermentation differ based on availability of structural (fiber) and nonstructural (starch) carbohydrates. Two experiments were conducted to evaluate the effect of dietary components (starch and fiber) on energy metabolism, nutrient digestibility, growing and finishing phase performance, and carcass composition.

In an initial metabolism experiment, 10 yearling steers were used in a 5×5 replicated Latin square. Experimental diets were formulated to contain an increasing proportion of concentrate with a concomitant decrease in forage resulting in diets of disparate forage-to-concentrate (**F:C**) ratios. Fecal and urinary energy loss decreased ($P < 0.04$) while methane energy loss responded quadratically ($P < 0.01$), increasing and then decreasing, as the F:C decreased. As a result, the efficiency of the conversion of digestible energy to metabolizable energy increased quadratically ($P < 0.01$) as the F:C decreased.

In a follow up feedlot experiment, light-weight (initial BW = 175.59 ± 1.3 kg) steer calves (n = 970) were fed diets of disparate starch content for a 119 d growing period and then finished on a common diet. Growing diets were formulated to contain 1 of 3 levels of starch on a dry matter basis. The concentration of starch in the growing diet did not affect ADG or DMI during the growing ($P \geq 0.15$) or finishing period. ($P \geq 0.20$) At the end of the growing period, 12th rib fat linearly decreased ($P = 0.04$) as starch level increased while marbling score was not affected ($P = 0.57$). Final HCW and 12th rib fat were not different ($P \geq 0.66$).

An evaluation of cattle source and season of arrival on feedlot on performance and animal health outcomes was also performed. A commercial feedlot database of 230 lots representing 15,659 cattle was used. The cattle were classified as originating from Mexico or the United States and date of arrival to the feedlot was used to assign season of arrival. Average daily gain exclusive of deads was greater in native sourced compared to Mexican sourced cattle for all seasons of arrival ($P = 0.01$). Total death loss was greater in native compared to Mexican origin cattle in the Summer and Fall ($P < 0.01$), but were similar among cattle country of origin during the Spring and Winter ($P \geq 0.28$).

DEDICATION

To my daughter Steeley. You can do hard things. I love you.

I would also like to dedicate this Dissertation to Dr. Hollis Klett. Thank you will never

be enough.

ACKNOWLEDGEMENTS

I am now fully aware of the true meaning of the expression, "It takes a village to raise a child." However, I can also say that it takes a village to produce a Ph.D. I would like to acknowledge my tribe.

My committee members: Dr. Tryon Wickersham, Dr. Jason Sawyer, Dr. Stephen Smith, and Dr. Kristin Hales. Dr. Wickersham, I will be forever grateful for the chance that you took on me 8 years ago in ANSC 408. Your influence and mentorship have shaped the course of my life and you have gently guided me into the woman that I was always capable of becoming – even when I didn't believe it myself. The opportunities that you have given me, from pushing me out into the industry to allowing me to pursue this Ph.D., have allowed me to create a life I always dreamed of but never thought possible. Dr. Sawyer, thank you for always making time for me among your endless list of job titles and responsibilities. Thank you for making me and this degree a priority. Thank you for cultivating my mind as a thinker and philosopher when I would come to you with 1 question and leave with a million more. I can appreciate the importance of those lessons now. Dr. Smith, I feel incredibly blessed to have had the opportunity to work with and learn from you over the past 3 years. Your teaching methods and passion for what you do created in me a love for Biochemistry that I never thought was possible. Ironically, when I designed Experiment 2 of this Dissertation, I did not realize that I had one of the worlds leading experts on fat deposition as a member of my committee, but God has a great sense of humor. And to Dr. Hales, in addition to a mentor and member

of my committee, thank you for being my *friend* through this process. I am humbled by the opportunity that you gave me to complete an experiment with you at MARC. Thank you for your faith and trust in me and my abilities as a researcher.

I am forever indebted to the many graduate students that filmed and uploaded lectures for me, allowed me to help with their studies so that I could further my research experience, and completed hours of lab work for me. These include Jessica Baber, Courtney Hemphill-Truelock, Levi Trubenbach, Vinicius Briani, Libby Schneider, and Jodi Cox. Also, to the MARC crew, Angela Menke, Nikki Krupicka, and Butch Hassler. 250 fecal bags washed, 250 totes weighed and washed, over 3 tons of feed weighed, and I am grateful for every single second that I got to spend with y'all.

To my parents, Ray and Susan Hight. Without the support that you have provided for so many years and in so many ways, I absolutely would not be where I am today. There have been some hard lessons along the way, which I attribute to my stubbornness that I get from Dad, but they have made me who I am today and for that I am grateful. You each set an example of sacrificial love for me and Andrew and I hope that I can do the same for Steeley. Thank you for never letting me give up and teaching me that with hard work you can achieve anything that you want to in this life.

And lastly, to my husband Clay. YOU have made the ultimate sacrifice throughout this experience. If you had not made me pinky promise you that I would finish this degree, I probably would have never completed it. You pushed me every single day for the past 5 years, through my tears and temper tantrums, you remained my rock. Like everything we do in life, we earned this degree together.

CONTRIBUTORS AND FUNDING SOURCES

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CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

Introduction

Of the macronutrients, carbohydrates make up the largest proportion of beef cattle diets. Based on their chemistry, carbohydrates can be classified as either fiber (NDF) or non-fiber (non-NDF) or often structural and nonstructural, respectively. Fiber is generally located in the plant cell wall which consists of cellulose, hemicellulose, and lignin. Lignin is not a carbohydrate; however, it is closely associated with and negatively affects the digestibility of NDF and acid detergent fiber (ADF). Non-fiber carbohydrates are found in the cell contents of a plant and are comprised of organic acids, water soluble carbohydrates, and starch. Like lignin, organic acids are not carbohydrates although they are considered part of the non-NDF fraction because they are utilized as energy substrates and are more closely related to carbohydrates than to fat or protein in terms of their digestion characteristics (NASEM, 2016). The proportion of cellulose, hemicellulose, and lignin within the NDF fraction varies among feedstuffs; however, starch is the main nonstructural carbohydrate in plants.

Starch and cellulose are both polymers of glucose; however, the linkages forming the glycosidic bond between glucose molecules differ. Starch can be either a branched or linear polymer of glucose connected by α-1,4 or 1,6 linkages. Cellulose is a linear polymer of glucose connected by β-1,4 linkages while hemicellulose can be comprised of various monomers such as xylose, arabinose, galactose, and mannose also connected

in β-1,4 linkages. Mammalian digestive enzymes cannot hydrolyze β-1,4 bonds,1

therefore, hydrolysis and subsequent fermentation by ruminal microbes are required for

the ruminant to derive energy from fiber carbohydrates.

Fermentation of carbohydrates to volatile fatty acids

The predominate microorganisms found in the rumen are bacteria, protozoa, and

fungi. Enzymes produced by these microorganisms are used to degrade ingested

carbohydrates into monomers with glucose being hydrolyzed from starch and cellulose.

Glycolysis in ruminal microorganisms yields pyruvate, which is either decarboxylated to

acetyl-CoA, carboxylated to oxaloacetate, or can be reduced to lactate. Conversion of

pyruvate to acetyl-CoA leads to the production of acetate or butyrate while oxaloacetate

is used to produce propionate (Figure 1.1). Major end products of fermentation include

volatile fatty acids (acetate, propionate, and butyrate), methane, hydrogen, carbon
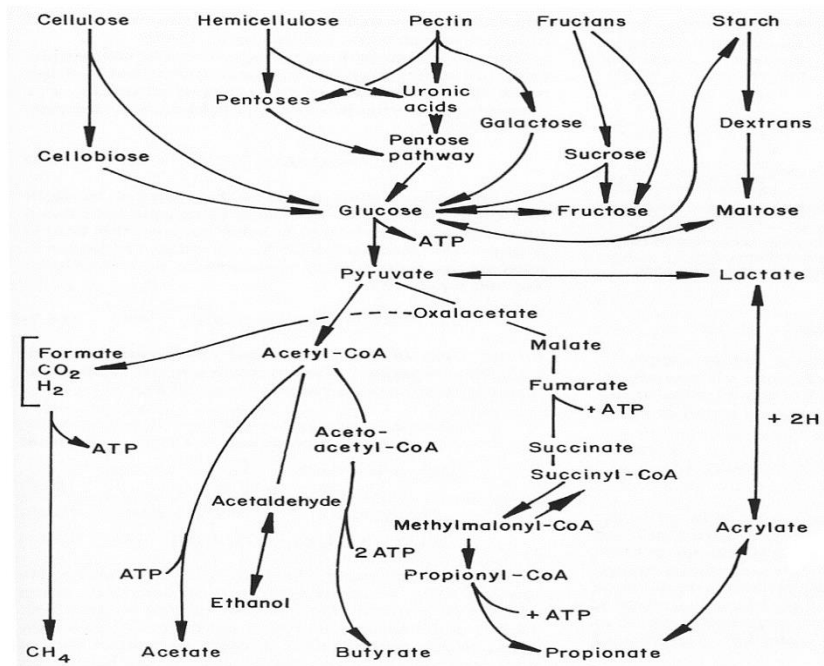
Figure 1.1 Pathway of fermentation of carbohydrates to volatile
fatty acids (Reprinted from Smith, 2016)

dioxide, and to a lesser degree lactate. Microbial crude protein is also produced as microbes utilize energy from carbohydrate fermentation to synthesize proteins, with ammonia being produced as a waste product.

Volatile fatty acids serve as the primary energy source for ruminants (Bergman, 1990). Absorbed across the rumen wall into the blood stream these compounds are used for productive functions such as maintenance, growth, or lactation, with diverging degrees of efficiency (Armstrong and Blaxter, 1957a, b). The analysis of 72 calorimetric experiments in which the percentage of hay and flaked corn varied from 0 to 100% indicated that the partial efficiency of use of metabolizable energy (ME) for growth (k_g) was negatively correlated with the molar proportions of acetic acid in the rumen fluid. The efficiency of use of acetic, propionic, and butyric acids when infused individually in the rumen of fattening sheep were 32.9, 56.3 and 61.9%, respectively (Blaxter and Wainman, 1964). Relative proportions of VFA produced are dependent on the substrates available to the rumen microorganisms for fermentation. Generally, fermentation of fiber by cellulolytic bacteria results in production of acetate and butyrate while fermentation of starch by amylolytic bacteria produces propionate. Starch is rapidly fermented in the rumen and results in a decrease in ruminal pH as the production of VFA exceeds absorption. This decrease in pH negatively affects the cellulolytic bacteria population and results in a decrease in the acetate-to-propionate ratio.

Bioenergetics

Utilization of energy in animals has been a subject of research for centuries. In 1780, Lavoisier and La Place related metabolism and combustion by establishing the

relationship between oxygen use, carbon dioxide production, and heat production (reviewed by Ferrell and Oltjen, 2008). Subsequently, the laws of thermodynamics were developed in the 1840s. The first law of thermodynamics states that energy can neither be created nor destroyed but can be changed from one form to another. The second law states that all forms of energy are convertible to heat. These laws and the law of Hess make up the foundation on which all measurements of nutritional energetics are made.

Gross energy (GE), or heat of combustion, is the energy released as heat when an organic substance is completely oxidized to carbon dioxide and water (NASEM, 2016). Gross energy of a feedstuff is related to chemical composition i.e., the relative proportions of carbohydrate, protein, and lipid, and provides little information regarding the availability of energy to the animal. In ruminants, GE obtained through feed consumption is lost via fecal and urinary excretion and through the production and subsequent loss of methane and heat. Energy partitioning in beef cattle follows that GE minus the energy lost in the feces (FE) is defined as digestible energy (DE) such that DE = GE - FE. Fecal energy losses range from 40-65% of GE for mature, weathered forages high in fiber to 15-20% for processed cereal grains (NASEM, 2016). Metabolizable energy is DE minus urinary energy (UE) and gaseous energy (GASE) losses. Methane is the primary source of GASE loss and is produced during feedstuff fermentation. Heat energy (HE) is the final energetic loss and the remainder is retained energy (RE), the energy available for tissue growth, lactation, or gestation. Energy balance is represented using the equation ME = HE + RE.

Development of the California Net Energy System

In the early 1960s, it was established that the partial efficiency of ME use for maintenance (k_m) is greater than k_g (Kleiber, 1961). This led to the development of the California Net Energy System (CNES; Lofgreen and Garrett, 1968). The CNES was the first to assign separate net energy (NE) values to feeds, either for maintenance (NE_m) or gain (NE_g) and is the predominant energy system used for cattle today. Five original comparative slaughter studies, where cattle were fed common diets at two or more levels of ME intake and RE was determined after slaughter, were used to derive the equations comprising the CNES (Lofgreen and Garrett, 1968). Although some NE_m and NE_g values for feedstuffs were directly measured and are listed in the CNES, most have been derived from ME using cubic equations established by Garrett (1980).

These equations were developed from a much larger database of 72 comparative slaughter studies and were based on a constant factor of 0.82 for the conversion efficiency of DE to ME (Garrett, 1980). Subsequently, these equations were incorporated into the NRC (1984). However, the NRC (1996) issued a precautionary statement that the relationship between DE and ME can vary considerably among feed ingredients. Data summarized by Vermorel and Bickel (1980) clearly indicate that the ME:DE ratio ranged from 0.82 to 0.93 in growing cattle and was dependent on age, dietary concentrate level, and intake. More recent data (Hales et al., 2014, 2015a, 2015b, and 2017) also demonstrated a conversion efficiency of greater than 0.9 for feedlot diets. The NASEM (2016) recognized the inaccuracies associated with a constant conversion factor and attempted to apply the equation ME = $(1.01 \times DE) - 0.45$ (NRC, 2001) to

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beef cattle diets. Use of this equation resulted in a substantial and unrealistic overprediction of animal daily bodyweight gain. Therefore, the equation ME = 0.82 DE was retained.

Predicting bodyweight gain requires accurate estimation of RE. If feed ME values are biased by using the 0.82 conversion, the cubic equations used to calculate dietary NE_m and NE_g (RE) would be affected (Galyean et al., 2016). This can be problematic for cattle feeders that rely on these equations for approximating animal feeding performance and determining harvesting endpoints. Galyean et al. (2016) compiled data consisting of 87 treatment means from 23 published papers utilizing beef or dairy animals in which direct measurements of fecal, urinary, and methane losses were made with respiration calorimetry. The linear regression equation developed by these authors was ME = $0.9611 \times$ DE $- 0.2999$, in which ME and DE are expressed in megacalories per kilogram of DM. However, other dietary factors that modify ruminal fermentation, such as the concentration of dietary NDF and starch, might alter this linear relationship.

Effects of the forage-to-concentrate ratio on energy metabolism

In 1898, Zuntz and Hageman first noted the correlation between diet fiber content and increased loss of metabolizable energy as heat energy (Reynolds et al., 1991). Later, the effects of diet fiber content and metabolizable energy density on the efficiency of utilization of metabolizable energy for tissue gain were described by Blaxter and Wainman (1964), although, the physiological basis for these differences was still unclear.

Reynolds et al. (1991) utilized seven Hereford × Angus heifers fed diets differing in forage-to-concentrate ratio at two levels of metabolizable energy intake to assess whole body energy metabolism. Diets contained approximately 75% alfalfa:25% concentrate or 25% alfalfa:75% concentrate and were fed at 0.586 and 1.13 MJ ME per kilogram of $BW^{0.75}$ which was approximately one- and two-times maintenance energy intake, respectively. The experiment was split into two trials. In trial 1, four heifers received the 75% alfalfa diet initially and in trial 2 three heifers received the 75% concentrate diet initially. Intake levels were alternated within dietary treatment groups and comparisons of intake effects were made within diet periods. The interaction between diet × intake level was not significant for any of the energy utilization components measured. For the main effect of diet, fecal energy excretion, urinary energy excretion, methane energy losses, and heat energy were lower when heifers were fed the 75% concentrate vs. the 75% alfalfa diet. Intake also had a significant effect on energy utilization such that fecal, urinary, and methane energy losses were greater at the higher level of intake.

In order to understand how the forage-to-concentrate ratio and ad libitum versus restricted feeding affects energy output, Kirkpatrick et al. (1997) used six Charolais cross steers in a 3 × 2 factorial design. Treatments consisted of three diet types and two energy levels. Diet types were 1) unsupplemented high digestibility grass silage offered ad libitum (**HD**), 2) low digestibility grass silage offered ad libitum and supplemented with sufficient cereal-based concentrates to provide the same estimated ME intake as diet 1 (**LDC**), and 3) high digestibility grass silage supplemented with concentrates at

the same forage-to-concentrate ratio as diet 2 and with intake restricted to the same ME intake as diets 1 and 2 (**HDC**). Thus, treatment 2 had the same forage-to-concentrate ratio as the restricted diet in treatment 3 but was offered ad libitum as in treatment 1. Fecal energy loss as a proportion of GE intake was higher for animals offered the LDC diet than for those offered HD or HDC diets. Urinary energy loss was significantly higher in cattle offered HD diets than in those offered LDC or HDC. Diet HDC had a significantly higher ME:DE ratio than HD or LDC.

Fecal and methane energy losses are the two greatest contributors to differences in ME for diets of varying forage-to-concentrate ratio. When alfalfa hay was decreased and dry-rolled corn was increased in diets fed ad libitum to MARC II composite breed steers, fecal and methane energy loss as a percentage of GE intake decreased linearly (Hales et al., 2014). Although the NASEM (2016) retained the equation $ME = DE \times 0.82$, previous research has demonstrated that energy output, specifically methane production, is dependent on relative amounts of dietary fiber and starch.

Effects of dietary starch in backgrounding diets on feeding performance and carcass characteristics

Backgrounding programs allow cow-calf producers to add value to early-weaned calves, primarily through weight gain, and can increase annual gross revenue. Backgrounding is as diverse as calves grazing wheat, being fed hay or corn silage, or being limit-fed a high-concentrate diet (Pritchard, 2013). Various management practices during the growing phase can affect finishing phase performance; therefore, managing early-weaned calves to avoid potential price discounts is essential. Many production systems exist to grow early-weaned calves before finishing and research has been

conducted investigating the effects of these different production systems on finishing performance and carcass characteristics.

In 3 trials, Loerch (1990) compared the effects of restricted intake of high-concentrate diets vs ad libitum intake of corn silage-based diets during the growing phase on feedlot cattle finishing performance. For experiments 1 and 3, finishing performance was not affected by source of energy during the growing period. Average daily gain and G:F were improved for steers fed the restricted-intake diet in the growing period during experiment 2.

Immediately placing early-weaned calves on a high-energy diet allows for rapid and efficient growth; however, considerable amounts of energy are still partitioned to subcutaneous fat deposition and physiological maturity is more rapidly achieved resulting in decreased final weights (Schoonmaker et al., 2001 and 2002). Kilograms of live or carcass weight added drives profitability for feedyards; therefore, calves coming out of background facilities usually receive a price discount compared to traditionally weaned or yearling cattle due to lighter finishing weights (Smith, 2000). Similarly, calf-feds managed to achieve high rates of gain (> 1.25 kg per day) during the growing period are often fatter upon feedlot entry and feedlot managers have a general perception that ADG and G:F are poorer during finishing as body fat at arrival increases (McCurdy et al., 2010). Inclusion of cereal grains of greater than 20% of dietary DM in growing diets is believed to result in excessive fat deposition – possibly due to increased propionate production, a glucogenic precursor, from the fermentation of starch.

Lancaster et al. (2014) compiled a total of 10 articles comprising 13 experiments to compare level of dietary starch during backgrounding on subsequent finishing performance and carcass characteristics. In these experiments, the medium or high-starch diets were limit-fed to achieve similar NEg intake and rate of body weight gain as the low-starch diet fed to *ad libitum* intake. This removed any confounding effect of energy intake and growth rate. Finishing performance was similar between medium and high starch diets with no differences for ADG, DMI, or G:F. In addition, there were no differences in LM area, backfat thickness, yield grade, or marbling score. Results were similar when comparing finishing performance of steers fed low or high starch diets during the backgrounding phase. There were no differences in final BW, DMI, G:F, LM area, backfat thickness, yield grade and marbling score.

As previously stated, fat accumulation during the growing phase driven by the energy density of the backgrounding diet, is believed to negatively affect ADG and G:F during the finishing period as well as final live BW and HCW. McCurdy et al. (2010) utilized 4 growing programs designed to result in different rates of fat accumulation but similar rates of BW gain to determine the effects on subsequent finishing performance, carcass merit, and body composition. Treatment groups were: 1) ad libitum fed a high-concentrate diet 2) grazed on wheat pasture, 3) fed a sorghum silage-based diet, or 4) program fed a high-concentrate diet. During the growing phase, the program fed steers accreted fat (g/d) and energy (Mcal/d) in the offal and empty body at a greater rate the wheat pasture steers, which is consistent with the objective of the experiment. The program fed steers also had greater ADG and G:F than the wheat pasture steers during

the finishing phase. Final live BW, HCW, dressing percent, and marbling score were similar for the program and wheat pasture fed steers. Those authors concluded that growing programs that increase fat composition of feeder calves did not negatively affect subsequent finishing performance.

CHAPTER II

EFFECTS OF FORAGE-TO-CONCENTRATE RATIO ON CONVERSION OF

DIGESTIBLE ENERGY TO METABOLIZABLE ENERGY IN GROWING BEEF

STEERS

Synopsis

Metabolizable energy (**ME**) is calculated from digestible energy (**DE**) using a

constant conversion factor of 0.82. Methane and urine energy losses vary across diets

and DMI levels suggesting that a static conversion factor fails to describe the biology.

To quantify the effects of the forage-to-concentrate (**F:C**) ratio on efficiency of

conversion of DE to ME, 10 Angus steers were used in a 5×5 replicated Latin square.

Dry-rolled corn was included in experimental diets at 0, 22.5, 45.0, 67.5, and 83.8% on a

DM basis, resulting in a high F:C (**HF:C**), intermediate F:C (**IF:C**), equal F:C (**EF:C**),

low F:C (**LF:C**) and a very low F:C (**VLF:C**), respectively. Each experimental period

consisted of a 23-d diet adaption followed by 5 d of total fecal and urine collections and

a 24-h gas exchange collection. Contrasts were used to test the linear and quadratic

effects of the F:C. There was a tendency ($P = 0.06$) for DMI to increase linearly as F:C

decreased. As a result, gross energy intake (**GEI**) increased linearly ($P = 0.04$) as F:C

decreased. Fecal energy loss expressed as Mcal/d ($P = 0.02$) or as a proportion of GEI (P

< 0.01) decreased as F:C decreased, such that DE (Mcal/d and Mcal/kg) increased

linearly ($P < 0.01$) as F:C decreased. As a proportion of GEI, urine energy decreased

linearly ($P = 0.03$) as F:C decreased. Methane energy loss as a proportion of GEI

responded quadratically ($P < 0.01$), increasing from HF:C to IF:C then decreasing thereafter. Efficiency of DE to ME conversion increased quadratically ($P < 0.01$) as F:C decreased, ranging from 0.86 to 0.92. Heat production (Mcal) increased linearly ($P < 0.04$) as F:C decreased, but was not different as a proportion of GEI ($P \geq 0.22$). As a proportion of GEI, retained energy responded quadratically ($P = 0.03$), decreasing from HF:C to IF:C and increasing thereafter. Dry matter, OM, and NDF digestibility increased linearly ($P < 0.01$) and starch digestibility decreased linearly ($P < 0.01$) as the F:C decreased. Total nitrogen retained tended to increase linearly as the proportion of concentrate increased in the diet ($P = 0.09$). In conclusion, the efficiency of conversion of DE to ME increased with decreasing F:C due to decreasing methane and urine energy loss. The relationship between DE and ME is not static, especially when feeding high-concentrate diets.

Introduction

Estimates of energy available from feeds are required for determining the quantity of a given feed needed to meet maintenance energy requirements and for growth models used to predict body weight gain. In beef cattle, GE obtained through feed consumed is lost via fecal and urinary excretion, and through the production and loss of methane and heat. The amount of energy lost through a single route varies depending on diet type; however, the sum of these losses often represents a large proportion of the GE intake. For this reason, the California Net Energy System (**CNES**) was created and described by Lofgreen and Garrett (1968). The CNES was the first beef cattle feeding system to assign separate net energy values to feeds, either for

maintenance or production, and is the predominate energy system used for beef cattle in the United States today.

Comparative slaughter studies were used to derive feed net energy values on a limited number of selected feeds during development and refinement of the CNES. It is infeasible to directly quantify net energy by comparative slaughter or calorimetric techniques for each feedstuff available, or potentially available, for beef cattle. Therefore, most net energy values used today are derived from ME using cubic equations established by Garrett (1980). Indeed, the NASEM (2016) utilizes these equations for the determination of the net energy values found in its standard feed library.

As an input into these equations, ME is estimated using a fixed efficiency of 0.82 of DE (Agricultural Research Council, 1965; Garrett, 1980). However, methane and urinary energy losses vary across diets and DMI levels, suggesting that the true relationship between DE and ME is not constant. The objective of this study was to quantify the effects of decreasing dietary forage and increasing concentrate on the efficiency of conversion of DE to ME.

Materials and Methods

The experimental protocol was approved by the U.S. Meat Animal Research Center Institutional Animal Care and Use Committee.

Ten purebred Angus yearling steers (365 ± 15.95 kg of initial BW) were used in a 5×5 replicated Latin square. Each of the 5 experimental periods consisted of a 23-d diet adaption followed by 5 d of total fecal and urine collections. Prior to the start of the

first period, cattle were trained to metabolism stanchions, fecal bags, urine harnesses, and headbox respiration calorimeters in order to facilitate collection procedures. After adaptation to the metabolism facility, steers were stratified by BW and assigned to 1 of 2 Latin square replicates.

Dietary treatments were formulated to contain an increasing proportion of dry-rolled corn (**DRC**) with a concomitant decrease in forage supplied by corn silage and alfalfa hay (Table 1). Dry-rolled corn was included in the experimental diets at 0, 22.5, 45, 67.5 and 83.8% on a dry matter (DM) basis resulting in a high F:C (**HF:C**), intermediate F:C (**IF:C**), equivalent F:C (**EF:C**), low F:C (**LF:C**) and a very low F:C (**VLF:C**), respectively. Urea was added (0.20% DM) to the VLF:C treatment in order to compensate for the decreased dietary CP associated with the reduced inclusion of alfalfa hay.

During diet adaptation, the cattle were housed in a partially enclosed group pen and fed individually using Calan-Broadbent electronic head gates (American Calan, Inc., Northwood, NH). Cattle were adapted to the experimental diets by mixing the previous diet with the new diet for up to 7 days to prevent acidosis when transitioning from diets of less to more concentrate. All steers were on their final diet by day 8 of each adaption period. Throughout the experiment, steers were fed once daily at 0800 and were provided *ad libitum* access to feed and fresh water. On d 0 of each collection period, the steers were moved into the metabolism barn and housed in individual stanchions (87 × 214 cm) where urine and feces were collected for a total of 5-d.

During the collection period, orts were removed from the feed box 24-h after the initial diet offering, weighed, and a subsample was saved for subsequent lab analysis. A 100 g sample of each experimental diet was also collected daily and composited within period for later determination of DM, GE, OM, CP, NDF, ADF, and starch. Total feces were collected into a canvas bag attached to a harness secured around the heart girth of each steer as described by Tolleson and Erlinger (1989). A custom rubber funnel was placed under the sheath, secured by an elastic strap over the back of the steer, and urine was collected into a polypropylene jug under vacuum. To prevent ammonia losses, 100 mL of 3.7 N HCl was added to each urine jug before daily collections to ensure the pH remained < 5.0. Contents of the fecal bags and urine jugs were weighed each morning at approximately 0700, thoroughly mixed, and a 3% aliquot of each was composited by steer and stored at -20°C for subsequent analysis.

Gas exchange was measured over a 24-hour period on d 2 for one-half of the experimental animals and on d 3 for the remaining animals. Each treatment was equally represented on each day of measurement. O_2 consumption, CH_4 production, and CO_2 production were determined using portable respiration calorimeters designed for indirect, open-circuit calorimetry. Portable headboxes were $0.76 \times 0.76 \times 1.78$ m and contained a 0.76×117 cm opening on one side. Steers were given their daily feed allotment inside the calorimeter which was equipped with an automatic water bowl. A vinyl hood was placed over the steers neck and used to create a barrier between the inside of the box and outside air. Samples of gases entering and exhausting from each box were collected into polytheylene-aluminum-Mylar laminate bags and analyzed for

O_2, CO_2, and CH_4 as described by Nienaber and Maddy (1985). Values for each of these variables along with urinary nitrogen were then used to calculate heat production (**HP**) using the Brouwer (1965) equation.

Diets, orts, and fecal samples were partially dried in a forced-air oven for 96 h at 55°C, allowed to air-equilibrate, and then weighed for determination of partial DM. Samples were then ground through a 1-mm screen using a Wiley mill (Thomas Scientific, Swedesboro, NJ) and further dried at 105°C for 24 h for determination of DM. Organic matter was determined as the loss in weight following combustion in a muffle furnace for 8 h at 450°C. Analysis for NDF and ADF was performed sequentially using an Ankom Fiber Analyzer (Ankom Technology Corp., Macedon, NY). Energy values for diet, ort, and fecal samples were determined on dry samples by bomb calorimetry using a Parr 6300 Calorimeter (Parr Instrument Co., Moline, IL). To analyze urinary energy, cotton rounds were weighed and placed into bomb calorimeter crucibles. Standards were created using the average energy content of the cotton rounds. Four mL of urine were added to the crucible and differences in energy content were attributed to the urine. The difference of the urine and standard was divided by the mL of urine added to determine calories per mL of urine. Diet, orts, fecal, and urine samples were sent to a commercial laboratory (SDK Labs, Hutchinson, KS) for analysis of CP and starch (not including urine).

One animal was removed from the experiment during period 3 due to unwillingness to cooperate with the collection procedures resulting in 1 steer for the given treatment for that period. An alternate animal was used for the remaining 2

periods. The alternate was previously adapted to the experimental procedures and the same dietary treatment assignments as the steer that was removed and had, therefore, received the same diet in each period.

Calculations

Methane and heat production energy losses were calculated as:

CH_4, Mcal = $(9.45 \times CH_4) \div 1000$

Heat production, Mcal = $((3.866 \times O_2) + (1.2 \times CO_2) - (0.518 \times CH_4) - (1.413 \times N)) \div 1000$

where:

CH_4 = Methane production (L/d)

O_2 = Oxygen consumption (L/d)

CO_2 = Carbon dioxide production (L/d)

N = Urinary nitrogen excretion (g/d)

DE, ME, and retained energy (RE) were calculated as follows:

DE, Mcal = gross energy intake (GEI) – fecal energy (FE)

ME, Mcal = DE – (urinary energy (UE) + CH_4)

ME:DE = ME, Mcal/ kg DM ÷ DE, Mcal/kg DM

RE, Mcal = ME – HP

where:

GEI = DMI (g/d) × diet GE (Mcal/g DM)

FE = Fecal production (kg DM/d) × fecal energy (Mcal/kg DM)

UE = Urine production (kg/d) × urinary energy (Mcal/kg)

CH$_4$ = Methane production (Mcal)

HP = Heat production (Mcal)

Nitrogen (**N**) retained was calculated as:

N retained (g) = N intake (g) – N excreted in feces (g) – N excreted in urine (g)

Digestibility of DM, OM, NDF, ADF, and starch were calculated as:

$$\text{Digestibility, \%} = \left(\frac{\text{Intake} - \text{Fecal}}{\text{Intake}}\right) \times 100$$

where:

Intake = DMI (kg/d) × dietary nutrient concentration (% DM)

Fecal = Fecal production (kg DM/d) × fecal nutrient concentration (% DM)

Statistics

All data were analyzed as a replicated Latin square design using the Mixed
procedure of SAS (SAS Inst. Inc., Cary, NC). The model included fixed effects of period
and diet treatment and the random effects of square and steer within square. Contrast
statements were used to test the linear and quadratic effects of the F:C. Effects were
considered significant at *P*-value of ≤0.05, with tendencies declared at *P*-values between
0.05 and 0.10.

Results

Formulated ingredient composition and analyzed nutrient content (DM basis) are
presented in Table 1. Diets were formulated with increasing concentrations of DRC that
replaced a combination of alfalfa hay and corn silage as the F:C ratio decreased. Gross
energy content ranged from 4.22 to 4.29 Mcal/kg and was formulated to be similar
across diets. However, the DM content of the experimental diets differed, and ranged

from 46.8% to 83.8%, where corn silage inclusion decreased from 62% of the dietary DM in the HF:C treatment to 0% for the LF:C and VLF:C treatments. The decrease in corn silage was the cause of the large differences in DM. By design, the CP concentration was similar across diets – ranging from 12.0% to 12.8%. As expected, the NDF and ADF content decreased as the F:C decreased. The VLF:C contained 53% more starch than the HF:C.

Dry matter intake tended to increase linearly (Table 2; $P = 0.06$) as the F:C decreased. Consequently, GE intake (Mcal) also increased linearly ($P = 0.04$) as the concentration of DRC in the diet increased. Fecal energy loss expressed as Mcal ($P = 0.02$) or as a proportion of GE intake ($P < 0.01$) decreased linearly as F:C decreased. The DE of the diets expressed as Mcal or Mcal/kg increased linearly ($P < 0.01$). Urinary energy loss (Mcal or as % of GE or DE intake) decreased linearly ($P \leq 0.04$) as the proportion of forage decreased and concentrate increased in the diet. Methane energy loss in Mcal ($P = 0.01$) and as a proportion of GE or DE intake responded quadratically ($P < 0.01$) increasing from HF:C to IF:C then decreasing thereafter. As F:C decreased, ME intake (Mcal) increased linearly ($P < 0.01$), but ME density of the diet (Mcal/kg DM) responded quadratically, where ME concentration was similar for HF:C, IF:C, and EF:C, but increased thereafter as F:C ratio decreased. Conversion efficiency of DE to ME increased quadratically ($P < 0.01$) as the F:C decreased, ranging from 85.8 to 91.9. The linear regression equation developed from this data set for converting DE to ME was: ME = $1.0504 \times$ DE – 0.481 where ME and DE are expressed in Mcal/kg of DM (r^2 = 0.940; Figure 1). Heat production (Mcal) increased linearly ($P = 0.04$) as F:C

decreased in the diet, but was not different as a proportion of GE intake ($P = 0.22$). Megacalories of RE increased linearly ($P < 0.01$) as F:C decreased, while RE as a proportion of GE intake responded quadratically ($P = 0.03$) in that it decreased from HF:C to IF:C then increased at an increasing rate for each dietary treatment thereafter.

Intake of N increased linearly ($P = 0.01$; Table 3) as F:C decreased. Nitrogen excreted in the feces and total grams of N excreted responded quadratically ($P < 0.01$) increasing from HF:C to EF:C then decreasing thereafter; whereas, N excreted in the urine increased linearly ($P < 0.01$) as F:C decreased. As a proportion of total N excretion, fecal N excretion linearly decreased ($P < 0.01$) whereas urine excretion linearly increased ($P < 0.01$) as F:C decreased. When expressed as a proportion of total N intake, fecal N excretion responded in a quadratic manner ($P < 0.01$), remaining constant from HF:C to EF:C, and decreasing for each dietary treatment thereafter. Conversely, the proportion of N excretion in the urine was not different across treatments ($P \geq 0.27$). Apparent grams of N digested increased linearly as the proportion of DRC increased in the diet ($P < 0.01$). Additionally, grams of N retained tended to increase linearly ($P = 0.09$) as the F:C decreased.

Dry matter digestibility (Table 4) increased linearly as F:C decreased ($P < 0.01$). Intake of OM increased linearly and fecal OM excretion decreased linearly ($P = 0.01$) as the F:C decreased ($P = 0.01$), such that grams of OM digested and OM digestibility as a proportion of OM intake increased linearly ($P < 0.01$). Intake of NDF responded quadratically in that it increased from HF:C to IF:C then decreased for each treatment thereafter ($P = 0.01$). Fecal excretion of NDF linearly decreased ($P < 0.01$) and there was

no difference in grams of NDF digested across treatments ($P = 0.44$). As a proportion of NDF intake, NDF digestibility increased linearly as F:C decreased ($P < 0.01$). Intake of ADF and fecal ADF excretion responded quadratically ($P \leq 0.03$), not differing from HF:C to EF:C, but decreasing thereafter as F:C decreased. Grams of ADF digested and ADF digestibility as a proportion of ADF intake responded quadratically ($P < 0.01$) increasing from HF:C to EF:C then decreasing thereafter. Starch intake responded quadratically ($P < 0.01$) with modest increases from HF:C to EF:C, but increasing from LF:C to VLF:C. Fecal excretion of starch increased linearly ($P < 0.01$) as F:C decreased; whereas, grams of starch digested and digestibility as a proportion of starch intake responded quadratically ($P < 0.01$).

Discussion

Based on diet formulation, no difference in GE among the treatment diets was anticipated. Treatment diets contained comparable proportions of protein and total carbohydrates while the type of carbohydrates (namely starch and cellulose), although inconsequential to the gross energy content, varied. As corn silage and alfalfa hay were replaced with dry-rolled corn to achieve different F:C ratios NDF and ADF decreased whilst starch increased.

It is generally accepted that decreasing the dietary roughage level decreases DMI in cattle fed high concentrate diets (Galyean and Defoor, 2003), accordingly reductions in intake of the LF:C and VLF:C treatments in the present experiment were expected. Gill et al. (1981) evaluated the effects of 5 roughage levels (8, 12, 16, 20, or 24% DM) in diets based on steam flaked or high-moisture corn and found that decreasing roughage

level decreased DMI, presumably because cattle eat to a constant energy intake and grain is more energy dense than forage. Lovett et al. (2003) used individually fed heifers to evaluate the effects of three forage-to-concentrate ratios (65:35, 40:60, or 10:90) on animal performance and reported that as F:C decreased, both DMI and GE intake increased quadratically such that DMI and GE intake increased up to the 40:60 treatment then decreased thereafter. Arelovich et al. (2008) compiled published literature for dairy (18 experiments) and beef cattle (11 experiments) to evaluate the relationship between dietary NDF and DMI. Total dietary NDF for the dairy cattle database ranged from 22.5 to 45.8% and 7.5 to 35.3% for the beef database. It was reported that DMI increased as NDF concentration decreased in the dairy database while in the beef database DMI decreased with decreased dietary NDF. This disparity between the dairy and beef database is likely due to differences in sources of NDF (e.g. NDF supplied by forages vs. NDF supplied by other ingredients) and the greater starch content, and thereby greater fermentability, of the beef diets. In the present study, DMI tended to increase linearly as the F:C ratio (and dietary NDF concentration) decreased. A possible explanation is an increase in passage rate as F:C decreased, up to our 45% concentrate treatment (EF:C); however, in the LF:C and VLF:C treatment, intake was likely controlled by chemostatic factors (Galyean and DeFoor, 2003; Allen et al., 2009). For the HF:C, IF:C, and EF:C diets which ranged in forage concentration from 92 to 47% of DM, DMI was likely limited by gut fill. A linear increase in GE intake can be attributed to the DMI response, as GE of the diets were not different.

Fecal energy loss is driven by the digestibility of the diet. It is plausible that fecal energy was derived primarily from fiber. Dietary concentration of ADF is correlated with digestibility (citation), and as F:C decreased, the amount of ADF in the diet, and thus in the feces, decreased, such that fecal energy losses were reduced, even though ADF digestibility responded quadratically. Thus, the linear decrease in fecal energy excretion was caused by the decreased concentration of fiber (NDF and ADF) in the feces as the F:C ratio decreased. Additionally, the decrease in fecal energy loss as a proportion of GE intake is due to the increase in DM digestibility as the F:C decreased because, generally, concentrate is more digestible than forage. Hales et al. (2014) evaluated the effects of 4 levels of alfalfa hay inclusion (2, 6, 10, or 14%) in DRC-based diets containing wet distillers' grains on energy balance and nutrient digestibility. It was noted that as a proportion of GE intake, as alfalfa hay increased fecal energy loss increased (Hales et al., 2014). In that study, alfalfa hay replaced DRC, so the increase in fecal energy resulted from alfalfa hay replacing starch in the diet. Zinn and Plascencia (1996) used 4 ruminally and duodenally cannulated Holstein steer calves in a 4×4 Latin square design to determine the effects of 2 supplemental fat levels and 2 forage levels (10 or 30% alfalfa hay) on characteristics of digestion. Decreasing forage (alfalfa) from 30 to 10% of diet DM reduced fecal energy losses, and correspondingly, increased DE.

Decreasing F:C resulted in modest, but detectable, linear decreases in total urinary energy loss (Mcal) and urinary energy as a proportion of both GE and DE intake. Urinary energy is primarily derived from urinary N constituents, including urea, purine derivatives, creatine and creatinine, and hippuric acid (Dijkstra et al., 2013). Both N

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intake and N excreted in the urine (g/d) increased linearly as the F:C decreased in the diet. Increases in N intake resulted primarily from increases in DMI. However, urinary N excreted as a proportion of total N intake was not affected by F:C, such that urinary energy losses expressed per unit of urinary N also decreased as F:C decreased. This changing ratio suggests that differences in urinary energy losses may be due to changes in the relative proportion of N constituents as F:C decreased. Specifically, the proportion of hippuric acid excreted in the urine may have decreased as the F:C decreased. Formation of hippuric acid in the liver is driven by the dietary concentration of degradable phenolic acids which would be higher in forages than concentrates (Spek et al. 2013). A decrease in hippuric acid excretion could result in a decrease in urinary energy as the heat of combustion of hippuric acid is higher than that of urea (Blaxter et al., 1966). While these changes may be quantitatively small, urinary energy accounts for approximately 1/3 of the energy losses from DE to ME. Variation in urinary energy constituents of the magnitude observed in this study may account for differences in ME to DE of 0.02 units; i.e. from 0.87 to 0.89.

In contrast to the results of the present study, Hales et al. (2014) reported no differences in urinary energy loss as alfalfa hay decreased from 14 to 2% of the dietary DM in finishing beef steers; however, the MP balance was greater in that study because all diets included 25% wet distillers' grains plus solubles. Additionally, in the present study, the range of forage inclusion varied from 92% to 8%; in the prior study, the response surface may not have been sufficient to detect an effect. Reynolds et al. (1991) fed diets containing either 75% alfalfa hay or 75% concentrate (primarily ground corn)

and found that urinary energy losses were lower when heifers were fed the 75% concentrate versus the 75% alfalfa hay diet, supporting the observation that diet type may alter urinary energy losses and thus affect the conversion of DE to ME.

Methane is produced as a byproduct of ruminal carbohydrate fermentation (Mitsumori and Sun, 2008; Hook et al., 2010). Methanogens utilize hydrogen, carbon dioxide, formate, and acetate to produce methane (Qiao et al., 2014). Fermentation of structural carbohydrates to acetate yields substrates for methane production. Reducing forage and increasing concentrate in the diet decreases the acetate-to-propionate ratio, and reducing the substrates available for methanogenesis (Yan et al., 2000; Mitsumori and Sun, 2008).

In the present study, methane energy losses responded quadratically. With the exception of the HF:C treatment, methane energy losses per unit of GE intake decreased at an increasing rate as the F:C decreased. Lovett et al. (2003) fed three F:C ratios (65:35, 40:60, or 10:90) and reported a quadratic response in liters of methane emitted each day which increased from the 65:35 to the 40:60 and then decreased for the 10:90 treatment which agrees with the results of the present study. Moss et al. (1995) using wethers determined the effects of the forage-to-concentrate ratio on methane production, with grass silage and rolled barley diets fed at 1.5× maintenance. Diets represented 4 F:C ratios (100:0, 75:25, 50:50, or 25:75). They observed a linear decrease in OM intake, and a quadratic response in the volume of methane produced which increased from the 100:0 to the 75:25 F:C ratio and then decreased thereafter. As in the current study, decreasing F:C ratio had a quadratic effect on energy lost as methane, with initial concentrate

additions increasing methane production and subsequent additions reducing methane losses as a proportion of GE. Lower DMI observed with the HF:C treatment in combination with the lower OM digestibility (and presumably ruminal fermentation rate) may have been sufficient to limit methane production relative to other treatments, in spite of the higher forage content of that diet. Overall these results suggest that the changes in methane energy losses across diets are sufficient to have substantial impact on the conversion of DE to ME.

The quadratic response in dietary ME (Mcal/kg) with decreasing F:C is a result of the linear decrease in urinary energy and the quadratic response in methane energy losses. Zinn and Plascencia (1996) also reported that decreasing forage level in the diet from 30 to 10% alfalfa hay (similar to the LF:C to VLF:C treatments in the present study) increased dietary ME in Mcal/kg of DM. In the present study, the observed ME in Mcal/kg is 5 to 12% higher than would be predicted by the equation ME = 0.82 DE found in the current edition of the NASEM (2016). However, these authors noted that recent data indicate a variable relationship in ME:DE ranging from 0.82 to greater than 0.95 and is dependent on cattle age, intake level, and composition of the diet (Vermorel and Bickel, 1980; Hales et al., 2012, 2013, 2014, 2015a, b, 2017). Galyean et al. (2016) compiled data consisting of 87 treatment means from 23 published papers utilizing beef or dairy animals in which direct measurements of fecal, urinary, and methane losses were made with respiration calorimetry. The linear regression equation developed by Galyean et al. (2016) was ME = $0.9611 \times$ DE $- 0.2999$ ($r^2 = 0.986$). Their equation had a greater r^2 compared to the linear regression equation derived using individual animal

data in our study as opposed to treatment means. The quadratic response in the conversion of dietary DE to ME results from the quadratic response in methane energy loss as a percentage of both GE and DE intake. In combination with the linear decrease in urine energy loss as a percentage of GE or DE intake, these results support the hypothesis that the conversion of DE to ME is not constant across diets and is a function of dietary components.

Heat production increased linearly and mirrored GE intake which is reasonable as CO_2 is the larger coefficient in the Brouwer (1965) equation used to estimate heat production. Dry matter intake is generally correlated with the amount of enteric CO_2 produced as it is a byproduct of ruminal fermentation. In fed animals, HP is comprised of basal metabolism, heat of activity associated with obtaining feed, and heat increment (Lofgreen and Garrett, 1968; NASEM, 2016). Assuming that basal metabolism and heat of activity with obtaining feed were equivalent for all treatments, differences in heat increment would drive treatment differences in HP. The linear increase in RE followed the increase in ME above maintenance (i.e. heat energy) which was driven by the increase in DE resulting from increased DMI, decreased fecal energy losses, and increased ME:DE conversion.

Differences in N intake were not anticipated as the experimental diets were formulated to have similar CP concentrations. Therefore, the increase in N intake as F:C decreased was because of the effects of the dietary treatments on DMI. The quadratic effect on grams of N excreted in the feces may be the collective result of a reduction in microbial crude protein (**MCP**) synthesis and hindgut fermentation occurring

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specifically in the HF:C, IF:C, and EF:C treatments. Strobel and Russell (1986) demonstrated a significant decline in the efficiency of MCP synthesis at pH values less than 6.0 often observed when feeding high-concentrate diets. Cattle in the present experiment were adapted to the experimental diets for 21 d prior to the collection period, the decline in fecal N for the LF:C and VLF:C treatments may be the result of depressed MCP synthesis as the proportions of grain in these diets would lead to a sustained pH level of 6.0 or less; however, pH was not measured in the present study. Additionally, the decrease in NDF and ADF intake coupled with the increase in starch intake as the F:C decreased reduced the amount of fermentable carbohydrate reaching the hindgut, lowering fecal N excretion specifically for the LF:C and VLF:C treatments. Furthermore, if MCP production was reduced due to low pH or production of ammonia from ruminal degradable protein exceeded microbial requirements, it is plausible that ammonia was absorbed across the rumen wall, converted to urea in the liver, and excreted in the urine causing the observed increase in urinary N excretion. Castillo et al. (2001) supplemented grass silage-based diets with concentrates of divergent starch degradabilities and found that N excreted in the urine (grams per day) was greatest for the high-degradable starch diet. The increase in apparent N digested is a result of the increase in N intake combined with the decrease in fecal N excreted.

It has been documented that different carbohydrate sources can cause variation in the distribution of excreted N between feces and urine. Bierman et al. (1999) evaluated the effect of level and source of dietary fiber on N and OM excretion. The formulated diets contained 28.4, 13.6, or 9.9% NDF either from wet corn gluten feed (WCGF), corn

silage and alfalfa hay, or DRC, respectively. These diets are most similar to the EF:C, LF:C and VLF:C used in the present experiment. As in our study, when expressed as a proportion of total N excretion, fecal N excretion decreased and urinary N excretion increased (numerically) as the proportion of fiber in the diet decreased.

In the present study, all experimental diets were of similar OM content; therefore, the increase in OM intake is a result of the dietary effects on DMI. As in our study, Reynolds et al. (1991) noted that DM, OM, and NDF total tract digestibility increased in heifers fed a 75% concentrate diet compared to a 75% alfalfa hay diet which is because of a greater TDN content of ground corn than alfalfa hay. Crawford et al. (2008) also noted an increase in NDF digestibility as alfalfa hay inclusion decreased from 13.5 to 4.5% of DM in high moisture and DRC-based diets. Conversely, Hales et al. (2014) noted no difference in NDF digestibility, as a percent of intake, when alfalfa hay was decreased in the diet from 14 to 2% of DM replacing DRC. Cole et al. (1976) reported that when NDF was increased in the diet in the form of dietary forage, cellulose digestion typically increased. The quadratic response in ADF total tract digestibility is likely a result of negative associative effects. It is generally accepted that as the proportion of concentrate in the diet increases, specifically to levels seen in the LF:C and VLF:C treatments, negative associative effects cause a decrease in fiber digestibility due to the effects of low pH levels on the fibrolytic bacterial population. Ruminal microorganisms on the higher forage diets (HF:C, IF:C) were most likely more fibrolytic bacteria such as *Butyvibrio fibrisolvens* and *Fibrobacter succinogenes*, which cannot tolerate a ruminal pH below 5.7 (Russell and Wilson, 1996). *Streptococcus bovis* and

Selenomonas ruminantium, which are starch utilizing bacteria, would have predominated in the VLF:C diets.

By design, starch intake increased linearly because DRC replaced forage in the diets. However, as the F:C ratio decreased, starch digestibility as a proportion of total starch intake decreased. A potential explanation for the decrease in starch digestibility could be a shift in the site of starch fermentation from the rumen to the small intestine. Shifts in site of digestion to the small intestine are often accompanied by a decrease in overall starch digestibility (Huntington et al., 2006).

In conclusion, many of the changes across the range of diets fed in the present experiment were caused by replacing moderately digestible substrates, corn silage and alfalfa hay, with a more digestible DRC. The decrease in the F:C ratio caused an increase in energy intake, a decrease in fecal and urine energy loss, and an increase in methane at a decreasing rate. Similarly, ME was increased as the F:C ratio decreased, and the ME:DE ratio also increased as DRC replaced corn silage and alfalfa hay.

Tables and Figures

Table 2.1 Ingredient and analyzed composition (DM basis) of experimental diets formulated to contain disparate forage-to-concentrate ratios fed to growing beef steers at *ad libitum* intake

	Treatment[1]				
Item	HF:C	IF:C	EF:C	LF:C	VLF:C
Ingredient, %					
Dry-rolled corn	-	22.5	45.0	67.5	83.8
Alfalfa hay	30.0	30.0	30.0	24.5	8.0
Corn silage	62.0	39.5	17.0	-	-
Soybean meal	5.0	5.0	5.0	5.0	5.0
Supplement[2]	3.0	3.0	3.0	3.0	3.0
Urea	-	-	-	-	0.2
Analyzed composition, %					
DM	46.79	57.02	68.65	83.83	83.59
OM	91.37	90.99	91.81	92.60	94.35
CP	11.99	12.62	12.61	12.82	12.49
NDF	40.60	39.31	35.15	28.23	27.95
ADF	25.16	23.30	21.06	14.29	9.30
Starch, %	21.10	24.20	26.72	36.46	45.26
GE, Mcal/kg	4.24	4.22	4.27	4.22	4.29

[1]DRC replaced corn silage and alfalfa hay at 0 (**HF:C**), 22.5 (**IF:C**), 45 (**EF:C**), 67.5 (**LF:C**), and 83.8% (**VLF:C**) of dietary DM.

[2]Formulated to contain Rumensin (Elanco Animal Health, Greenfield, IN) at 700 g/ton and vitamins and minerals to exceed NASEM (2016) requirements.

Table 2.2 Energy partitioning in growing beef steers fed diets of disparate forage-to-concentrate ratios at *ad libitum* intake

| | Treatment[1] | | | | | | P-value | |
Item	HF:C	IF:C	EF:C	LF:C	VLF:C	SEM[2]	Linear	Quadratic
DMI,g	7543	8045	8649	7777	8522	423.3	0.06	0.25
GE intake, Mcal	31.9	34.0	36.9	32.9	36.6	1.84	0.04	0.29
Fecal energy, Mcal	11.8	12.4	12.5	10.4	9.7	0.89	0.02	0.06
Fecal energy loss, % of GE	36.3	36.2	34.0	30.8	26.8	1.72	<0.01	0.09
DE, Mcal	20.2	21.7	24.3	22.6	26.8	1.34	<0.01	0.81
DE, Mcal/kg	2.7	2.7	2.8	2.9	3.2	0.07	<0.01	0.07
Urinary energy, Mcal	0.9	0.88	0.90	0.82	0.78	0.05	0.04	0.54
Urinary energy loss, % of GE	2.9	2.6	2.5	2.6	2.2	0.20	0.03	0.98
Urinary energy loss, % of DE	4.5	4.1	3.8	3.7	3.0	0.24	<0.01	0.63
Methane energy, Mcal	1.7	2.3	2.3	1.8	1.3	0.19	0.03	<0.01
Methane energy loss, % of GE	5.2	6.5	6.3	5.2	3.7	0.44	<0.01	<0.01
Methane energy loss, % of DE	8.1	10.4	9.5	7.6	5.1	0.65	<0.01	<0.01
ME, Mcal	17.6	18.6	21.1	20.1	24.7	1.26	<0.01	0.24
ME, Mcal/kg	2.4	2.3	2.4	2.6	2.9	0.07	<0.01	<0.01
ME:DE	87.4	85.8	86.7	88.7	91.9	0.72	<0.01	<0.01
Heat production, Mcal	15.0	16.4	17.3	16.7	17.7	0.97	0.04	0.44
Heat production, % of GEI	46.9	47.4	48.6	51.1	49.2	2.51	0.22	0.80
Retained energy, Mcal	2.7	2.5	3.6	3.5	6.8	1.02	<0.01	0.06
Retained energy, % of GEI	8.4	7.2	8.4	10.2	18.0	2.75	<0.01	0.03

[1]DRC replaced corn silage and alfalfa hay at 0 (**HF:C**), 22.5 (**IF:C**), 45 (**EF:C**), 67.5 (**LF:C**), and 83.8% (**VLF:C**) of dietary DM.

[2]Pooled standard error of the least squares mean ($n = 10$ except in period 3 $n = 9$).

Table 2.3 Nitrogen balance in growing beef steers fed diets of disparate forage-to-concentrate ratios at *ad libitum* intake

Item	Treatment[1]					SEM[2]	*P*-value	
	HF:C	IF:C	EF:C	LF:C	VLF:C		Linear	Quadratic
N intake, g/d	146.1	163.1	174.7	160.4	170.7	8.84	0.01	0.06
N excretion, g/d								
Feces	67.7	73.7	80.8	64.1	58.4	4.13	<0.01	<0.01
Urine	65.9	80.3	83.0	82.7	83.7	5.56	0.01	0.09
Total	133.6	154.5	163.4	147.2	141.7	7.57	0.48	<0.01
N excretion, % of total N excretion								
Feces	53.2	48.8	49.6	44.9	41.3	2.71	<0.01	0.57
Urine	46.9	51.1	50.3	55.1	58.7	2.71	<0.01	0.57
N excretion, % of total N intake								
Feces	46.5	45.8	46.5	40.2	34.3	1.65	<0.01	<0.01
Urine	45.5	48.7	48.1	52.4	50.2	4.04	0.27	0.76
Apparent N digested, g/d	78.3	89.5	93.9	96.4	112.2	6.17	<0.01	0.62
N retained, g/d	12.3	9.6	10.3	14.2	28.0	7.04	0.09	0.11

[1]DRC replaced corn silage and alfalfa hay at 0 (**HF:C**), 22.5 (**IF:C**), 45 (**EF:C**), 67.5 (**LF:C**), and 83.8% (**VLF:C**) of dietary DM.

[2]Pooled standard error of the least squares mean (*n* = 10 except in period 3 *n* = 9).

Table 2.4 Diet digestibility in growing beef steers fed diets of disparate forage-to-concentrate ratios at *ad libitum* intake

Item	Treatment[1]					SEM[2]	*P*-value	
	HF:C	IF:C	EF:C	LF:C	VLF:C		Linear	Quadratic
Dry matter digestibility, %	61.8	62.7	65.3	69.3	73.6	1.54	<0.01	0.06
OM								
Intake, g/d	6888.5	7321.2	7943.6	7206.5	8050.9	397.3	0.01	0.47
Fecal excretion, g/d	2376.9	2519.7	2500.7	2065.8	1916.2	182.9	0.01	0.07
Digested, g/d	4514.1	4824.7	5421.8	5163.9	6113.5	294.4	<0.01	0.55
Digestibility, %	66.0	65.8	68.4	72.3	75.7	1.64	<0.01	0.08
NDF								
Intake, g/d	3047.6	3156.2	3020.2	2192.6	2362.9	152.50	<0.01	0.01
Fecal excretion, g/d	1856.6	1699.8	1524.8	1098.3	890.1	91.05	<0.01	0.02
Digested, g/d	1197.0	1462.4	1494.5	1100.3	1471.8	93.84	0.44	0.13
Digestibility, %	40.0	46.0	49.9	50.2	62.7	1.88	<0.01	0.10
ADF								
Intake, g/d	1890.3	1866.6	1815.8	1104.7	794.5	91.93	<0.01	<0.01
Fecal excretion, g/d	1260.5	1118.3	952.6	679.0	494.5	56.97	<0.01	0.03
Digested, g/d	640.2	758.3	862.1	435.6	298.9	60.67	<0.01	<0.01
Digestibility, %	33.3	40.0	47.1	38.9	35.3	2.94	0.58	<0.01
Starch								
Intake, g/d	1568.0	1976.7	2287.3	2863.4	3852.5	194.99	<0.01	0.01
Fecal excretion, g/d	1.1	109.3	161.9	221.7	256.0	35.79	<0.01	0.40
Digested, g/d	1564.6	1867.5	2123.3	2641.8	3594.3	190.19	<0.01	<0.01
Digestibility, %	99.7	94.4	92.7	92.1	93.3	1.28	<0.01	<0.01

[1]DRC replaced corn silage and alfalfa hay at 0 (**HF:C**), 22.5 (**IF:C**), 45 (**EF:C**), 67.5 (**LF:C**), and 83.8% (**VLF:C**) of dietary DM.

[2]Pooled standard error of the least squares mean ($n = 10$ except in period 3 $n = 9$).
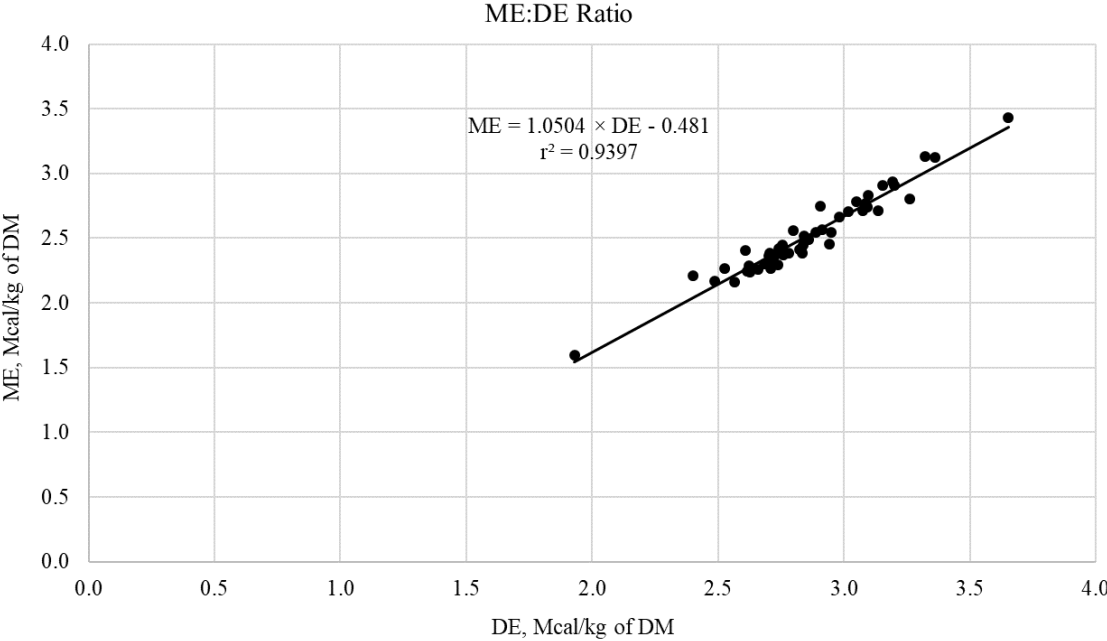
Figure 2.1 Efficiency of conversion of DE to ME in growing beef steers fed diets of disparate forage-to-concentrate ratios at ad libitum intake.

ME:DE Ratio

$ME = 1.0504 \times DE - 0.481$
$r^2 = 0.9397$

ME, Mcal/kg of DM

DE, Mcal/kg of DM

CHAPTER III

EFFECTS OF STARCH CONCENTRATION IN GROWING DIETS ON FEEDING

PERFORMANCE AND COMPOSITION OF GAIN DURING THE GROWING AND

FINISHING PERIOD IN EARLY-WEANED BEEF CALVES

Synopsis

Backgrounding programs allow cow-calf producers to add value to early-weaned

calves, primarily through weight gain, and can increase annual gross revenue. Various

management practices during the growing phase can affect finishing phase performance;

therefore, managing early-weaned calves to avoid potential price discounts is essential.

Corn based byproducts that are low in starch offer an alternative to traditional grain-

based growing diets that may accelerate physiological maturity. Lightweight (initial BW

$= 175.59 \pm 1.3$ kg), crossbred bull and steer calves (n $= 970$) were utilized in a

randomized complete block to determine the effects of starch level in growing diets on

growing and finishing phase performance, ultrasonic measurements, and final carcass

composition. Loads of cattle were blocked by receiving week with 10 replications (pens)

per treatment with an average of 32 head per pen. Growing diets were formulated to

contain 1 of 3 levels of starch; 1) LOW, 22.3% starch, 2) MED, 26.4% starch, or 3)

HIGH, 31.0% starch on a DM basis and to provide similar energy and protein intake

(isocaloric and isonitrogenous). The growing period began on d 45 and ended on d 119

of the experiment. Prior to d 45 all cattle were fed a common receiving diet. Ultrasonic

measurements were collected at the beginning (d 45) and end of the growing period (d

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119) and a common finishing diet was fed to all cattle for the remainder of the trial. The model for all measurements included treatment as a fixed effect and block and pen within treatment as a random effect. Contrast statements were used to test the linear and quadratic effects of level of dietary starch in the growing diet. Starch concentration in the growing diet did not significantly affect ADG or DMI during the growing ($P \geq 0.15$), finishing ($P \geq 0.20$), or overall period ($P \geq 0.26$). There was a tendency for G:F to decrease linearly ($P = 0.06$) during the growing phase as the concentration of starch in the growing diet increased but was not different during the finishing ($P \geq 0.40$) or overall period ($P \geq 0.20$). At the end of the growing period, 12th rib fat linearly decreased ($P = 0.04$) as starch level increased while marbling score was not affected ($P = 0.57$). At slaughter, there was a quadratic response ($P < 0.01$) in dressing percent and a tendency for a quadratic response ($P = 0.09$) for marbling score, both increasing from the LOW to MED treatment then decreasing. Final HCW and 12th rib fat were not different ($P \geq 0.66$).

Introduction

Cow-calf producers traditionally wean their calves at approximately 7 months of age. This time frame overlaps with the breeding season and coincides with the beginning of the third trimester of gestation, which can be problematic for a number of reasons. During times of limited forage availability, lactating cows can lose body condition score which can be difficult and costly to recover prior to rebreeding or calving. Research has shown that early weaning can have positive effects on rebreeding rates, cow body condition score, and can reduce annual cow costs (Lusby et al., 1981; Myers et al., 1999;

Story et al., 2000). However, calves weaned at an earlier age may be lighter and, if sold at weaning, would generate fewer dollars per head thereby reducing gross revenue for cow-calf producers.

Backgrounding or growing programs are an alternative to selling at weaning that allow producers to add value primarily through weight gain. Many production systems exist to grow calves between weaning and finishing and much research has been conducted investigating the effects of these different production systems on subsequent finishing performance and carcass characteristics (Lancaster et al., 2014). Immediately placing early-weaned calves on a high energy diet allows for rapid and efficient growth, however, physiological maturity is more rapidly achieved resulting in decreased final weights (Schoonmaker et al., 2001, 2002). Pounds of live or carcass weight added drives gross revenue for feedyards, therefore, calves coming out of background facilities usually receive a price discount compared to traditionally weaned or yearling cattle due to anticipated reductions in finished weights. Additionally, calf-feds managed to have high rates of gain during the growing period are often fatter upon feedlot entry and it is a general perception that average daily gain and feed efficiency worsen during finishing as initial body fat increases (McCurdy et al., 2010). Inclusion levels of cereal grains of greater than 20% of dietary DM in growing diets is believed to result in excessive fat deposition, possibly due high rate of body weight gain or the fermentation of starch to propionate which can then be used for gluconeogenesis in the ruminant animal. Smith and Crouse (1984) reported that intramuscular adipocytes preferentially use glucose as the primary substrate for fatty acid synthesis, whereas subcutaneous fat uses acetate.

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Previous research studies comparing starch content of growing diets on finishing performance have primarily evaluated diets of differing energy densities – achieved by altering the proportion of grain - at different levels of intake so that NE_g intake and rate of gain were similar across diets. While limit feeding a high energy diet during backgrounding has been shown to improve G:F, there can be carryover effects in which dry matter intake is also reduced during the finishing period (Schoonmaker et al., 2004; McCurdy et al., 2010).

One alternative to traditional grain-based diets is the inclusion of byproducts. Corn-based byproducts primarily result from starch removal during the production of ethanol or various other corn milling products. Although starch is limited in these feeds, some by-products such as distillers' grains and corn gluten pellets contain similar or even greater amounts of net energy for gain than corn grain (Ham et al., 1995; Loy et al., 2008; NASEM, 2016). Therefore, the objective of this study was to evaluate isocaloric and isonitrogenous growing diets of varying starch content fed *ad libitum* on growing and finishing phase performance and composition of gain in early-weaned beef calves.

Materials and Methods

All experimental procedures followed the guidelines described in the Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (FASS, Savoy, IL).

Lightweight (initial BW = 175.59 ± 1.3 kg), crossbred (British × Continental) bull and steer calves (n = 970) were utilized in a randomized complete block. Cattle were procured weekly in groups of at least 90 head from multiple auction markets

located in Oklahoma and Arkansas. Loads assembled in Bristow, Oklahoma were shipped to OT Feedyard and Research Center, Hereford, Texas from May 1 to July 10, 2017. Each of the 10 weekly receiving groups contained an average of 97 head (range = 90 – 109 head) and represent a single block in the experimental model. Each receiving group was treated as a block and managed as a cohort, such that the same timeline was followed within each block. On arrival, calves were given free-choice access to fresh hay and water and allowed to rest overnight. The following morning (d 0), cattle were randomly assigned to pen using a 2-head gate cut. Pens were randomly assigned to receive 1 of 3 dietary treatments. This resulted in 10 pens per treatment with an average of 32 head per pen (range = 30 – 37 head). Immediately after randomization each pen was weighed in a single draft using platform scales for determination of initial BW.

After each pen was weighed, the cattle were processed. Initial processing included intranasal inoculation for infectious bovine rhinotracheitis virus, parainfluenza 3 virus, and bovine respiratory syncytial virus (Inforce 3); vaccination for clostridial organisms (Covexin 8); metaphylactic antibiotic treatment with tulathromycin (Draxxin); injectable trace mineral solution (Multimin), oral drench with electrolyte solution (Bovine BlueLite); treatment for internal parasites (Safe-guard); branding; and administration of an ear tag containing an individual animal identification number and a common lot number for each pen. An ear notch sample was collected from each individual animal to test for persistent infection with bovine viral diarrhea virus. Bull calves were band castrated.

On d 21, all cattle were implanted with 20mg estradiol benzoate, 200mg progesterone, and 29mg tylosin tartrate (Component E-S with Tylan), treated with an injectable parasiticide for internal and external parasites (Ivomec), and revaccinated for infectious bovine rhinotracheitis virus and bovine viral diarrhea virus type I and II (Titanium 3). At the end of the growing period (d 119) the cattle were reimplanted with 200mg of trenbolone acetate and 40mg estradiol (Revalor-XS).

A common receiving diet (Table 1) was fed to all experimental cattle until d 45 to allow for acclimatization to the feedyard. Long-stem wheat hay was top dressed in the bunk for the initial 7 days. Beginning on d 45, dietary treatments were applied.

Growing diets were formulated to contain 23 % (**LOW**), 29.5 % (**MED**) or 36% (**HIGH**) starch on a dry matter basis (Table 2). Diets were formulated to be isocaloric and isonitrogenous. During transition, cattle were adapted to growing diets by feeding the receiving diet at the first daily feeding and the growing diet at the second daily feeding for 10 d. Growing diets were fed until d 119 of the experiment. A common finishing diet (Table 1) was then fed for the remainder of the trial. Adaption to the finishing diet consisted of a 3-ration step up system during which each of 2 step-up rations were fed for 7 d and the cattle were on the final diet by d 15 of the finishing phase.

Bunk management allowed for trace amounts of feed left in the bunk from day to day to ensure *ad libitum* intake. Feed bunks were evaluated each morning before feeding and a daily feed call was made for each pen based on the quantity of feed, if any, remaining in the bunk. When feed was left in the bunk the feed call was adjusted to

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ensure the total amount of feed delivered was consumed. Feed was batched and delivered twice daily using a staggered rotor mixer (Roto-Mix 620-16; Roto-Mix, Dodge City, KS). Weekly diet samples were collected from the bunk throughout the duration of the experiment. A subsample of each diet was evaluated for DM immediately following collection by drying in a forced-air oven at 105°C for 24 h. For determination of CP, ADF, NE_m, NE_g and starch, samples were analyzed by a commercial laboratory (ServiTech Labs, Amarillo, Texas). Feed samples collected during the growing period (d 45-119) were analyzed by week while samples collected during the finishing phase were composited by month. Net energy for maintenance was calculated as: $NE_m = (1.37 \times ME) - (0.3042 \times ME^2) + (0.051 \times ME^3) - 0.508$. Net energy for gain was calculated as $NE_g = (1.42 \times ME) - (0.3836 \times ME^2) + (0.0593 \times ME^3) - 0.7484$. Total starch was determined by enzymatic hydrolysis using Megazyme amyloglucosidase enzyme. Lab results were averaged by treatment for the determination of final nutrient composition.

Pen level bodyweights were measured using a platform scale on d 0, 45, 119, and on the day each receiving group was shipped to the harvest facility (finished BW). Cattle were weighed at daylight prior to feeding and actual scale BW data (unshrunk) were used for determination of average BW for d 0, 45, and 119. A 4% pencil shrink was applied to the finished BW data to adjust for gastrointestinal fill as is common practice in the industry. Average initial BW for each pen was calculated as total pen scale weight divided by the total number of cattle in the pen at the start of the trial. Day 45 and 119 BW was calculated as total pen scale weight divided by the number of the cattle in the weigh group excluding deads and cattle shipped early due to chronic illness or injury.

Finished BW was calculated as shrunk weight of the cattle at shipping divined by number of head shipped (excluding deads and cattle shipped early). Average daily gain (excluding mortalities and realizers) was calculated as (finished BW – initial BW) divided by days on feed for each pen within each period. Daily DMI was calculated as total amount of feed dry matter delivered divided by the number of head days for the given period. Feed efficiency (G:F) was calculated as individual ADG divided by daily DMI.

A subsample of 10 steers per pen was randomly selected for determination of initial (d 45) and final growing phase (d 119) body composition. The same individuals were evaluated on both collection days. Longissimus muscle (LM) area, 12th rib fat, and marbling scores were estimated with an Aloka 210 ultrasound system using a 3.5-MHz probe by a trained, independent technician (Cattle Performance Enhancement Company) who was blind to treatment assignments. Readings were given in millimeters for 12th rib fat, and centimeters squared for LM area. The scale used for ultrasound marbling score corresponded to USDA marbling scores (300 = slight; 400 = small; 5 500 = modest; USDA, 2016).

Two receiving groups of cattle were shipped on each harvest date to a commercial slaughter facility (Tyson Fresh Meats, Amarillo, Texas) when approximately 65% of the cattle within the entire receiving group were expected to grade USDA Choice or greater based on visual appraisal. Carcass data were collected by the Beef Cattle Research Center (West Texas A&M University, Canyon, Texas). Lot number was maintained for each carcass and linked to individual carcass measurements.

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Carcass measurements included HCW and, after a 48-h chill, fat thickness, LM area, quality grade, and marbling score. Data collected were used to calculate USDA yield grade. Dressing percentage was determined for each pen as the total hot carcass weight divided by the total shrunk live weight obtained at the feedyard the morning of shipping. Marbling score was reported as [10 = practically devoid, 20 = traces, 30 = slight, 40 = small, 50 = modest, 60 = moderate, 70 = slightly abundant, 80 = moderately abundant, 90 = abundant]. Yield grade was calculated as: $2.5 + (2.5 \times$ fat thickness, inches) + $(0.0038 \times$ hot carcass weight, lbs) + $(0.2 \times$ kidney-pelvic-heart fat, %) - $(0.32 \times$ LM area, square inches).

Data were analyzed as a randomized complete block design. The MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) was used to analyze feeding performance, ultrasound measurements, and final carcass data with pen serving as the experimental unit. The proportion of steers within each quality grade category was analyzed using the GLIMMIX procedure of SAS. Steers were classified as USDA Premium Choice, Choice, Select, or Standard using a binary system (0 or 1). The model for all measurements included treatment as a fixed effect and receiving group and pen within treatment as a random effect defining the experimental unit. Contrast statements were used to test the linear and quadratic effects of level of dietary starch in the growing diet. Effects were considered significant at P-value of ≤ 0.05, with tendencies declared at P-values between 0.05 and 0.10.

Results

The diets were formulated to be isonitrogenous and isocaloric and, generally, this objective was met (Table 2). Analyzed starch content, specifically for the MED and HIGH treatments, was slightly less than expected based on formulation. However, the MED and HIGH treatments contained 15.5 and 28% more starch than the LOW treatment, respectively.

Although a quadratic effect of increasing starch was observed for BW on d 0 (P = 0.01), this effect is an artifact of the randomization process and is not likely biologically meaningful, as it was driven by a 3 kg difference between the MED versus LOW and HIGH treatment groups. Mean BW did not differ among treatments at any of the other experimental periods ($P \geq 0.42$). During the receiving period (d 0 – 44), there was a tendency for a quadratic response in ADG (P = 0.06) and DMI (P = 0.09) as both decreased from the LOW to MED treatment then increased from the MED to HIGH treatment; although, a common diet was fed to all cattle regardless of designated experimental treatment during this period. Concentration of starch in the growing diet did not affect ($P \geq 0.26$) ADG or DMI during the growing ($P \geq 0.15$) or finishing periods ($P \geq 0.20$). Ratio of G:F tended to decrease linearly (P = 0.06) during the growing phase (d 45 - 119) as starch concentration in the growing diet increased but was not different during the receiving ($P \geq 0.30$) or finishing periods ($P \geq 0.40$).

Neither linear nor quadratic effects were observed for 12th rib fat ($P > 0.14$), longissimus muscle area ($P > 0.58$), and marbling score ($P > 0.59$)   measurements (Table 4) determined by ultrasound at the beginning of the growing period. As starch

concentration increased in the growing diet, 12th rib fat at the end of the growing period (d 119) decreased linearly ($P = 0.04$). Longissimus muscle area and marbling score at the end of the growing period were not affected ($P \geq 0.57$) by starch concentration.

No effects ($P = 0.79$) of starch concentration in growing diets were observed in HCW following the finishing period. Dressing percentage responded quadratically ($P < 0.01$) to starch concentration in the growing diet increasing from the LOW to MED treatment and decreasing from the MED to HIGH treatment; however, this response was small. There was a tendency for a quadratic response ($P = 0.09$) in marbling score following the same pattern as dressing percentage. Carcass 12th rib fat thickness and LM area were not affected ($P \geq 0.39$) by starch level in the diet during the growing period. Likewise, no effect ($P = 0.70$) of treatments was observed on calculated yield grade.

Percentage of cattle grading Premium Choice was not affected ($P = 0.12$) by starch level in the growing diet; however, there was a quadratic response ($P = 0.01$) to treatment for the percentage of steers grading USDA Choice. Steers grading USDA Choice increased from the LOW to MED treatment then decreased from the MED to HIGH treatment. Similarly, the percentage of steers graded USDA Select responded quadratically ($P = 0.01$) as the concentration of starch in the growing diet increased. Percentage of Select carcasses decreased from the LOW to MED treatment then increased for the HIGH treatment, inverse of the results for the carcasses grading USDA Choice.

Discussion

Concentration of starch in the experimental diets was increased from the LOW to HIGH treatments by replacing wet distillers' grains (WDG) and corn silage with steam-flaked corn and soybean meal. These formulation differences slightly decreased ADF resulting in lower predictions of NE_m and NE_g for LOW as ADF is used to predict NE_m and NE_g. In spite of inherent differences in ADF between steam-flaked corn and WDG, 3.5 vs 15.3%, respectively, the NE_g value for WDG is higher than that for steam-flaked corn according to the Nutrient Requirements of Beef Cattle (NASEM, 2016) suggesting our NE_m and NE_g values were probably closer than predict by the laboratory.

Growing diets were formulated to provide similar NE_g intake such that ADG during the growing period would not differ and this objective was met. Previous research examining the effects of either corn- or byproduct-based growing diets, and thus dietary starch concentration, has demonstrated mixed results. Schoonmaker et al. (2003) fed diets of either whole-shelled corn (concentrate) or soybean hulls (fiber) as the primary energy source to early-weaned (119 days of age; initial BW = 170.5 kg) steers for a 100-d growing period. The whole-shelled corn diet was fed either *ad libitum* or limit-fed to achieve 1.2 or 0.8 kg/d BW gain and the soybean hulls-based diet was fed *ad libitum*. Growing phase ADG increased by 0.38 kg/d for steers fed the corn-based diet *ad libitum* compared to steers fed the soybean hulls-based diet. Daily DMI was not different, therefore, the effect of diet type on ADG was driven by differences in energy intake as the calculated NE_g for the concentrate and fiber-based diets was 1.38 and 1.03 Mcal/kg of DM, respectively. Conversely, Retallick et al. (2010) fed diets of very low, low, and

intermediate starch concentrations to early-weaned steers (initial BW = 128 kg) and demonstrated no differences in growing phase ADG. Dietary starch concentration was altered by decreasing the inclusion rate of dried distillers' grains with solubles (DDGS) and wet corn gluten feed, both by-products of corn milling, and increasing high-moisture corn inclusion. Experimental diets in their study were more similar in calculated NE_g (1.27 Mcal/kg for the very low starch vs. 1.40 Mcal/kg for the intermediate starch) than reported by Schoonmaker et al. (2003) which probably contributed to the lack of observed differences in growing phase ADG. Additionally, those authors observed no differences in DMI during the growing phase. Results from the present experiment agree with Retallick et al. (2010) and indicate that dietary starch level does not affect growing phase ADG when diets are formulated to provide similar energy intake.

Effect of starch level in growing diets on DMI is likely related to the overall NE_g of the diet and the proportion of energy derived from either structural or non-structural carbohydrates. Bedwell et al. (2008) reported a linear decrease in growing period DMI as dietary starch increased from the low starch treatment comprised of 9% dry-rolled corn, 40% DDGS, and 35% soybean hulls with a calculated NE_g of 1.40 Mcal/kg DM to a high starch diet comprised of 78% dry-rolled corn and 15% corn silage with a calculated NE_g of 1.42 Mcal/kg DM. Similarly, Meteer et al. (2013) fed diets comprised of primarily either whole corn (starch) or soybean hulls and corn bran (fiber) as the main energy source with calculated NE_g values of 1.49 and 1.48 Mcal/kg DM (starch and fiber-based diets, respectively) and observed DMI was less for early-weaned steers fed the starch-based growing diet. Alternatively, Schoonmaker et al. (2013) found no

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differences in DMI in early-weaned steers (134 d of age) fed 3 diets containing either: 1) 58.0% corn, 0% DDGS, 2) 44.2% corn, 30.8 DDGS, or 3) 13.3% corn, 61.7 % DDGS with calculated NE_g values of 1.31, 1.34, and 1.35 Mcal/kg, respectively. These data indicate that in cattle consuming a high-energy diet (> 1.35 Mcal/kg DM), DMI is decreased as starch, and thus the proportion of energy coming from nonstructural carbohydrates, is increased in the diet while DMI is not affected by starch level in diets of intermediate to low energy (< 1.35 Mcal/kg DM). It is probable that the amount of starch available to the animal in high-energy diets leads to acidosis and thus decreases DMI. The results of the present study are in agreement with Retallick et al. (2010) and Schoonmaker et al. (2013) in which growing period DMI was not affected by starch level of the growing diet. Although no differences were detected for ADG and DMI during the growing period in the present study, the tendency for G:F to decrease as starch level increased is likely a result of numerically higher DMI for the MED and HIGH starch treatments.

An objective of this experiment was to evaluate possible carryover effects of starch level in growing diets on finishing performance. Lancaster et al. (2014) compiled data from 10 published studies consisting of 13 experiments comparing growing diets differing in starch content. Nine experiments compared high-starch versus medium-starch and seven experiments compared high-starch and low-starch. When comparing finishing performance of steers fed high-starch or low-starch diets during the growing period, the meta-analysis found no differences in final BW, DMI, or G:F; however, steers previously fed high-starch diets tended to have greater ADG during the finishing

period. Similar to the results of the present study, Schoonmaker et al. (2013) found no differences in finishing phase ADG, DMI, or G:F when DDGS replaced corn in growing phase diets at 0, 30, or 60% of the dietary DM. It is generally accepted that characteristics of the backgrounding phase such as initial age or BW, rate of BW gain during the growing period, or placement weight at the initiation of the finishing period, can influence performance during the finishing phase. As rate of gain during the growing phase and initial BW at the beginning of the finishing phase were not different, differences in finishing phase performance were not expected.

Another characteristic of growing programs that may negatively affect feedlot performance is body composition at the initiation of the finishing phase; although, research results have been mixed (Lancaster et al., 2011). Body fat of feeder cattle is typically evaluated by visual assessment of the overall condition, or flesh, of an animal. Acetate, primarily produced from the fermentation of fiber in the rumen, is the main substrate used for subcutaneous fat lipogenesis (Smith and Crouse, 1984). The linear decrease in 12th rib fat observed in the present study may be a result of greater acetate production from fiber fermentation in the LOW and MED starch diet; although, the percentage of ADF for each growing diet was similar. Furthermore, data has shown a decrease in ruminal acetate concentration and the acetate:propionate ratio with distillers' grains (dry or wet) inclusion in dry-rolled or steam-flaked corn-based diets (Vander Pol et al., 2009; Uwituze et al., 2010). However, it has been demonstrated that feeding distillers' grains results in greater ruminal lactate concentration (May et al., 2009; Uwituze et al., 2010) which can also be used for subcutaneous adipose tissue lipogenesis

(Smith and Prior, 1982; Smith and Crouse, 1984). Similar to the results of the present study, Bedwell et al. (2008) observed as starch level in isocaloric growing diets increased there was a linear decrease in backfat at the end of a 73-d growing period. These results may be confounded by rate of BW gain as ADG and DMI also decreased as starch level increased. Prior (1983) established that total energy intake was more important than energy density of the diet for increases in adipocyte hypertrophy. Additional research has shown no difference in ADG or backfat depth following the growing period in early-weaned calves fed either corn- or coproduct-based (soybean hulls, DDGS, and corn gluten feed) diets (Segers et al., 2014) which agrees with the results of Prior (1983).

In conclusion, starch of up to 31% of the diet DM in growing diets fed to light-weight beef calves had no effect on growing or finishing phase feeding performance. Similarly, starch level in the growing diet did not affect final HCW. As the concentration of starch in growing diets did not negatively affect feeding performance, cow-calf producers and backgrounders should select growing diets on a least cost basis.

Tables and Figures

Table 3.1 Ingredient and analyzed nutrient composition (DM basis) of common receiving (d 0 to 45) and finishing (d 119 to final) diets fed to early weaned calves grown on diets of disparate starch content

	Diet[1]	
Item	Receiving	Finishing
Ingredient composition		
Steam-flaked corn	42.45	65.03
Corn silage	5.01	8.43
Cottonseed burrs	-	3.72
Cottonseed hulls	26.17	-
Wet distillers' grains	4.60	-
Corn gluten pellets	13.89	4.90
Whole cottonseed	-	8.78
Suspension	4.43	4.75
Fat	-	2.73
Westway blend	3.45	1.65
Nutrient composition, % of DM		
CP	13.78	13.52
ADF	25.05	16.73
NE_m,[2] Mcal per kg	1.84	2.18
NE_g,[2] Mcal per kg	1.21	1.65

[1]Common diets fed to all experiment cattle
[2]Calculated from ME

Table 3.2 Ingredient and analyzed nutrient composition (DM basis unless otherwise stated) of treatment diets

Item	Diet[1] LOW	MED	HIGH
Ingredient composition, % DM basis			
Steam-flaked corn	-	10.8	21.5
Corn silage	55.8	52.5	49.3
Cottonseed burrs	4.9	8.2	10.5
Soybean meal	-	8.0	15.4
Wet distillers' grains	35.6	17.4	-
Suspension	3.7	3.1	3.3
Nutrient composition			
DM, % as fed	36.69	42.32	49.65
CP, %	17.9	18.7	17.4
Starch[3], %	22.3	26.4	31.0
ADF, %	26.9	24.3	25.0
NE_m,[2] Mcal per kg	1.72	1.81	1.76
NE_g,[2] Mcal per kg	1.10	1.17	1.15

[1]Diets fed for 74 d growing period (d 45 – 119) and formulated to contain disparate levels of starch

[2]Calculated from ME

[3]Determined by enzymatic hydrolysis using Megazyme amyloglucosidase enzyme

Table 3.3 Effect of growing diets of disparate starch content fed for 74 d growing period to early-weaned beef calves on performance

Item	Treatment[1]			SEM[2]	P-value	
	LOW	MED	HIGH		Linear	Quadratic
BW, kg						
d 0	175	178	175	1.29	0.45	0.01
d 45	234	235	235	3.48	0.49	0.52
d 119	341	343	341	6.60	0.91	0.42
Finished	583	582	581	4.92	0.50	0.99
ADG, kg/d						
d 0 – 45	1.33	1.29	1.33	0.06	0.96	0.06
d 45 – 119	1.43	1.44	1.42	0.04	0.60	0.58
d 119 – end	1.43	1.41	1.42	0.02	0.64	0.55
Overall[3]	1.43	1.42	1.42	0.02	0.37	0.79
DMI, kg/d						
d 0 – 45	5.41	5.17	5.30	0.23	0.38	0.09
d 45 – 119	6.89	7.10	7.09	0.21	0.15	0.33
d 119 – end	8.34	8.20	8.48	0.17	0.44	0.20
Overall[3]	7.89	7.86	8.04	0.16	0.26	0.39
G:F						
d 0 – 45	0.246	0.249	0.252	0.005	0.30	0.99
d 45 – 119	0.208	0.203	0.200	0.003	0.06	0.72
d 119 – end	0.172	0.173	0.168	0.004	0.48	0.40
Overall[3]	0.182	0.182	0.177	0.003	0.20	0.46

[1]Diets fed for 74 d growing period (d 45 – 119) and formulated to contain disparate levels of starch
[2]SE of least squares means, n = 10 for all performance responses
[3]Calculated as differences from d 45 to final to test hypothesis

Table 3.4 Effect of growing diets of disparate starch content fed for 74 d growing period to early-weaned beef calves on carcass composition

Item	Treatment[1]			SEM[2]	P-value	
	LOW	MED	HIGH		Linear	Quadratic
12th rib fat, cm						
d 45	0.35	0.36	0.34	0.01	0.14	0.19
d 119	0.50	0.51	0.46	0.01	0.04	0.07
LM area, cm^2						
d 45	42.6	42.5	42.3	0.44	0.58	0.99
d 119	50.1	50.2	49.7	0.80	0.78	0.78
Marbling score[3]						
d 45	4.08	4.02	4.04	0.09	0.69	0.59
d 119	4.00	3.99	4.04	0.06	0.57	0.67
Carcass characteristics						
HCW, kg	373	374	374	3.31	0.83	0.79
Dressing %	64.13	64.34	64.18	0.03	0.16	<0.001
Marbling score[4]	45.41	46.21	44.83	1.10	0.42	0.09
12th-rib fat, cm	1.44	1.46	1.46	0.05	0.66	0.90
LM area, cm	89.8	91.4	91.2	1.56	0.39	0.54
Yield grade[5]	2.96	2.89	2.91	0.11	0.70	0.71
Premium Choice, %	24.64	23.20	18.33	5.60	0.12	0.59
Choice, %	41.81	54.20	46.46	5.17	0.28	0.01
Select, %	26.76	16.39	27.92	5.22	0.80	0.01

[1]Diets fed for 74 d growing period (d 45 – 119) and formulated to contain disparate levels of starch

[2]SE of least squares means

[3]3 (300 = slight), 4 (400 = small), 5 (500 = modest)

[4]30 = slight, 40 = small, 50 = modest

[5]USDA calculated yield grade = $2.5 + (2.5 \times FT) + (0.2 \times KPH) + (0.0038 \times HCW) - (0.32 \times REA)$, where FT = 12th rib fat depth in cm, KPH = percentage of kidney, pelvic, and heart fat, HCW = hot carcass weight in kg, and REA = longissimus muscle area in cm^2

CHAPTER IV

EFFECTS OF POINT OF ORIGIN AND RECEIVING SEASON ON FEEDLOT

CATTLE PERFORMANCE AND ANIMAL HEALTH

Synopsis

Slightly less than 1 million head of feeder cattle were imported into the United

States from Mexico in 2017. Cattle from Mexico typically cost per pound than calves of

similar weight from the United States due to perceived advantages in animal health such

as lower morbidity and mortality. Along with point of origin, the season in which cattle

arrive to the feedyard can also have an effect on animal health. A commercial feedlot

database of 230 lots representing 15,659 cattle was used to analyze differences in

performance and health outcomes of feeder cattle based on point of origin and receiving

season. Data were analyzed using the MIXED procedure of SAS (SAS Inst. Inc., Cary,

NC). The model included the fixed effects of country of origin, receiving season, and the

interaction between country of origin and season. Mexican cattle finished at a lighter

BW ($P \leq 0.01$; 529 kg) than native cattle (588 kg) but required more days on feed (301

vs. 291, respectively). Inclusive of mortalities, ADG was greater for native sourced

cattle compared to Mexican cattle received in the spring and winter but was not different

between countries of origin for cattle received during summer and fall. Total death

losses were greater in native compared to Mexican origin cattle in the Summer and Fall,

but mortality rates were similar among cattle country of origin during the Spring and

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Winter. The percentage of first pulls for respiratory treatment was 2-3x greater in native compared to Mexican origin cattle for all seasons of arrival.

Introduction

Light-weight calves present a unique buying opportunity to cattle feeders for a number of reasons. Lighter entry weights afford the opportunity for greater total gain to finish. Generally, as more total weight gain is generated, non-feeding costs such as medicine, death loss, and interest per kilogram of final BW are diluted, thereby total cost of gain is reduced and the breakeven selling price is reduced. Also, cattle purchased as calves can be marketed as feeder cattle or retained through finishing allowing operators to consider multiple marketing options and take advantage of selling opportunities in either the feeder or live cattle market. However, sale barn origin light-weight calves are often considered "high risk" due to expected morbidity of 50% and mortality of at least 5%, although animal health outcomes can be unpredictable and largely variable. This requires that purchase prices be adjusted; however, substantial deviations from expected values can quickly erode any advantage.

The United States imported over 961,000 head of feeder steers and heifers from Mexico in 2017 (USDA AMS, 2018). Feeder cattle of Mexican origin typically garner a price premium at purchase due to expectations of decreased morbidity and mortality risk compared to cattle of similar size and class from the United States (Wagner et al., 2014). While this expectation is reflected in market dynamics, limited published data exists demonstrating the differences in cattle health and performance between native and Mexican source feeder cattle.

Bovine respiratory disease (BRD) is the leading cause of morbidity and mortality in newly received feedlot cattle. The disease complex is multifaceted with numerous potential contributing factors (Duff and Galyean, 2007). Combined with various viral and bacterial pathogens, commonly proposed predisposing factors include transportation, commingling with cattle from other sources, weather, castrate status, and even disposition (Taylor et al., 2010). Weather patterns typically follow seasonal trends, therefore, season upon arrival to the feedyard may also have an effect on the incidence of BRD and consequentially, animal health and feeding performance. Cattle feeders typically use historic data and personal experience to estimate performance outcomes such as ADG, G:F, and death loss to generate a projected breakeven for a lot of cattle and to make informed purchasing decisions. The objective of this modeling exercise was to evaluate the effects of cattle source of origin and season of arrival on feeding performance and animal health outcomes using data from a commercial feedlot located in Hereford, Texas.

Materials and Methods

Animal Care and Use Committee approval was not obtained for this study because all data was historical and collected from a commercial yard.

A commercial feedlot database of 230 lots representing 15,659 cattle was used to analyze performance and health outcomes. For a lot to be included in the database, initial individual average pay weight was less than 227 kg, with final average BW exceeding 455 kg at slaughter to ensure only cattle fed to finish were included. Only 20 lots of heifers met the initial and final BW requirements; therefore, heifers were excluded.

Information obtained for each lot included: arrival date, source (i.e. location, order buyer name, etc.), initial head count, initial total pay weight, average initial pay weight, total number of deads and railers, weight of railers when shipped, death loss percentage (calculated from number of deads), cause of death, date when cattle were shipped to packing facility, final head count, total pay weight out with and without railers, head days, dry matter intake, processing and medicine cost per head, and the number of animals treated once, twice, and three times for respiratory disease.

Source was used to classify each lot as either Mexican or native (United States) origin. Arrival date was used to assign season of arrival, defined as winter = December, January, February; spring = March, April, May; summer = June, July, August; and fall = September, October, November.

Performance measures were calculated twice, including and excluding mortalities. Average initial BW was calculated by dividing lot total initial pay weight by initial head count. Average final BW was calculated as the total weight of the cattle at shipping (scale weight shrunk 4%) divided by the number of head shipped (thus excluding mortality losses and and cattle shipped early as railers). Average daily gain excluding mortalities was determined by dividing the average weight change per individual (average final BW – average initial BW) by days on feed for the individuals that remained when the lot was shipped for slaughter. Average daily gain inclusive of mortalities and early shipments was calculated as the total pay weight out (including pay weight of any railers) minus total initial pay weight divided by total head days adjusted

for deads and early shipments. Days on feed was calculated as total head days divided by initial head count.

Dry matter intake was calculated by dividing the total amount of feed dry matter delivered to the pen by the number of head days for the feeding period. Gain-to-feed exclusive of mortalities was calculated as ADG exclusive of mortalities divided by DMI while G:F inclusive of mortalities was determined as ADG inclusive of mortalities divided by DMI.

Processing cost included all charges incurred at initial processing such as vaccination, ear tag, branding, castration, initial implant, dewormer, metaphylaxis, re-vaccination, re-implant, etc. Medicine cost included any ancillary treatments received after initial processing for treatment of illness. Treatment records for each lot were used to calculate the number of 1st, 2nd, and 3rd pulls for respiratory disease. Any treatments administered for sickness not diagnosed as BRD (i.e. footrot, coccidosis, encephalitis, etc.) were not included morbidity calculations. Deads were categorized as respiratory, digestive, or other and death loss percentage was calculated as number of deads divided by initial head count. Case fatality rate was also determined for each lot as the total number of deads due to respiratory disease divided by the total number of animals treated at least once for respiratory disease.

Data were analyzed using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC). The model included the fixed effects of country of origin, receiving season, and the interaction between country of origin and season. It was determined that initial average pay weight was significantly different ($P < 0.05$) for steers from Mexico compared to the

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United States (188 vs. 164 kg, respectively), therefore, initial average pay weight was included in the model as a covariate for all variables analyzed. Treatment means were determined using the LSMEANS option of SAS.

Results

The interaction between country of origin and arrival season was not significant for initial BW, final BW, or days on feed ($P \geq 0.08$; Table 4.1). For the main effects, there was an effect of country of origin and season of arrival for final BW ($P \leq 0.01$) and days on feed ($P \leq 0.04$). Mexican cattle finished at a lighter BW ($P \leq 0.01$; 529 kg) than native cattle (588 kg) but required more days on feed (301 vs. 291, respectively). Final BW was greater for cattle received in the winter than any other season for both Mexican or native cattle. There was an interaction between country of origin and arrival season for ADG calculated either inclusive or exclusive of mortalities ($P \leq 0.02$). Inclusive of mortalities, ADG was greater for native sourced cattle compared to Mexican cattle received in the spring and winter but was not different between countries of origin for cattle received during summer and fall. Exclusive of mortalities, ADG was greater for every season of arrival in native sourced cattle compared to Mexican cattle. The interaction between country of origin $\times$ arrival season was also significant for DMI ($P = 0.01$) and G:F calculated either inclusive or exclusive of deads ($P \leq 0.01$). Dry matter intake was greater for native cattle compared to Mexican cattle received in the winter but was similar for all other seasons of arrival. For native sourced cattle, G:F inclusive of deads was greater when cattle were received during the spring or summer compared to Mexican sourced cattle received during similar seasons. Gain-to-feed exclusive of

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mortalities was also greater for native compared to Mexican sourced cattle received during the spring, summer, or fall.

There was a country of origin $\times$ arrival season interaction ($P \leq 0.02$) for all animal health outcomes except for case fatality rate (Table 4.2). Total death losses were approximately 3-fold greater in native compared to Mexican origin cattle in the Summer and Fall, but mortality rates were similar among cattle country of origin during the Spring and Winter. This difference was driven by increases in mortality rate among cattle of US origin during these seasons ($P < 0.001$), as mortality rate among cattle of Mexican origin was similar across all seasons ($P > 0.47$). Processing and medicine cost per head were greater for every season of arrival in native sourced compared to Mexican sourced cattle. The percentage of first pulls for respiratory treatment was 2-3x greater in native compared to Mexican origin cattle for all seasons of arrival. Case fatality rate was similar for either native or Mexican origin cattle ($P = 0.46$) but there was different for season of arrival to the feedyard ($P < 0.01$).

Discussion

Mexican feeder cattle have been compared to US sourced cattle from the southeast and southwest regions of the United States in that, often, they are of considerable Brahman breed type and gain less efficiently than US cattle from the northern regions. However, unlike US cattle from the southeast, it is believed that they experience fewer health problems than cattle sourced from the US as a whole (Wagner et al., 2014). In the present database, cattle classified as native sourced were not from a common region and consist of both *Bos taurus* and *Bos indicus* genotypes. Parish et al.

(2014) demonstrated that Beefmaster and Brangus steers had lighter final BW than Angus or red Angus steers indicating that Brahman breed type cattle finish at a lighter BW and agree with the results of the present study. Seasonal effects on final BW are likely a result of the effects of season on ADG such that for Mexican cattle final BW and ADG were both highest when cattle were received during the winter.

The interaction between country of origin × season of arrival for ADG inclusive of mortalities can be attributed to differences in death loss percentage. That is to say that daily gain was greater in the native sourced cattle during the months when death loss was not different (spring and winter) than Mexican sourced cattle but was not different for country of origin during the months when death loss was greater for cattle sourced from the United States (summer and fall). In a similar study, Irsik et al. (2006) compiled data for 53,890 head of cattle from a feedlot database to determine the effect of animal health on feeding performance. It was demonstrated that for each percentage increase in mortality in a pen of cattle ADG decreased by 0.036 kg per day.

Differences in magnitude across similar seasons for ADG exclusive of mortalities is likely the cause of the interaction between country of origin × season of arrival as gain is greater for native compared to Mexican sourced cattle for every season of arrival. Therefore, the main effects will be discussed. Similar to final BW, the effect of country of origin on ADG exclusive of mortalities is driven by differences in breed type. Irsik et al. (2006) showed that, relative to a British breed steer, direct additive effects for feedlot ADG were -0.07 and -0.19 kg/d in American (i.e. Beefmaster, Brangus, Simbrah, Santa Gertrudis) and Brahman breeds, respectively.

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Kelly and Janzen (1986) reviewed the literature for rates of morbidity and mortality in North American feedlot cattle as well as other factors such as season, age, sex, breed to describe disease patterns. Multiple studies have reported that morbidity and mortality rates were highest in fall, less in winter, and least in spring and summer (Andrews, 1976; Jensen et al., 1976a, b). These results agree with the results of the present study. More recent research (Babcock et al., 2006) has also demonstrated seasonal differences in death loss in for both steers and heifers of unknown origin fed in Kansas feedlots. The authors of this dissertation are not aware of any data that exists comparing differences in death loss between cattle sourced from the United States or Mexico or differences in death loss of Mexican feeder cattle based on season or month of arrival to the feedyard.

In conclusion, feeder cattle sourced from Mexico do show improvements in animal health outcomes over cattle sourced from the United States; however, these differences are dependent upon season of arrival.

Tables

Table 4.1 Final feedlot performance for light-weight calves originating from either Mexico or the United States received during each quarterly season of the year

Item	Mexican				Native				SEM	*P*-value		
	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter		COO	Season	COO × Season
Initial BW, kg	181	211	189	179	158	167	167	163	12.2	<0.01	0.01	0.08
Final BW, kg	528^{xy}	521^{x}	523^{x}	542^{y}	594^{xy}	582^{x}	585^{x}	591^{y}	9.72	<0.01	0.01	0.39
Days on feed	307^{x}	299^{xy}	297^{x}	302^{x}	292^{x}	278^{xy}	287^{x}	305^{x}	11.7	0.04	0.04	0.16
ADG deads-in, kg	1.13^{a}	1.11	1.10	1.17^{a}	1.33^{b}	1.19	1.09	1.26^{b}	0.05	0.01	<0.01	0.02
ADG deads-out, kg	1.15^{a}	1.14^{a}	1.15^{a}	1.21^{a}	1.40^{b}	1.32^{b}	1.25^{b}	1.32^{b}	0.03	<0.01	0.01	0.01
DMI, kg	7.46	7.52	7.38	7.36^{a}	7.84	7.20	7.31	7.87^{b}	0.21	0.16	0.01	0.01
G:F deads-in	0.15^{a}	0.15^{a}	0.15	0.16	0.17^{b}	0.17^{b}	0.15	0.16	0.006	<0.01	<0.01	0.01
G:F deads-out	0.15^{a}	0.15^{a}	0.16^{a}	0.16	0.18^{b}	0.18^{b}	0.17^{b}	0.17	0.006	<0.01	0.53	<0.01

[a,b] Within a row and within a season, means with different superscripts differ among cattle origin ($P \leq 0.02$)

[x,y,z] Seasons without a common superscript differ ($P \leq 0.04$)

Table 4.2 Animal health outcomes for light-weight calves originating from either Mexico or the United States received during each quarterly season of the year

| | Mexican | | | | Native | | | | | P-value | | |
Item	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	SEM	COO	Season	COO × Season
Death loss, %	1.89	3.57[a]	4.53[a]	3.45	5.22	10.95[b]	15.07[b]	5.21	2.96	<0.01	<0.01	0.02
Processing cost, $ per head	14.17[a]	12.89[a]	14.12[a]	14.72[a]	21.60[b]	21.83[b]	20.69[b]	20.08[b]	1.26	<0.01	0.92	0.02
Medicine cost, $ per head	7.60[a]	3.61[a]	8.41[a]	12.35[a]	29.80[b]	35.76[b]	39.63[b]	29.88[b]	3.57	<0.01	0.08	<0.01
1st pull, %	8.08[a]	7.84[a]	18.89[a]	15.64[a]	26.43[b]	45.56[b]	50.68[b]	29.92[b]	8.32	<0.01	0.01	0.01
2nd pull, %	3.71	3.77[a]	6.40[a]	4.08[a]	8.13	22.79[b]	28.80[b]	10.57[b]	6.05	<0.01	0.01	0.01
3rd pull, %	1.63	3.19[a]	2.97[a]	2.07	3.14	12.18[b]	13.75[b]	3.70	4.12	0.01	0.01	0.02
Case fatality rate, %	15.76[x]	28.94[yz]	13.23[xz]	12.60[x]	10.01[x]	19.11[yz]	22.05[xz]	10.50[x]	7.68	0.46	<0.01	0.09

[a,b] Within a row and within a season, means with different superscripts differ among cattle origin ($P \leq 0.02$)

[x,y,z] Seasons without a common superscript differ ($P < 0.001$)

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CHAPTER V

SUMMARY

Carbohydrates, namely fiber and starch, are the major macronutrient found in all cattle diets. Differences in the end products of fermentation of these carbohydrates results in differences in the efficiency of energy utilization as well as feeding performance and the composition of gain in beef cattle. Historically, the efficiency of the conversion of digestible energy to metabolizable energy has been demonstrated as ME = DE × 0.82. This equation assumes that energetic losses in urine and methane production are constant for all diet types or forage: concentrate ratio. Results from this study indicate that the efficiency of conversion of DE to ME linearly increases as the proportion of concentrate (starch) increases in the diet. Additionally, starch concentration in growing diets is generally a point of concern for cow-calf producers or backgrounding facilities when considering diets fed to early-weaned, light weight beef calves prior to the finishing period. In this study, growing diets of divergent starch concentration did not negatively affect subsequent finishing performance or final carcass characteristics. Therefore, backgrounding diets can be formulated up to 30% starch on a dry matter basis on a least cost basis without concern for impacts during the finishing period.

Results from the modeling exercise demonstrate that feedyard producers may choose to make purchasing decisions based upon point of origin of feeder cattle, although, season upon arrival to the feedyard should also be considered.

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