EVALUATING FEASIBILITY OF ALTERNATIVE FEEDING METHODS FOR

LIMIT-FED COW-CALF SYSTEMS

A Thesis

by

JESSICA RAE BABER

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

MASTER OF SCIENCE

Chair of Committee,	Tryon A. Wickersham
Co-chair of Committee,	Jason E. Sawyer
Committee Members,	David P. Anderson
Head of Department,	H. Russell Cross

December 2016

Major Subject: Animal Science

ABSTRACT

To evaluate the performance and economic sustainability of alternative intensified cow-calf production systems, two trials were conducted and a simulation model was built. In experiment 1, a limit-fed total mixed ration (80% of NRC predicted NE_m requirements, 52.88 mg/kg $EBW^{0.75}$) was separated into a roughage and concentrate component where concentrate was fed at -2, 0, 2 or 12 h after forage delivery to determine effects on nutrient utilization and solid passage rate. Experiment 2 was conducted to compare BW and BCS changes over 112 d of limit-fed production systems, fed either as a total mixed ration (**TMR**) or as roughage and concentrate components fed separately (**SEP**), to a conventional hay (**HAY**) fed system. A simulation model based on a cow-calf enterprise budget was constructed to determine economic viability of the three production systems. Four levels of intake (70, 85, 100, and 115% of NRC predicted NE_m requirements) were compared for the two limit-fed systems, TMR and SEP. Stochastic variables in the model included weaning weights, prices of weaned steers and heifers, and feed ingredient prices.

Time of concentrate delivery relative to roughage did not affect DM or OM digestion ($P \geq 0.88$). Nadir of pH was consistently observed 4 to 8 h after concentrate was delivered, but mean ruminal pH was similar among treatments ($P = 0.22$) ranging from 6.44 to 6.55 for 2S and 12S, respectively. Treatment did not affect final BW (1143 lb; $P = 0.72$) or BCS (5.6; $P = 0.67$), but tended to affect final RE ($P = 0.06$) with RE of 137.1, 98.9 and -14.6 Mcal for TMR, SEP, and HAY, respectively.

Probability of negative net returns was 0.35 for HAY, which was slightly less than the probability observed in the TMR at 115% (0.37). All other probabilities for negative returns ranged from 0.13 (SEP 70%) to 0.30 (TMR 115%). Limit-feeding of TMR or separate delivery of forage and concentrate rations sustained cow performance compared to ad libitum hay consumption. Economic analysis suggests limit-feeding cattle is preferred to hay feeding, and that separate delivery of forage and concentrate would be most profitable and least risky.

ACKNOWLEDGEMENTS

Completing this degree has been one of the most challenging yet gratifying things I’ve done, and it would not have been possible without the help, support, and guidance of many. I would like to thank my committee: Drs. Tryon Wickersham, Jason Sawyer, and David Anderson. Each of you have uniquely contributed to my experience throughout my program and I’m grateful to have you as mentors. Dr. Wickersham: I’m not sure there is a way to ever thank you enough for all opportunities you’ve given me. Over the past 5 years, you’ve continually challenged me to grow and become a better student and researcher. Dr. Sawyer: Whenever I had questions about running statistics, I knew I could count on you for guidance. Although you and Dr. Wickersham had many other obligations, you always made time to discuss my projects and any questions I had. Dr. Anderson: Thank you for taking the time to talk with me about how to incorporate economics into my research. I’ve enjoyed taking your class and am grateful for all the support you’ve provided. Additionally, I would like to extend my appreciation to Dr. Richardson, who has taught me everything I know about simulation modelling.

Over the years, I’ve enjoyed getting to work with many graduate students, student workers, and 491 research students. Original 017B posse (Merritt, Courtney, Kyle, and Josh): Thank you for putting up with me when I was just starting out as a student worker, answering all of my questions, and setting the example of what it means to be a graduate student. Merritt: you probably don’t realize the impact you made on me as a student worker and graduate student, but I’m truly grateful for everything you taught me during the time we spent together. Thank you Amelia for being an awesome roommate, friend and coworker. You have been there with me through everything (including the countless middle of the night samplings, snowcone and ice cream runs, and vent sessions). Myriah: thank you for introducing me to simulation modelling, something I never knew existed before you joined our lab. I’m grateful for all you have taught me over the years. I could always count on you and Alex for a laugh when I was worried about Dr. Richardson’s classes.

Alyssa, Levi, Natasha, Marcia, Caleb, Cassidy, Jessie, Nessie, Lauren, Courtney, Vinicius, Emily, Shelby, and Sarah: thank you sincerely for all the help you have provided during my feeding trials. Through the unique interests each of you have, I have been fortunate to have helped with many different types of research trials and learn something new from all of you. Student workers (Emily, Courtney, Jordan, and Natalie): I know what it’s like to spend hours grinding and weighing samples, and I’m very thankful for each of you to have helped me accomplish all of the labwork involved in these projects.

I would also like to extend my appreciation to the Wickersham family. Tryon, Erin, and Katherine: Thank you for including me in your family gatherings for every major holiday and letting me come help work cattle. I’ve enjoyed being able to watch Katherine over the years grow into the young girl she is today. Plus, she was always a great source of entertainment. Katherine will be such a great role model to Lydia.

To my family, I’m sorry I did not come home as often as you would have liked, but thank you for understanding and every time I called to say I wasn’t going to be coming home. Jenna and Kaleb: I’m sorry I wasn’t able to be as involved in your high school careers as you would have wanted, but I’m so proud of what you both have accomplished. Thank you for calling to update me on everything happening at home so I wouldn’t feel left out when I finally made it home and for listening to me as I talked about all of my projects. Mom and Dad: Thank you for the support and encouragement you have given me over the years. Because of you, I had the strength and courage to move 12 hours away and to follow my passion of agriculture. Growing up on the farm, you each instilled in me the values of hard work and discipline that have been instrumental in my career so far. There is nothing that I can say or do to make up for the time I’ve been away or to repay you for everything you’ve given me, but all I can say is thank you.

TABLE OF CONTENTS

Page

LIST OF FIGURES

Page

LIST OF TABLES

Page

CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

Introduction

As consumers gain spending power through rising in socio-economic status, diet becomes more diversified and consumers have more options available to them. In fact, consumers choose animal proteins more often than plant based sources for their protein needs. Gerbens-Leenes et al. (2010) reported increased consumption (% of total consumption) of animal sourced products, like meat and dairy products, as per capita GDP increased. Consumption of meat and eggs in developing countries, such as countries in Southeast Asia, has increased dramatically since 1970 (FAO, 2012). Additionally, developing countries are expected to increase imports of beef by

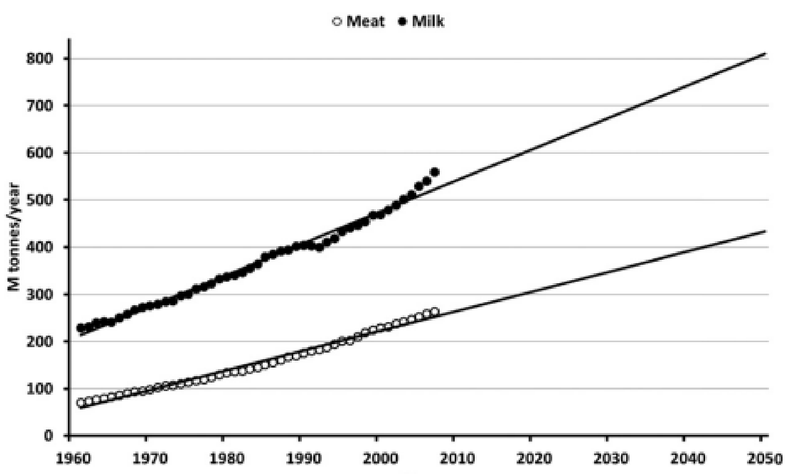

Figure 1. Linear projection of rates of increase of production of meat and dairy based on FAOSTAT data from 1960 to 2007. (From Boland et al., 2013)

4.1% from 2013 to 2022 whereas poultry and pork are expected to see 3.4 and 2.9% increases, respectively (Trostle and Seeley, 2013). Expected growth in population along with increased spending power of developing countries (Ozturk, 2016) has resulted in an increased demand for beef production (Figure 1).

At the same time global demand for beef is increasing, the long-term sustainability of cow-calf operations to produce beef is challenged by the dependency on grazing forage, especially during drought or other periods of reduced forage availability (Foran and Smith, 1991; Bahre and Shelton, 1993; Coppock, 2011). Hay is a common feed purchased when grazing lands are limited. However, hay tends to be overpriced ($/lb of TDN) compared to other sources of TDN, such as corn, and the price difference

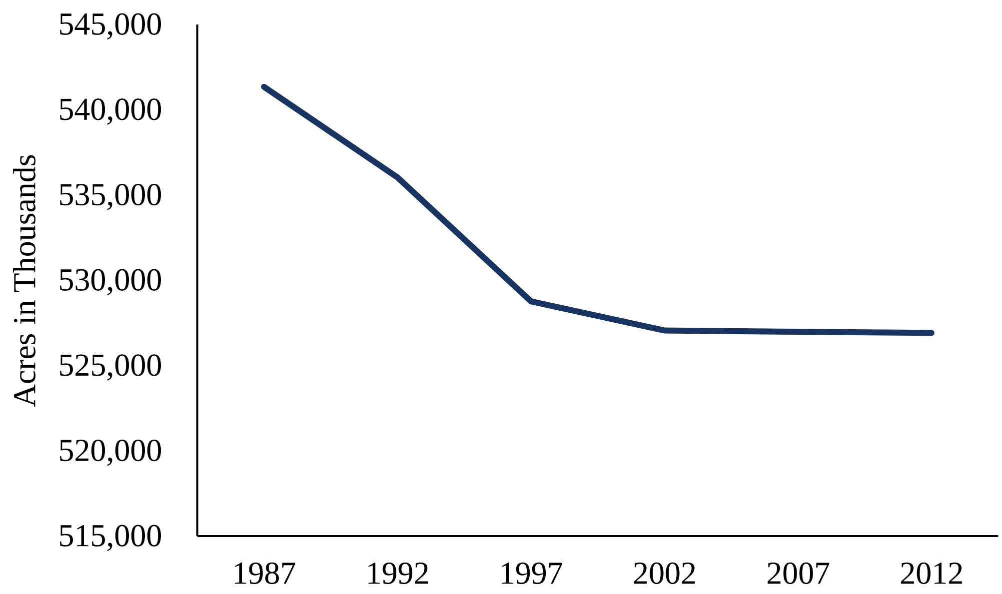

Figure 2. Acres of pasture and rangeland from 1987 to 2012. (Data from NRCS, 2015)

observed is further distorted in areas of regional droughts. Weather risk subjects grazing ruminant production systems to significant risk often resulting in the procurement of expensive feed resources (Tokgoz et al., 2008) or herd depopulation (NASS, 2016). Texas experienced a significant drought in 2011 causing a 12% decrease in the state's beef cow inventory (USDA, 2016), and it was estimated the drought which impacted the Midwest in 2012 cost Missouri livestock and poultry operations $547 million (Nixon, 2013). Midwest land values are influenced by commodity prices, and the historically high commodity prices experienced over the last 10 years has driven land values higher. Additionally, commodity prices have motivated farmers to convert pastureland to cropland (USDA, 2015). Diminishing pastureland availability over the last 30 years has impacted the ability of cow-calf producers to secure grazing lands needed (Figure 2)

Intensively managing cow-calf production systems in confinement or partial confinement has been one proposed solution to global food security and sustainability, and may meet challenges faced domestically offering an alternative in times of limited forage availability (Warner et al., 2011; Jenkins et al., 2015). Intensified cow-calf systems are not only useful when forage is limiting, but also when producers want to expand their cowherd without cost of purchasing more land. Perceived costs and managerial requirements of intensified systems may limit widespread adoption of these systems during times of limited forage availability and prevent further herd expansion in the United States.

Limit-feeding effect on production

When pastures are unavailable or not sufficient, an attractive alternative to liquidating the cow herd or purchasing large amounts of expensive hay is limit feeding cattle (Galyean, 1999). Additional motives to consider limit feeding in cattle are avoiding overconsumption by animals, simplifying bunk management, identifying sick cattle, and improving feed efficiency. Restricting feed, commonly used in cattle starting out on feed or in finishing cattle, is a way to control intake of an animal. Beef producers strive for improved feed efficiency in growing and finishing cattle so that feed costs per kg of gain are reduced. Most commonly, limit-feeding has been used in backgrounding operations and feedyards to improve efficiency and performance of cattle (Loerch, 1990; Sainz et al., 1995).

Hicks et al. (1990) demonstrated feed efficiency improvements in steers consuming rations primarily of wheat or corn. Steers restricted to 85% of *ad libitum* intake had a gain to feed of 0.124 whereas steers fed *ad libitum* had a gain to feed of 0.113. Loerch (1990) investigated the effects of restricting intake of high concentrate diets in feedlot cattle. Steers were fed *ad libitum*, 20%, or 30% restricted below *ad libitum*, but each intake level differed in diet composition with increasing energy density as intake was decreased. *Ad libitum* diet was silage (1.67 Mcal NE_m/kg), 20% restricted intake contained corn and silage (1.96 Mcal NE_m/kg), and 30% restricted intake was primarily corn (2.21 Mcal NE_m/kg). Intake was 5.9, 4.7, and 4.1 kg/d for *ad libitum*, 20%, and 30% restricted, respectively. As a result of the intakes offered and the formulation, energy intake was similar between treatments. Feed efficiency was improved from 0.149 to 0.215 as intake decreased from *ad libitum* to 30% restricted. However, it is hard to tell if this improvement is an effect of intake restriction or from increasing energy density of the ration.

A feeding regimen was implemented by Rossi et al. (2001) over three periods during the feedlot phase. During the first 68 d, steers were fed a ration containing approximately 92% concentrate *ad libitum* (8.2 kg/d) or fed (6.1 kg/d) to gain 1.13 kg/d. Restricting feed decreased feed efficiency by 8.0%, from 0.209 to 0.192. In the second 70 d, restricted intake was increased so steers would gain 1.36 kg/d; however, intake remained lower than control steers. Feed efficiency improved from 0.192 in the first period to 0.211 in the second period for restricted steers. Additionally, restricted steers had 20% greater feed conversion than *ad libitum* steers, 0.211 vs. 0.179, respectfully. For the final period, all steers were allowed *ad libitum* access to feed. Overall, feed efficiency was 4% greater for steers on the restricted treatment compared to steers given *ad libitum* access over the entire feeding phase.

Similarly, Murphy and Loerch (1994) restricted intake to 80 and 90% of *ad libitum* during both the growing and finishing phases or a control was fed *ad libitum.* Concentrations of NE_m were similar between treatments, and the finishing ration was formulated to contain more energy than the growing ration. Feed efficiency (0.16) was not different when intake decreased from 7.18 (*ad libitum*) to 5.74 kg (80%) during the growing period. However, once cattle reached the finishing period, feed efficiency increased linearly from 0.159 to 0.182 as intake decreased. When Murphy and Loerch (1994) restricting intake during only the feedlot phase, no effects were observed for intake level on feed efficiency which ranged from 0.194 to 0.197. Compensatory gain was likely resulted during the finishing phases in the studies by Rossi et al. (2001) and Murphy and Loerch (1994). Growth or energy restriction results in compensatory gain once cattle are refed above nutrient requirements, and the increased gain realized is likely due to differences in composition of gain with greater amounts of protein being deposited. Additionally, Sainz et al. (1995) suggests early energy restriction could be from changes in energy content of the gain, like previously mentioned, and also a decreased maintenance requirement for energy restriction cattle.

Energy intake was restricted in cattle during the growing phase in a study by Sainz et al. (1995). One group of cattle were fed a high forage diet *ad libitum* (1.87 Mcal ME /kg), a second group was fed a high concentrate diet *ad libitum* (3.06 Mcal ME /kg), and the final group was fed the high concentrate diet at a restricted intake level to match gain in cattle fed forage *ad libitum*. Accordingly, ME intake was greater in the high concentrate *ad libitum* treatment (25.7 Mcal/d) than the restricted high concentrate treatment (13.92 Mcal/d). Feed efficiency was reduced by 36% when cattle were restricted. In the finishing phase, cattle that switched from restricted high concentrate treatment to a high concentrate diet *ad libitum* were 31% more efficient than cattle remaining on concentrate *ad libitum* throughout both phases and 17% more efficient than those remaining on restricted intake of concentrate.

Energy intake is increased by increasing DMI or by increasing energy density of the ration. In the previously mentioned study by Hicks et al. (1990), greater gains from steers fed *ad libitum* were observed compared to intake restricted steers on the same diet

(1.35 vs. 1.25 kg/d). However, Rossi et al. (2001) reported cattle gained more when given *ad libitum* access to feed compared to restricted fed cattle. Although intake was restricted such that gain would be 1.36 kg/d, actual ADG was 1.75 kg/d which was greater than steers fed the same diet *ad libitum* (1.63 kg/d). In the first two periods, steers on a restricted level of intake tended to have lower ADG (1.51 kg/d) than steers fed *ad libitum* (1.60 kg/d), and during the third period all steers were given *ad libitum* access to the same finishing ration. Murphy and Loerch (1994) observed a linear decrease in ADG (1.34 to 1.07 kg/d) when intake was restricted from 100 to 90 to 80% *ad libitum* in feedlot cattle. During the 84 d growing period in a similar trial, steers consuming an *ad libitum* growing ration gained 0.24 kg/d more than restricted cattle (Murphy and Loerch, 1994). Since restricted cattle took longer to reach a similar end weight, days fed during the finishing period were increased by 14 and 28 d for 90 and 80% *ad libitum*, respectively. Accordingly, overall daily gain decreased as intake was restricted. In agreement with Murphy and Loerch (1994), Sainz et al. (1995) reported increased ADG from 0.69 to 1.96 kg/d as ME intake increased. Previously discussed studies fed the same diet at different DMI levels thus different levels of ME intake were fed. However, Loerch (1990) formulated diets for each level of intake restriction so that NE_m and NE_g intake (Mcal/d) was similar when steers were fed 70, 80, or 100% *ad libitum*. As a result, ADG (0.88 kg/d) was not affected by intake restriction (Loerch, 1990).

When calculating ME availability, restricting intake from 11.98 to 10.13 kg/d increased apparent ME concentration of the diet (2.66 vs. 2.84 Mcal/kg; Hicks et al., 1990). Diets fed in Murphy and Loerch (1994) contained similar NE_m concentrations (2.15 Mcal/kg). However, when calculated, NE_m concentrations increased linearly from 2.30 to 2.46 Mcal/kg, and similarly, NE_g concentrations increased from 1.60 to 1.73 Mcal/kg from when intake was reduced from 100 to 80% *ad libitum*. Linear increases in observed apparent energy availability may be attributed to increased energy digestion as intake was restricted. As intake or ME intake was restricted, cattle seemed to more efficiently utilize energy (Hicks et al., 1990; Murphy and Loerch, 1994).

Effects of limit-feeding on digestion and fermentation

In general, digestion of a diet decreases as intake increases (Galyean, 1979; Zinn and Owens, 1983; Murphy et al., 1994). Early research on digestion of limit-fed rations focused primarily on DM and starch. Anderson et al. (1959) increased intake from 0.5X maintenance to 2.7X maintenance and found total DM digestion decreased from 85.7 to 74.3%, respectively. The correlation coefficient reported was 0.99 between intake level and DM digestion, indicating a strong relationship exists between these two variables. Wheeler et al. (1975) fed four rations at two intake levels (*ad libitum* and maintenance) with varying forage-to-concentrate ratios. Forage in rations increased from 30 to 75%. Decreases between 9 and 12% were observed for starch digestion as intake increased from maintenance to 3.2 X maintenance (*ad libitum*) regardless of forage percentage in the diet. Kratchner et al. (1973) fed steers *ad libitum* (58 g starch/d/$EBW^{0.75}$) or 75% *ad libitum* of a diet that was 80% sorghum grain containing 66% starch. Total tract (98%) and ruminal starch digestion (63%) were not affected by intake restriction. Their observations likely resulted from ability of the rumen and small intestine to rapidly digest starch.

Galyean et al. (1979) further investigated the effects of the level of intake on nutrient digestion and found results similar to Anderson et al. (1959) and Wheeler et al. (1973). Steers were fed an 84% corn diet (2.11 Mcal NE_m /kg) and levels of intake consisted of 1.00, 1.33, 1.67 and 2.00 X maintenance. Steers consuming 1.67 and 2.00 X maintenance digested less DM and OM (78.9 and 77.6%, respectively) than steers consuming 1.00 and 1.33 X maintenance (85.7 and 84.1%, respectively). Ruminal DMD (66.2, 63.2, and 59.4% for 1.00, 1.33, and 1.67 X, respectively) and OMD (69.9, 67.0, and 63.1% for 1.00, 1.33, and 1.67 X, respectively) followed a similar pattern, likely explaining the total tract digestion differences. Passage rate of high concentrate diets when fed at greater levels may have been faster explaining the decreases in digestion observed. Steers fed high concentrate diets (80% concentrate) at increasing levels of intake relative to body weight (1.2, 1.5, 1.8, or 2.1% of BW) expressed a linear decrease in OM, and ADF digestion (Zinn and Owens, 1983). Starch digestion linearly increased from 79.6 (1.2% BW) to 91.0% (2.1% BW). Ruminal ADF digestion decreased from 32.2% when steers were fed 1.2% of BW to 0.0% when fed 2.1% of BW. Reduced ADF digestion likely resulted from shorter retention time when intake is increased, and increased amounts of non-structural (or rapidly fermentable) carbohydrates creating an unsuitable environment for fiber fermenting bacteria in the rumen. Results similar to OM and ADF digestion observed by Zinn and Owens (1983) have been reported in lambs which were fed 70, 80, 90, or 100% of *ad libitum* (Murphy et al., 1994). Digestion of

OM decreased from 82.4% (70% of *ad libitum*) to 77.7% (100% *ad libitum*). Digestion of ADF decreased approximately 12% when intake increased from 70 to 100% *ad libitum*; however, because the diet was primarily contained readily fermentable carbohydrates (92% concentrate diet), OM digestion only decreased 4%. Interestingly, when apparent diet ME was calculated for each treatment, there was a numerical decrease in the energy density from 2.98 Mcal/kg (70% *ad libitum*) to 2.81 Mcal/kg (*ad libitum*).

Murphy et al. (1994) reported effects of limiting energy intake on digestion in steers fed a corn silage based ration at 100, 90, or 80% of *ad libitum* intake. These intakes corresponded to calculated NE_m intakes of 1.7, 1.5, and 1.3 X maintenance, respectively. Digestion of DM was similar among treatments, although NDF digestion increased from 56.4 to 62.3% as DMI decreased. When a high concentrate ration was fed using the same treatments as previously stated, OM digestion was similar for 100 (82.8%), 90 (85.0%), and 80% (86.1%) of *ad libitum* intake.

Zinn et al. (1994) evaluated the effects of forage and monensin inclusion on digestion of a feedlot ration fed at 2.5% of BW. Net energy for maintenance was 2.27 Mcal/kg when forage was included at 10% and 2.16 Mcal/kg for 20% forage inclusion. No forage level effects were observed for ruminal OM or starch digestion; however, increasing forage level decreased total OM digestion from 83.5 to 81.2%. Similar to OM digestion, increasing forage inclusion from 10 (80.3%) to 20% (77.9%) resulted in decreased GE digestion. Monensin inclusion did not affect OM, ADF, starch or GE digestion at 10 or 20% forage levels. Zinn et al. (1995) quantified the interaction between corn processing (dry rolled vs steam flaked) and intake level (1.64 vs 2.38% of BW/d). Steam flaking corn resulted in greater apparent ME availability (3.09 vs 2.81 Mcal/kg) than dry rolled corn. Limiting intake increased total tract digestion of OM in steam flaked corn diet by 5% and only 1% for the dry rolled corn diet. Total tract OM digestion was likely a product of ruminal digestion of OM which was 56.5% for dry-rolled corn no matter intake level; but steam-flaked corn at fed at 2.38% BW/d was 10% lower than when fed at 1.64% BW/d.

Energy dense diets fed at restricted levels of intake had greater digestion than diets containing less energy (Trubenbach, 2014). A high energy (1.54 Mcal NE_m/kg) and low energy (1.08 Mcal NE_m/kg) diet were fed at 80% and 120% of NRC predicted NE_m requirements. Interactions between intake and energy levels were observed for OM and GE digestion. Organic matter digestion of the high energy diet increased 7.7% when intake was restricted from 120 to 80%, but the low energy diet only increased by 2.1%. Results from Trubenbach (2014) and Zinn et al. (1995) indicate increases in digestion from intake restriction may be exacerbated when diets with greater energy availability are fed.

Microbial population can adapt to but also influence the ruminal environment, with each species of bacteria performing optimally within a certain pH range. If pH decreases too much and for too long, cellulolytic fermenting bacteria may not be able to survive influencing the volatile fatty acids produced and the extent of fiber digestion. Mean ruminal pH was not different when the level of intake was increased above maintenance (Galyean et al., 1979), but pH tended to be greater (6.3) in the lowest intake

(1.0 X maintenance) compared to the highest intake (2.0 X maintenance; 6.0). Decreases in mean ruminal pH are reflective of the increased amounts of readily fermentable carbohydrate available in the rumen for fermentation as intake increased. Additionally, molar percentages of acetate (55%) and butyrate (22%) were not different when level of intake increased above maintenance. Murphy et al. (1994) observed that steers fed a concentrate ration at 90% of *ad libitum* had the greatest average pH, while the 80% of *ad libitum* was between *ad libitum* and 90% of *ad libitum*. Lowest pH was observed between h 6 and 9 for all treatments which is similar to results by Trubenbach (2014) when intake was restricted from 120 to 80% of NRC NE_m requirements. Ruminal pH dropped in restricted treatments to about 5.5 and remained relatively constant for the next 9 hours, whereas ruminal pH for *ad libitum* intake returned to baseline pH quicker. Erickson et al. (1999) evaluated bunk management strategies (*ad libitum* versus clean bunk) on ruminal pH and observed that average ruminal pH was not different for *ad libitum* (5.69) and clean bunks (5.75). Ruminal pH variance was greater in steers with clean bunk management (0.186) than steers on *ad libitum* intake (0.080).

Murphy et al. (1994) investigated effects of restricting intake on liquid dilution. When steers were fed a corn silage based ration, ruminal liquid dilution rate linearly decreased from 7.31 to 4.92 %/h as DMI decreased from 100 to 80% *ad libitum*. In a separate trial, a high concentrate ration was fed and similar linear effects were observed in steers (Murphy et al., 1994). However, because a high concentrate ration is less bulky than a silage ration, ruminal liquid dilution rate decreased from 4.31 to 2.01 %/h when DMI decreased. Adams and Kartchner (1984) also reported lower liquid dilution rates as forage intake decreased from 2.4 to 1.4% of BW, and attributed results observed with greater saliva flow. Furthermore, decreasing forage in a TMR from 60 to 40% decreased saliva production while eating from 3.45 to 2.84 L/kg (Maekawa et al., 2002) which supports the findings by Murphy et al. (1994).

To deliver a TMR, a mixer wagon or feed truck is required; however, this requires a significant capital investment by cow-calf producers wanting to implement a limit-fed production system. Larges investment in equipment can prevent some

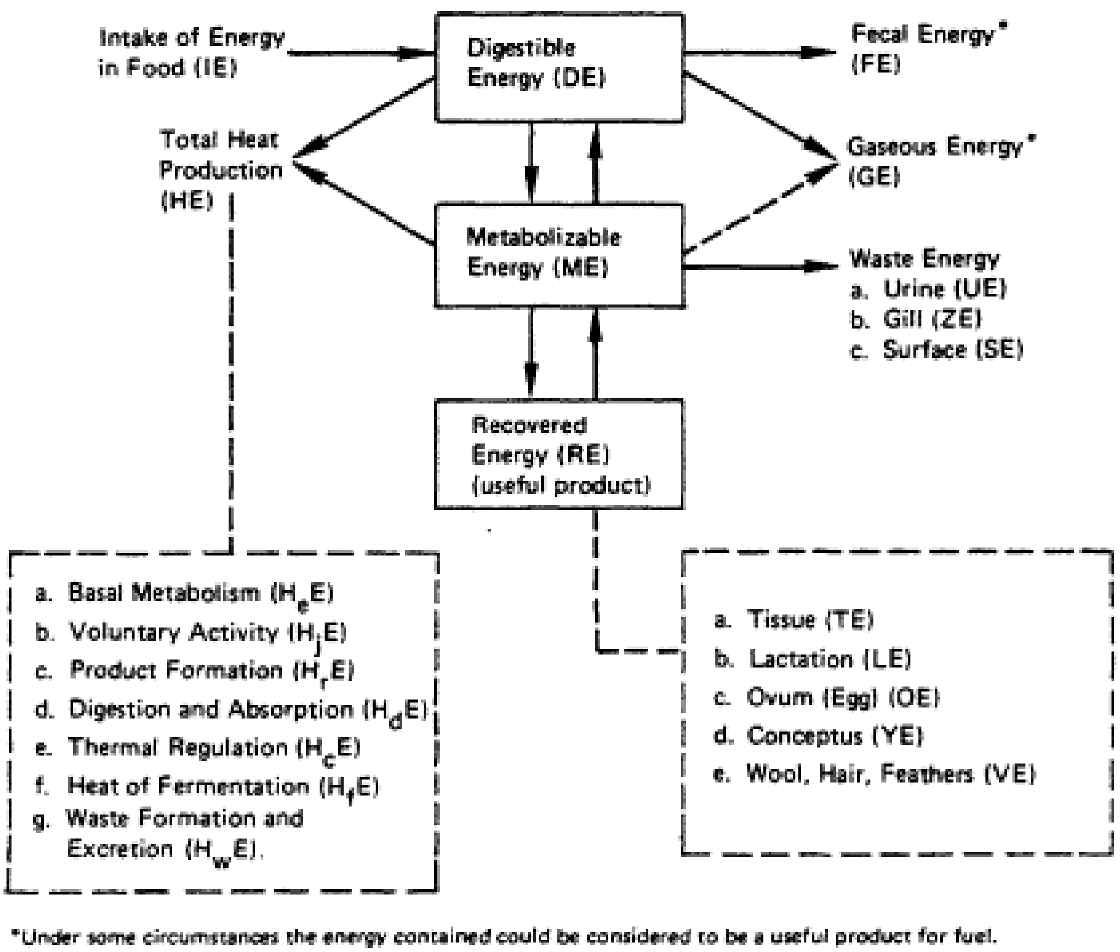

Figure 3. Diagram of energy utilization in the animal. (NRC, 1981)

producers from adopting intensified systems, but an alternative to a TMR may be a TMR deconstructed into two parts; forage and concentrate portions. Effects of feeding concentrate and forage separately or together on digestion and ruminal fermentation are unclear (Phipps et al., 1984; Gordon et al., 1995; Yan et al., 1998). However, depending on the amount of concentrate fed, fiber digestion can be depressed by 10 – 40% (Brink and Steele, 1985; Poore et al., 1990; Lardy et al., 2004), but when cattle are fed small amounts of concentrate, fiber digestion may not be negatively affected (Lardy et al., 2004). Depressed fiber digestion is observed because rapid fermentation of carbohydrates, in particular non-structural carbohydrates, results in decreased pH which alters the microbial population (Hoover, 1986; Dijkstra et al., 2012). Ruminal pH fluctuations are reduced by offering more meals throughout the day (Kaufmann, 1976). When a ration was separated into forage and concentrate fed at the same time, ruminal pH was not different from cattle consuming a total mixed ration (Yan et al., 1998).

Bioenergetics

Energy partitioning and utilization of feed by animals was established by the NRC (1981; Figure 3). Digestible energy (DE) is the amount of energy from feed energy intake (GE) minus energy in the feces. Metabolizable energy (ME) is the energy available to the animal for metabolism and is calculated as GE minus fecal, urine, and gaseous energy losses. Furthermore, ME from feed can be classified as either heat energy or retained energy. Retained energy is energy that is deposited as tissue, fetal growth, or milk production, but heat energy is another route for energy loss from the system. Seven types of heat energy are described: basal metabolism, activity, product formation, digestion and absorption, thermal regulation, heat of fermentation, and waste formation and excretion. Of the seven, product formation, digestion and absorption, heat of fermentation, and waste formation and excretion comprise heat increment. Heat increment is considered the energy associated with consuming feed. Maintenance energy requirements for the animal is heat energy produced when the animal is in a fasting state which is comprised of energy from basal metabolism, activity, and thermal regulation. Partial efficiency of energy utilization for maintenance, or proportion of ME that becomes heat energy, is greater than partial efficiency of energy utilization for growth, which is the proportion of ME that becomes retained energy.

Allowing producers to more precisely meet energy requirements of cows, but not exceed these requirements, is a benefit to providing feed in the form of a mixed ration. Producers can decrease feed costs when cattle are fed at their maintenance requirement. However, maintenance energy requirements in cattle seem to fluctuate depending on diet and intake, resulting in less rigid requirements than those described in the NRC (2000). Body weight stasis was achieved in response to reduced energy intake in study by Jenkins and Ferrell (1997). Cows were fed at multiple levels of intake (58, 76, 93, and 111 g DM/kg $BW^{0.75}$) and were fed until weight stasis was achieved for 8 consecutive weeks. When fed at the lowest level of intake, cows lost weight (20 to 110 kg), but were able to achieve weight stasis for 8 consecutive weeks (Jenkins and Ferrell, 1997). Freetly and Nienaber (1998) evaluated realimentation and energy efficiency of cattle fed at two levels of forage intake in 18 dry nonpregnant cows. Cows were fed *ad libitum* forage or 65% of *ad libitum* forage intake for 112 d. Losses in retained energy were greatest during the first 28 days after energy was restricted to 65% of *ad libitum* hay intake (Freetly and Nienaber, 1998) and remained in a negative energy balance through d 84. However, on d 112 restricted cows had retained energy values not different than zero suggesting cows achieved a “new” maintenance level. In another restricted feeding project, cows lost weight initially from d 0 to 28, but began to gradually gain weight over time as a new maintenance equilibrium was established. A new maintenance equilibrium was attributed to lower fasting heat production which was the result of a lower metabolic rate (Freetly and Nienaber, 1998). These data support the concept that the NRC (2000) may overestimate the maintenance requirements (77 kcal/kg of $EBW^{0.75}$) for limit-fed gestating cows. Trubenbach (2014) and Boardman (2015) estimated maintenance energy coefficients to be 54 and 62 kcal/kg of $EBW^{0.75}$, respectively, when mid-gestation cows were fed at 80% of NRC predicted maintenance energy requirements. Two diets (high energy with 1.56 Mcal NE_m/kg and low energy with 1.08 Mcal NE_m/kg) were fed at 80 and 120% of NRC predict NE_m requirements. Trubenbach (2014) observed a 41% decrease in maintenance requirements when cattle were fed 80% of maintenance requirements compared to NRC (2000) estimates. Although not as drastic, Boardman (2015) estimated an 18.4% reduction in maintenance requirements when cattle were fed the same diet as Trubenbach (2014) at 80% of maintenance requirements.

Effects of pre- and postpartum nutritional restriction

Energy intake restricted to less than maintenance requirements for cows reduced BW and BCS, but after cattle are refed at maintenance requirements (realimentation) these effects are diminished (Freetly et al., 2000; Camacho et al., 2014). Freetly et al. (2000) evaluated cow and calf performance under different feeding and realimentation strategies in mid- to late-gestation cows. Cows were either fed to lose body condition during the second trimester and regain condition during the last trimester, to lose condition during the second trimester and regain condition after 28 d of lactation to match BCS of other treatments by breeding (d 58), or maintain condition throughout pregnancy and lactation. At parturition, BW (552 kg) and BCS (5.5) was not different between cows maintaining condition throughout pregnancy and lactation and cows losing condition during pregnancy and gaining condition during lactation. Cows fed to lose condition during pregnancy and the first 28 d of lactation had lower BW (513 kg) and BCS (4.8). By 58 d after parturition, cows fed to lose condition until 28 d after parturition then realimented to gain condition had greater BW (584 kg) than the other two treatments (552 kg), but BCS was similar among all cows (5.2) which was a design of the trial. During this 30 d period, cows consumed 5 kg/d more than cows fed to maintain BCS and gained 70 kg. Camacho et al. (2014) restricted cows to 60% of NRC predicted NE_m requirements during early to mid-gestation (d 30 to 198). During the restricted intake period, both control fed (100% of NRC predicted NE_m requirements) and restricted cows lost BW over the 168 d period, but restricted cows lost more weight than controls. Change in BW from initial BW (expressed as a percentage) linearly decreased over time and restricted cows had a greater rate of BW change than controls. A treatment × day interaction was observed for BCS (Camacho et al., 2014). Across days, restricted cattle lost BCS decreasing from a 6 to less than a 3.4 whereas BCS in control cows remained near 6. Camacho et al. (2014) attributed the losses in BW but not BCS to underestimating maintenance requirements of the animal. During visual BCS assessment, cattle on treatments may have been compared where control cows may have seemed like they were not losing condition when in fact control cows were, but not as noticeable as the restricted cows. Once restricted cows were refed the control diet on d 140, restricted intake cows continued to have a lower BCS than cows fed to meet maintenance requirements throughout gestation.

As diets contain greater amounts of digestible energy, cattle are able to gain weight and improve body condition (Loerch, 1996; Schoonmaker et al., 2003). In gestating cows, limit-feeding corn has been explored as an alternative to wintering cows on hay (Loerch, 1996). Limit-fed cows ate 4.7 kg DM of corn, 1.2 kg DM of hay, and 1.2 kg DM of supplement. Limit-fed cows compared to cows consuming *ad libitum* hay (14.6 kg/d) were not different in final body weight or body condition score after 5 months. However, cows fed hay only had a greater decrease in BCS (-0.7) compared to limit-fed cows (-0.3). In a second trial, cows were limit-fed hay (0.8 kg DM/d) and more corn (4.9 kg DM/d) compared to *ad libitum* hay cows (Loerch, 1996). Weight change in this trial did differ between limit-fed cows (-53 kg) and hay cows (-23 kg), but BCS changes were similar, -0.7 and -0.6 for limit-fed and hay, respectively. Schoonmaker et al. (2003) also limit-fed during winter (November through February) to maintain mid- to late-gestation cows. Cows grazed orchardgrass, consumed a corn based limit-fed diet, or cows consumed *ad libitum* orchardgrass hay. Although body weight was not different between feeding methods at the end of the feeding period, BCS was greater for limit-fed cows (6.6) compared to cows fed hay (5.98) or on pasture (6.15). Even though these cattle were limit-fed a corn based diet, energy provided was similar to that of *ad libitum* hay fed cattle (approximately 14 Mcal NE_m/d).

Metabolic substrates such as glucose, acetate, propionate or amino acids provide positive or negative feedback to reproductive processes of cattle (Hess et al., 2005). Short and Adams (1988) suggested energy, specifically glucose, is an important substrate required for reproductive processes to occur. Once maintenance energy requirements are met, cattle can partition energy to other various uses depending on level of priority. The relative order of priority after maintenance is growth, pregnancy, lactation, estrous cycles and initiation of pregnancy, and excess reserves (Short and Adams, 1988). Order of priority tends to be relative since dairy cattle are an example where lactation is prioritized over pregnancy (de Vries and Veerkamp, 1999). If estrous cycles have not started and beef cattle are underfed, a normal release of gonadotropin and LH does not occur and additionally, ovulation does not happen (Short and Adams, 1988). However, if estrous cycles have started, underfeeding mainly impacts steroid production (Short and Adams, 1988).

Depending on timing of nutrient deficiencies or restriction, reproductive performance of beef cattle can be negatively impacted. Body condition scores and BW indicate the previous energy status of beef cows and these measures are used to predict the reproductive performance of cows after calving. Failure to return to estrous and rebreed by 80 days after parturition prevents a cow from staying in a one-year production cycle resulting in economic losses. Losses can be substantial due to failure to conceive or small but significant if the cow calves late in the season, resulting in lighter weaning weights (Dunn and Kaltenbach, 1980). A nonlinear relationship has been reported between BCS and postpartum interval with length of the interval getting longer when BCS drops to a four or below (Short et al., 1990). Also, postpartum interval is longer still when intake is restricted after calving. When BCS were reduced below 4 prior and at calving, postpartum anestrous intervals lengthen (Dunn and Moss, 1992) which is because cattle prioritize maintenance and growth before pregnancy (Short and Adams, 1988). Allowing cows to decrease condition and body weight during the second trimester and into early lactation did not impact pregnancy rates with rates of 93, 92, and 88% for cows fed to maintain condition throughout pregnancy and lactation, to lose condition during the second trimester and regain condition after 28 d of lactation, and to lose body condition during the second trimester and regain condition during the last trimester, respectively (Freetly et al., 2000).

As previously mentioned, Camacho et al. (2014) studied the effects of energy restriction on BW and BCS, but also determined impacts on uterine blood flow during gestation. Restricted and control cows had similar blood flow to the uterine horn containing the fetus during the restricted feeding period and blood flow increased throughout the feeding period. However, during the realimentation period, restricted cattle had greater total uterine blood flow and blood flow to the uterine horn containing the fetus. Treatments did not change the rate of increase in total uterine blow flow or blood flow to uterine horn containing the fetus. Also, there were no differences between treatments in blood flow to the uterine horn not containing the fetus during restriction or realimentation.

Selk et al. (1988) conducted a five-year experiment to evaluate relationships between prepartum BCS and BW on range cow reproductive performance. Cows were assigned to one of four feeding strategies: maintain BW, lose 5% of BW by 60 d prepartum then maintain BW, lose 5% of BW by 60 d prepartum then lose another 5% of BW after, or lose 5% of BW by 60 d prepartum then gain 5% of BW. Cows grazed forage and were supplemented cottonseed meal to produce the expected changes in BW. As per the design, cows restricted until 60 d prepartum lost approximately 23 kg and had a lower BCS (5.2) than cows fed to maintain BW (5.8). Regardless of treatment, cows lost weight between 8 weeks precalving and the time of breeding (50 kg on average). Selk et al. (1988) found minimal BW or BCS losses were associated with shorter periods to next conception. Body condition before calving was negatively correlated (-0.18) with days to ovarian luteal activity onset so as BCS decreased days to onset of ovarian luteal activity increased. A cubic response most accurately described the relationship between BCS and pregnancy percentage, where a change in BCS when cows were between a 4 and 6 has a greater response in pregnancy percentage than below 4 or above 6 (Selk et al., 1988). Moving from a BCS 4 to 5 would result in pregnancy rate increasing by 27%, and pregnancy rate increased further (28.6%) when BCS from 5 to 6.

Energy restriction has more of an impact on reproduction in beef cattle than protein deficiency (Dunn and Moss, 1992; DeRouen et al., 1994; Larson et al., 2009). When both are restricted (57% of NRC requirements for energy and protein) in the last

90 days before calving, BW and BCS are decreased (Hough et al., 1990). In first calf heifers, prepartum condition and weight was studied to determine the impact on reproductive performance (DeRouen et al., 1994). Heifers were fed hay and a supplement consisting of cottonseed meal and corn depending on treatment energy level. Intake of supplement provided low, recommended, or high levels of energy during the last 90 d of pregnancy. Heifers fed below recommended level of energy had lower BCS (-0.43) during the last 90 d of pregnancy, but gained 9 kg of BW. Change in BCS over the last 90 d of gestation for heifers fed at or above the recommended level either remained constant (0.03) or increased (0.23), respectively. First-calf heifers with a BCS of 6 or 7 had a greater pregnancy rate (89%) than first-calf heifers at BCS 4 or 5 (68%) and days to pregnancy was shorter (75 vs 87 d; DeRouen et al., 1994). Cows that were limit-fed corn during the winter to partially replace hay had numerically lower conception rates (90.0%) compared to *ad libitum* hay fed cows (95.1%), but this was not significant (Loerch, 1996). However, diets in this trial were formulated to meet or exceed maintenance requirements.

Cattle with a low BCS after calving may have an improved chance of breeding if put on a higher plane of nutrition (Richards et al., 1986). Three levels of postpartum energy intake were fed to beef cattle to determine effects on reproductive performance over a three-year period (Richards et al., 1986). Cows were fed at one of four nutritional levels: high, moderate, low, or low-flush. In cows with a BCS of 5 or greater, the cumulative percent of pregnant cows was not different between energy intake levels.

However, when BCS was less than 4, the percent of pregnant cows was 24% greater in cows fed to gain 0.45 to 0.68 kg/d compared to cows fed to lose 0.45 to 0.68 kg/d.

Calf performance and fetal programming from nutrient restricted dams

Overall nutritional status of cows during gestation may impact calf performance directly after birth. Additionally, long-term effects from maternal nutrient restriction during gestation may occur (Underwood et al., 2010). Fetal programming is the fetus' response to external signals experienced by the dam which alters fetal development (Du et al., 2010). During mid-gestation, decreases in number of muscle fibers and muscle fiber mass can be observed if maternal nutrient restriction occurs, and during late gestation, nutrient restriction has prevented intramuscular adipocytes from forming (Du et al., 2010). Protein restriction in mid- to late-gestation beef cows not only resulted in lower calf birth weight, but weaning weights were reduced by 10 kg (Stalker et al., 2007). Funston et al. (2010) postulated results from Stalker et al. (2007) were from fewer muscle fibers, which are fixed at birth.

In a previously mentioned trial conducted by Freetly et al. (2000) calf birth weights were reduced when cows were restricted during the last trimester and early lactation, 39.8 kg BW compared to 44.0 kg BW, but this difference diminished by 58 d of age (101 kg BW; Freetly et al., 2000). When postpartum energy intake of the dam is restricted, 90 d calf BW was 81 kg compared to calves from dams fed at a moderate or high level of energy intake which were 99 and 101 kg, respectively (Richards et al., 1986). Unlike the results of Freetly et al. (2000), calf weaning weight (205 d adjusted) were 182 kg in calves from low energy fed dams which was less than moderate (197 kg) or high energy (195 kg) fed dams (Richards et al., 1986). In a previously discussed trial, Loerch (1996) also measured calf performance in cows that were limit-fed corn during the winter. Calf birth weights were greater in calves from limit-fed corn cows (47 kg) than from hay fed cows (43 kg). Differences observed between the calves tended to carrying through to weaning, 306 and 286 kg for limit-fed and hay fed, respectively.

Economic fundamentals of ranching operations

Profitability must be considered when making management and investment decisions because the operation cannot survive if the business loses money for a long period. Profitability is measured with an income statement and is generally expressed as:

Net Income = Income – Expenses

Where:

Income = revenue received for the operation producing an output

Expenses = costs of resources used to produce the output

Income for a cow-calf operation consists of sales from weaned calves, cull cows and cull bulls with the majority of income coming from weaned calves. Producers can only influence income through weaning weights of the calves. While gross income is fairly straightforward, multiple variables impact total expenses and producers have more influence over these variables. Some of those variables include: feed costs, hired labor, veterinary and medicine, interest, depreciation, land leases, fuel and repairs on equipment, and investments in equipment and real estate. Often times net income is expressed on a per head basis meaning that the income and costs are spread over the entire head regardless of if that cow was productive or not. Profitability is impacted by numerous factors, some of which may be out of an operation's control. Cow-calf producers can experience wide swings in profit over a number of years due to market conditions; however, producers can influence their relative profitability compared to their peers through management decisions. Ultimately, determining what influences profitability can be difficult (Dhuyetter, 2012).

Economic efficiency and economies of scale

Economies of scale are the cost advantages that are realized due to the size of the operation. In the case of a cow-calf operation, this would the producers with larger herds. As fixed costs are spread across a larger number of cattle, total costs per cow decrease when economies of scale exist (Ramsey et al., 2005; Short, 2001; Dhuyetter, 2012). Ramsey et al. (2005) found herd size (coefficient of -0.006) decreased cost per cow but at a decreasing rate which was determined from a significant positive coefficient for herd size squared (3.708). Similarly, Dhuyetter (2012) found that in operations with less than 375 cows, profit increased at a decreasing rate when additional cows were added to the herd. Once operations were larger, profit per cow started to decline. Coefficients for herd size and herd size squared were negative (-0.70) and positive (0.0009), respectively, in the regression line for cost per cow. Costs, specifically fixed costs, were distributed across more cows allowing costs per cow to decline as herd size grew from 50 to 250. The positive coefficient for herd size squared indicated the declining costs occur at a declining rate, meaning as herd size continues to increase there is less of a decline in costs. However, it is important to note though that only 4 operations had greater than 375 cows which makes it difficult to be confident about what costs would be in herds greater than that.

Lower total operating costs were observed in operations that had more than 250 bred cows, which stemmed more from ownership costs than operating costs (Short, 2001). Featherstone et al. (1997) reported as the herd size approached 48 cows, the average cost curve leveled out indicating economies of scale exist up until this point with farms having increasing returns to scale. Once the farm had greater than 48 cows decreasing returns to scale were observed. The data set used by Featherstone et al. (1997) was for Kansas farms where, on average, 35% of the farm's total income was from beef cows and the average herd size was 97 cows.

Featherstone et al. (1997) also found the size of the operation (number of beef cows) was the most important farm characteristic explaining overall inefficiency in the farm. Larger farms were more efficient that the smaller farms. Technical efficiency can be defined as how effective an operation is at producing outputs with set inputs. Alternatively, how effective an operation is at producing an output with the fewest inputs. Feed costs were more important in explaining technical efficiency than other input variables such as capital, labor, or veterinary costs. Featherstone et al. (1997) reported farms were less technically efficient (78%) than allocative (81%) or scale (95%) efficient, which contributed to an overall efficiency of 60% for the Kansas farms. Furthermore, technical efficiency was more positively correlated with profitability than allocative or scale efficiency which suggests operations will see larger improvements in profitability when focusing on inputs such as feed costs which influence technical efficiency.

Kansas farms raising crops and livestock were analyzed to determine whether farmers optimized cost minimization or profit maximization (Featherstone et al., 1995). Producers between the years of 1973 and 1990, did not strictly rely on profit maximization or cost minimization. In fact, 52% of producers violated the profit-maximization hypothesis and 28% violated the cost-minimization hypothesis, suggesting farmers tend to minimize costs more than maximizing profits. However, significant numbers of farmers violate both of these hypothesis, possibly due to poor record keeping of the business (Featherstone et al., 1995). This supports the idea that most producers are risk-averse and that increased possibility of profit will be associated with increased risk.

Factors influencing profitability in cow-calf operations

In 1955, Breimyer summarized observations of the cattle cycle in which cattle numbers had expanded and contracted by 23 to 35% and the length of a cycle was between 10 and 16 years from 1880 to 1955. Similarly, Anderson et al. (1996) reported since 1928 cycles have averaged 10 years in length. These cycles occur because of the length of time it takes producers to respond to prices in the market. Dhuyvetter (2012) reported a similar trend for returns over variable cost for cow-calf operations in Kansas from 1979 to 2011. Approximately every 10 years cow-calf operations saw negative returns, possibly due to current market prices. Perhaps resulting in operators selling cattle which leads to contraction in the overall U.S. cattle inventory. However, other significant factors impacting profitability have been reported such as feed costs and ownership costs (Miller et al., 2001; Dhuyvetter, 2012).

Miller et al. (2001) evaluated control points for profitability in cow-calf operations. Data was collected from Iowa and Illinois producers. Feed costs accounted for 50% of the variation in profitability which was followed by depreciation costs. Other factors considered in the model were herd size, operating cost, capital charge, hired labor, calf birth weight, calf price, cull cow body weight, cull price, weaning percentage, and calving distribution and investment. These two critical factors (feed costs and depreciation costs) influencing profitability for cow-calf operations contributed to costs of production, suggesting returns to unpaid labor and management are driven more by costs than production performance and cattle prices.

Dhuyetter (2012) evaluated differences between Kansas producers with high and low profits from 2007 to 2011, and reported decreased feed costs of $80 per cow for operations in the top one third of profitability. Producers in the upper third had larger herd sizes of 191 compared to 92 cows in the bottom third of profitability. Additionally, decreased costs were observed for other variables associated with net returns such as depreciation, machinery and labor. Reduction in total costs enabled profitability to increase by $357 per cow. However, for this time period, the top one third of producers still lost $68 per head. Additionally, producers who are in the top one third in returns over variable costs were not necessarily in the top one third of producers for returns over total costs, indicating fixed costs also play a role in determining profitability of cow-calf operations.

Using cow-herd standardized performance analysis (SPA) data from Texas, Oklahoma, and New Mexico, Ramsey et al. (2005) evaluated factors impacting costs and profits of an operation. Independent variables used in a multiple regression equation for cow-herd costs and cow-herd profits included: herd size, herd size squared, investment in real estate, investment in machinery and equipment, investment in livestock, feed costs, calving percentage, calving death loss per exposed female, and length of breeding season. When a regression equation was fit for cow-herd costs, all independent variables were significant; however, when these same variables for fit for cow-herd profit, only 3 variables were significant (cow herd size, feed costs, and calving percentage). Neither the cost regression equation (R^2=0.3094) or the profit regression equation (R^2=0.1101) have very strong fit to the data, most likely because of large variances in the data. Machinery and equipment investment had a positive coefficient in the regression equation indicating this type of investment is associated with increased costs per head. Investment in machinery and equipment had a negative coefficient in the profit regression equation suggesting its relationship decreased profit. Amount of feed fed per cow was positively related to costs per cow and negatively related to profit. Additionally, amount of feed fed was significant for both estimated regression equations which is consistent with results from Miller et al. (2001). Feed (kg fed) was negatively associated with profit because there was production benefit associated with increased feeding more.

Similarly, Falconer et al. (1999) assumed Texas cow-calf producers prefer to minimize costs and estimated a cost function for Texas cattle producers using SPA data.

As grazing prices per acre were increased by 1%, the total cost of production for the producer increased by 0.14%. As other feed prices (per kg) were increased by 1%, the total cost of production were increased by 0.05%. From this analysis, Falconer et al. (1999) concluded grazing prices had a greater impact than other feed prices on the total cost of production. When feed costs, expressed as percent of total costs, increased by 1%, profit estimated by Dhuyvetter (2012) would increase $8.04 per cow. Expressing feed costs as a percent of total costs was a method to describe the management of costs not coming from feed.

Incorporating risk into agricultural models

Risk has been described as imperfect knowledge with a known distribution of probabilities whereas uncertainty is imperfect knowledge without a known distribution (Hardaker et al., 2004). Both of which exist in businesses and should be accounted for when making decisions. Therefore, when building models as support tools for cow-calf producers, these known probability distributions should be accounted for even though the producers do not have control over production risks (Richardson and Mapp, 1976). In agriculture and specifically the cattle industry, weather is a large source of risk. Other sources of risk can come from reproductive performance, weaning percentage, weaning weights, prices of feed ingredients and pasture, prices of cattle, or death loss. According to Patrick et al. (1985), producers viewed weather, input prices and output prices as the most important sources of risk to operations. Managing risk is difficult for ranchers, and if it is not considered when making management decision, losses in profit can occur.

Deterministic models for intensified or drylot cow-calf systems, like those presented by Anderson et al. (2013) and Warner (2015), do not incorporate risk. Decision making processes are simplified when producers use deterministic models because each scenario has only one outcome possible. Using simulation techniques, risk can be incorporated into models through stochastic, or random, variables which are based on a known probability distribution of the risky variable. Estimating a distribution of returns gives the decision maker multiple outcomes from one possible strategy because risk was simulated in the model (Richardson et al., 2000). Few have incorporated economic simulation models in ranching decisions (Adams et al., 1994; Van Tassell, 1997; Gadberry, 2010) and to our knowledge economic simulation has not been used extensively in intensified systems.

One of the first firm level models to evaluate investments with risk was developed by Richardson and Mapp (1976). Monte carlo simulation was used and critical stochastic variables were identified. Probability distributions were assigned to each stochastic variable and linked into the cash flow statement and net present value of the business. These are the basic steps of building a simulation model. Empirical distributions are commonly used in agriculture because distributions are often not normally distributed (Richardson et al., 2000). Additionally, historical agricultural data does not have adequate number of observations and using an empirical distribution fits the distribution to the historical data without requiring many observations. Correlating random variables when estimating forecasted variables is the multivariate component of the multivariate empirical (MVE) distribution which accounts for the historical correlations between the forecasted variables (Richardson et al., 2000). Another example of economic comparison incorporating economic simulation into agriculture was by Ribera et al. (2004). Conventional tillage and no till systems were analyzed using three crops on a South Texas farm. Yield and price data of each crop were used to forecast yield and price, and MVE distributions were used to construct probability distributions for these stochastic variables (yield and price of each crop). A partial budget was constructed and net incomes were simulated. Results from this model were presented as a cumulative distribution function (CDF) and using stochastic efficiency with respect to a function (SERF). A CDF shows the probability of net income being below zero or below certain levels of net income. However, CDFs of alternative strategies often cross each other when presented graphically making the decision process difficult. Thus, Ribera et al. (2004) reported graphs of certainty equivalences for each strategy and SERF incorporates the producers level of risk aversion.

Gadberry et al. (2010) used simulation techniques to evaluate the economics of break-evens with dried distillers' grains supplementation in calves grazing low-quality forage. In this evaluation, price of dried distillers' grains was not normally distributed so price was simulated through randomly selecting an observed price during the appropriate season (summer or winter). Because empirical distributions were not used like in Richadson and Mapp (1976) or Ribera et al. (2004), a truncated distribution was used as a way to cap the simulated values from being above or below the observed historical data set. Gadberry et al. (2010) found supplementing steers at 0.3 or 0.6% of BW had the greatest probability (0.99) of meeting or exceeding the break-even price of supplementing calves. However, if supplementation did not occur or calves were supplemented at 1.2% of BW, there was a lower probability of meeting or exceeding break-even price, 0.94 and 0.93, respectively.

Strategies to reduce feed costs

May et al. (1999) reported the effect of shifting calving season to align cow nutritional requirements to forage production in order to reduce feed costs. A multi-period mixed integer programming model (MIP) was used to analyze each calving month scenario's yearly feed costs. Feed costs were minimized subject to the cow's energy requirements, protein requirements and DMI. Body condition score was incorporated such that cattle must have a BCS 5 at calving in order for optimal reproductive performance. Many forage alternatives were available and cows were not able to graze two types of forage at once. Aligning forage production and a cow's nutrient requirements through June calving allowed for the greatest utilization of grazed forage reducing feeding costs ($173 vs $177-216 per cow). In this scenario, grazed forage provided 90.2% of CP and 91.2% of TDN consumed. Also, the lowest BCS occurred in January and February allowing cows enough time to regain condition before rebreeding for June calving herds.

Six grazing systems created from 3 winter treatments being cross classified with 2 spring treatments to analyze economic returns for cow/calf producers in the Nebraska sandhills over a period of 4 years (Adams et al., 1994). The three winter grazing systems were: 1.) grazing range, 2.) grazing subirrigated meadow, or 3.) full feed of meadow hay. Two spring systems were either subirrigated meadow hay or grazing subirrigated meadow then all other times of year all cows grazed range pasture. Calf performance was incorporated into the analysis and a partial budget was constructed to determine the sensitivity of each system to input price variation. Average return to other factors of production per calf was greatest for cows grazing winter meadow and may meadow ($455/calf vs $390-442/calf), partially because little hay and supplement was fed in comparison to other treatments. Grazing meadows in May was beneficial to improving returns compared to feeding hay.

Another strategy to reduce feed costs when there is little forage available to graze is intensifying the cow-calf system by putting cattle into confinement (Close, 2015; Warner, 2015). Intensified cow-calf systems research has focused primarily on cow performance (Trubenbach, 2014; Boardman, 2015) and not on the economic sustainability of the system. In a study previously mentioned, Loerch (1996) determined the effect of limit-feeding various amounts of corn or *ad libitum* hay to gestating cows on cow performance, calf performance, and also daily feed costs. As designed, DMI was greater for hay than corn. Subsequently, daily feed cost was greater for hay ($1.50) than corn ($0.77) when price of hay was valued at $0.088/kg and corn was $0.079/kg.

Intensified systems allow for incorporation of cheaper feed ingredients and profitability of this type of system has been estimated by Warner (2015). The year round intensified cow-calf system fed a base diet consisting of wet or modified distillers' grains plus solubles, corn stalks or wheat straw, and a premix. In this budget, total feed expense was more than 50% of total annual expenses with distillers' grains making up the bulk of the expense. Warner (2015) ran the model with the price of distillers' grains at varying levels of the price of corn and with the price of corn changing. As distillers' grains price decreased due to either the percent of corn price or actual corn price, *ceteris paribus*, profitability was improved, but was never sufficient to realize profits. Weaning rates were also altered and had a greater impact of profitability. As weaning rate increased from 75 to 95%, profitability improved. Additionally, Warner (2015) concluded that even if distillers' grains were priced in relation to $0.08/kg corn and weaned calf prices were $1.76 per 0.45 kg, revenues would not cover total costs and results in loss. Price estimates were used with known price parameters, but many times these parameters are unknown causing risk associated with implementing a new system like an intensified system.

Anderson et al. (2013) compared drylot and pasture cow-calf production systems from 2009 to 2012. Before yardage and manure was credited, cost per pair per year was $600.13 and $557.49 for drylot and pasture systems. Drylot cows were credited with manure value ($67.13/pair) and charged yardage of $40.02/pair which resulted in total net costs per pair per year to be $580.13 and $557.49 for drylot and pasture pairs, respectively. There were greater annual feed costs ($600.13 per pair) for drylot cows compared to pasture cows ($557.49 per cow). During 2009 and 2012, cow-calf producers experienced high feed prices which were reflective in the drylot feed rations. Daily feed costs were broken down by stage of production and compared to daily feed costs for pasture. Daily cost for the lactation ration was greatest ($1.72 per head per d) for drylot systems, but the cheapest for pasture systems ($1.00 per head per d). Mid-gestation ration cost was cheapest for drylot but intermediate for pasture systems, $1.25

and $1.36 per head per d, respectively. Last, late-gestation and calving ration was $1.63 per head per d for drylot systems and pasture cost per d for late-gestation cows was $1.59 per head per d. Additionally, diets fed to drylot cows were formulated to meet or exceed nutrient requirements which further increase feed costs for this system. Anderson et al. (2013) suggested more research is needed to find strategies to reduce feed and labor costs in drylot systems.

Conclusion

Limit feeding results in increased digestion through slower passage rates in the rumen, and appears to reduce maintenance requirements of cattle. Reproduction in beef cattle may be influenced by the cow's energy status depending on the degree of restriction. Body condition scores seem to be a useful tool in predicting reproductive performance. Purchasing or securing feed for the herd is one of the largest operating costs associated with cow-calf production. Limit-feeding allows producers to more precisely deliver nutrients required for maintenance, and producers are able to incorporate cheaper sources of feed into the diet. In larger herds, fixed costs are spread across a greater number of cattle, reducing fixed costs per cow. However, for small producers, these fixed costs per cow are much greater and limit the implementation of intensified systems unless alternative methods of TMR delivery are developed. For limit-feeding systems, more research is needed focusing on cow and calf performance and direct comparisons to conventional production systems. Further research is also needed to explore alternative delivery methods of a limit-fed system so that intensification is feasible for all producers. To evaluate the economic sustainability of these production systems, an economic analysis incorporating production data from these systems with current feed and cattle prices is needed.

CHAPTER II

EFFECT OF FEEDING METHOD ON NUTRIENT UTILIZATION AND COW PERFORMANCE OF MID- TO LATE-GESTATION COWS

Overview

Delivery of limit-fed, total-mixed rations requires significant capital investment and creates logistical challenges. Separate delivery of roughage and concentrate portions of diets may decrease feeding cost. Two experiments were conducted to evaluate the potential of separately limit-feeding roughage and concentrate. In experiment 1, 4 ruminally cannulated steers (371 ± 12 kg BW) were used in a 4 × 4 Latin square to evaluate the effects of time of concentrate delivery. Intake was restricted to 80% of NRC predicted NE_m requirements of a diet consisting of wheat straw (35%), cracked corn (29%), and distillers' grains (27%) formulated to contain 1.58 Mcal NE_m/kg. Treatments were: concentrate fed 2 h prior to wheat straw (**-2S**), concentrate and wheat straw fed as total mixed ration (**TMR**), concentrate fed 2 h after wheat straw (+**2S**), and concentrate fed 12 h after wheat straw (+**12S**). In experiment 2, 95 mid- to late-gestation cows (503 ± 151 kg) were used in a 112-d trial to evaluate feeding system on cow performance. Cows were assigned to one of 12 pens. Treatments were limit-fed TMR (TMR), roughage and concentrate portions of the limit-fed TMR separated and fed 12 h apart (SEP), and *ad libitum* Bermudagrass hay (HAY). Limit-fed treatments were fed the same diet as experiment 1. Body weight, BCS, and back fat measures were made every 28 d. In experiment 1, treatment did not significantly affect DM or OM digestion ($P \geq 0.88$).

No effects were observed for rate of particulate passage ($P \geq 0.55$), or ruminal DM fill ($P \geq 0.19$), which averaged 3.8 kg. Nadir of pH was consistently observed 4 to 8 h after concentrate was delivered, but mean ruminal pH was similar among treatments (P = 0.22) ranging from 6.44 to 6.55 for 2S and 12S, respectively. In experiment 2, treatment did not significantly affect final BW (518.4 kg; P = 0.72) or final BCS (5.6; P = 0.67). Treatment tended to affect final RE (P = 0.06) with RE of 137.1, 98.9 and -14.6 Mcal for TMR, SEP, and HAY, respectively. Delivering forage and concentrate separately did not change digestion and timing of concentrate delivery had only minor effects on ruminal fermentation. Limit-feeding a TMR or separate delivery of roughage and concentrate sustained cow performance compared to *ad libitum* hay consumption.

Introduction

Climatic variability, namely drought, subjects grazing ruminant production systems to significant risk often resulting in the procurement of expensive feed resources (Tokgoz et al., 2008) or herd depopulation (USDA, 2016). Long-term sustainability of beef as a global protein source improves when management options are developed to enhance production system resiliency (Darnhofer et al. 2010). One such option is development of sustainable intensified cow systems, where cows are limit-fed high-energy diets year round or for some portion of the production cycle (Warner et al., 2011; Jenkins et al., 2015). Previous research in our laboratory demonstrated that beef cows limit fed a high-energy diet (1.54 Mcal NE_m/kg) at 80% of NE_m requirements had reduced NE_m requirements (41%) compared to NRC (2000) NE_m requirements

(Trubenbach et al., 2014). An additional benefit of limit-fed systems is increased diet digestion (Galyean et al., 1979; Zinn and Owens, 1983; Murphy et al., 1994b).

Intensified systems that incorporate limit feeding a total mixed ration (TMR) potentially bring greater fixed costs to cow calf production. In a related publication, Coppock (1977) noted some of the primary disadvantages of feeding a TMR include the purchase of a grinder to process roughage and some method to deliver feed making a TMR an infeasible economic option for small producers. Therefore, to allow small producers to capture the benefits of limit-fed, high-energy rations an alternative method of processing and delivery is required The objective of this study was to compare separating the mixed ration into two components, a concentrate package and roughage package, on digestibility, ruminal fermentation, and passage rate in limit fed steers.

Materials and methods

The experimental protocol was approved by the Institutional Animal Care and Use Committee at Texas A&M University.

Experiment 1: Digestibility

Four steers (371 ± 12 kg of BW) fitted with ruminal cannulas were used in a 4 × 4 Latin square design. Steers were housed in an enclosed barn in individual pens (2.1 × 1.5m) with *ad libitum* access to water. Diets were fed at 52.88 g/kg $BW^{\wedge 0.75}$ (Table 1). Treatments consisted of: 1) concentrate delivered 2 h before hay (-2S), 2) hay and concentrate delivered as a TMR (TMR), 3) concentrated delivered 2 h after hay (+2S), 4) concentrate delivered 12 h after hay (+12S). Diets fed were restricted at 80% of NRC requirements for NE_m and wheat straw was fed daily at 0530 h. The four experimental

Table 1 Ingredient and nutrient composition of diets used in experiment 1 and 2.

Ingredient, % as fed	Limit-fed diet[1]	HAY[2]
Bermudagrass hay		100.00
Wheat Straw	34.52	
Corn	29.46	
Distillers' grains	27.46	
Mineral	2.46	
Urea	1.10	
Molasses	5.00	
Nutrient Composition, % DM Basis		
OM	92.80	91.31
CP	16.50	7.72
NDF	48.17	74.20
ADF	26.20	41.40
ME, Mcal/kg[3]	2.47	2.04
NE_m, Mcal/kg[3]	1.56	1.19

[1] Limit-fed diet fed to all treatments in experiment 1 and limit-fed systems in exeriment 2.
[2] Bermudagrass hay was fed *ad libitum* to conventional hay system in experiment 2.
[3] Estimated using BCNRM (2016).

periods contained: 1) 11-d for adaptation to treatments, 2) 7-d for intake and digestion measurements, 3) 1-d for ruminal fermentation profile, and 4) 1-d for rumen fill and solid passage.

Intake and digestion observations were made on d 12 through 18. Wheat straw and concentrate samples were collected on d 12 through 17 to correspond with fecal samples collected on d 13 through 18. Fecal bags were placed on steers to collect feces over a 24-h period. After feces was thoroughly mixed and weighed, a sample was collected (5% of total fecal matter) and frozen at -20°C.

A suction strainer (Raun and Burroughs, 1962; 19 mm diameter, 1.5 mm mesh) was used to collect rumen fluid samples prior to feeding (0 h) and 2, 4, 6, 8, 12, 14, 16, and 20 h after feeding. A portable pH meter (Symphony, VWR; Radnor, PA) was used to measure rumen pH of each sample immediately after each sampling time. Subsamples of rumen fluid were prepared for subsequent analysis of VFA. Before freezing at -20°C, 8 mL of rumen fluid was combined with 2 mL of 25% *m*-phosphoric acid for VFA analysis. On d 20 of each period, ruminal contents were removed by manual evacuation prior to feeding (0 h) and at 4 and 12 h after feeding wheat straw. Rumen contents were weighed, 3 subsamples were collected (approximately 500 g each), and the remaining digesta was returned to the rumen.

Hay, grain, fecal, and rumen content samples were dried at 55°C in a forced-air oven for 96 h, allowed to air equilibrate for 24 h, and weighed to determine partial DM. Samples were ground in a Wiley mill to pass a 1 mm screen. Hay and grain samples were composited on equal weight basis, while fecal samples were composited by steer across days within period. Hay, grain, fecal, and rumen content samples were dried at 105°C for 24-h to determine DM. Loss in dry weight during combustion for 8 h at 450°C was used to determined OM. Analysis of NDF and ADF were performed using an Ankom Fiber Analyzer with sodium sulfite admitted and without correction for residual ash (Ankom Technology Corp., Macedon, NY). Direct calorimetry using a Parr 6300 Calorimeter (Parr Instrument Company, Moline, IL) was used to measure gross heat of feed and fecal samples. Acid detergent insoluble ash (ADIA) was determined by combusting Ankom bags containing ADF for 8 h at 450°C and weighing the residue.

Rumen fluid samples were thawed and centrifuged at 20,000 × *g* for 10 min at room temperature. Concentrations of VFA were measured using a gas chromatograph with methods described by Vanzant and Cochran (1994). Using colorimetric procedures described by Broderick and Kang (1980).

Experiment 2: Cow performance

Ninety-five dry, mid- to late-gestation crossbred cows (503 ± 151 kg) were used in an experiment to compare alternative feed delivery systems to conventionally hay fed. Treatments were 1.) cows limit fed a total mixed ration (TMR; 1.58 Mcal NE_m/kg) 2.) separately fed concentrate and wheat straw from the TMR treatment based off of digestibility findings in steers (SEP; 1.58 Mcal NE_m/kg) and 3.) *ad libitum* grass hay (HAY; Table 1). Intake of cows fed the TMR and SEP were set at 80% of NE_m level (g/kg $EBW^{0.75}$) according to NRC (2000). Cows were stratified by body weight, day of gestation, body condition score, and age then randomly assigned to a pen. Pen served as the experimental unit and pen was randomly assigned to treatment. Cows were fed from approximately d 121 to 240 of gestation and had *ad libitum* access to water. Prior to the start of the feeding period, cows were weighed on d -6 to determine amount to be fed and treatments were applied for 6 days prior to d 0 to allow for adjustments in gut fill. The feeding period was broken into four 28-day periods and on d 0, 28, 56, 84, and 112 measurements of body weight, ultrasound of rib fat thickness (between 12^{th} and 13^{th} rib), and body condition score (BCS; scale of 1 to 9; 1, emaciated; 9, obese; average of 3 trained personnel) were collected. Rib fat thickness was used in a regression equation to estimate body condition score. Both subjective and predicted body condition scores were used for estimation of body energy reserves and direct comparisons. Offspring weights and cow BCS were collected at birth and approximately 45 after birth cows and calves were weighed and BCS of cows were recorded.

Formulas

Experiment 1: Digestion

Digestion coefficients were calculated using:

$$[1 - (\text{nutrient output}/\text{nutrient intake}) \times 100]$$

Average DM fill was calculated using the following equation:

$$DM\ fill = \frac{DM\ Fill_0 + DM\ Fill_4 + DM\ Fill_{12}}{3}$$

where: *DM Fill* = Average DM fill, kg

$DM\ Fill_0$ = Rumen evacuation dry matter contents before wheat straw fed

$DM\ Fill_4$ = Rumen evacuation dry matter contents 4 h after wheat straw fed

$DM\ Fill_{12}$ = Rumen evacuation dry matter contents 12 h after wheat straw fed

Passage rate per hour was calculated using ADIA and the following equation:

$$PR = \frac{\left[\frac{ADIA_{in}}{ADIA_{rumen}}\right]}{24}$$

Where: *PR* = solid passage rate, %/h

$ADIA_{in}$ = intake of ADIA, kg

$ADIA_{rumen}$ = average of ADIA (kg) amount at rumen evacuation at h 0, 4, and 12

Experiment 2: Cow performance

Predicted BCS was estimated using a regression equation (reference equation) adapted from Herd and Sprott (1998).

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

where: X = rib fat, c

Empty body energy was calculated using equations published in the NRC (2000). Body composition was estimated using the following equations:

$$AF = 3.768 \times CS$$

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

where: AF = proportion of empty body fat, %

AP = proportion of empty body protein, %

CS = body condition score

$$TF = AF \times EBW$$

$$TP = AP \times EBW$$

$$SBW = 0.96 \times BW$$

$$EBW = 0.891 \times SBW$$

where: TF = total fat, kg

TP = total protein, kg

BW = body weight, kg

SBW = shrunk weight, kg

EBW = empty body weight, kg

$$TBE = 9.4 \times TF + 5.7 \times TP$$

where: TBE = total body energy, Mcal

$$RE = TBE_f - TBE_i$$

Where:

TBE_f = total body energy at end of period, Mcal

TBE_i = total body energy on d 0, Mcal

RE = retained energy, Mcal

Statistical analysis

Experiment 1: Digestion

Intake, digestion and ruminal passage parameters were analyzed using the MIXED procedure of SAS 9.3 (SAS Inst. Inc., Cary, NC). Terms in the model included treatment and period with steer as the random effect. Volatile fatty acid and pH were analyzed using MIXED procedure and terms in the model included treatment, hour, and hour × treatment. The repeated term was hour and treatment × steer being the subject. The LSMEANS in SAS was used to calculate treatment means.

Experiement 2: Cow performance

Measures of cow BW, subjective BCS, predicted BCS, and RE were analyzed using MIXED procedure of SAS 9.3 (SAS Inst., Cary, NC). Terms in the model were treatment, cow, and pen and the random effect was cow within treatment. Standard deviation of BW, BW change, and BCS were analyzed using the MIXED procedure of SAS 9.3 (SAS Inst., Cary, NC). Terms in the model included treatment and pen and the random effect was pen × treatment. Means for treatments were calculated using LSMEANS in SAS.

Results

Experiment 1: Digestion and ruminal fermentation

Nutrient intakes were similar among all treatments, as designed (Table 2; $P \geq 0.52$), and no differences in digestion of DM, OM, NDF, ADF or GE were observed ($P \geq 0.73$). Molar concentrations of total VFA was not significantly different between treatment ($P = 0.65$) and averaged 81.10 m*M*. Differences in mean ruminal acetate proportions between treatments were not observed ($P = 0.53$; Figure 4). A significant effect of time ($P = 0.04$) and a treatment × time interaction ($P = 0.01$) was observed for ruminal acetate proportions, driven by reductions in acetate proportions occurring after feeding concentrate for each treatment. Additionally, there was a significant treatment × time interaction ($P = 0.04$) and a tendency for an effect of time ($P = 0.08$) in propionate proportions (Figure 5). Similar to acetate proportions, an increase in propionate proportions occurred after concentrate was fed. Similar to acetate and propionate proportions, there was a treatment × time interaction ($P = 0.01$) for butyrate proportions with proportions increasing slightly 2 h after concentrate delivery (Figure 6). Molar percentages of butyrate, isobutyrate, isovalerate, and valerate were not significantly affected by treatment (P > 0.26) and averaged 8.19, 0.77, 0.88 and 0.59, respectively. Acetate:propionate ratios were not different between treatments ($P = 0.23$) and were 4.35, 3.91, 4.11, and 4.38 for -2S, TMR, +2S, and +12S, respectively. Additionally, there was a tendency for a treatment × time interaction to occur ($P = 0.08$; Figure 7). Lowest pH time points were observed approximately 4 to 8 h after concentrate was fed

Table 2. Effect of time concentrate is offered on nutrient intake and digestibility in steers consuming wheat straw.

	Treatment[1]					
Item	-2S	TMR	+2S	+12S	SEM	*P*-value[2]
No. of observations	4	4	4	4		
Intake, kg/d						
DM	3.34	3.34	3.34	3.34	0.04	0.67
OM	3.10	3.10	3.10	3.10	0.03	0.67
NDF	1.62	1.62	1.62	1.62	0.02	0.52
ADF	1.00	1.00	1.00	1.00	0.01	0.96
GE, Mcal/d	14.84	14.84	14.84	14.84	0.16	0.83
DE, Mcal/d	10.31	10.29	10.40	10.44	0.18	0.89
Total Tract Digestion, %						
DM	68.35	68.32	68.81	69.27	1.16	0.99
OM	71.07	71.17	71.74	72.09	1.12	0.88
NDF	61.08	62.70	62.55	62.07	1.68	0.90
ADF	51.01	52.88	53.89	53.68	2.12	0.73
GE	69.46	69.38	70.04	70.31	1.08	0.90

[1]-2S = Concentrate fed 2 h before wheat straw; TMR = Concentrate and wheat straw fed as TMR; +2S = Concentrate fed 2 h after wheat straw; +12S = Concentrate fed 12 h after wheat straw

[2] Treatments with differ superscripts differ ($P < 0.05$).

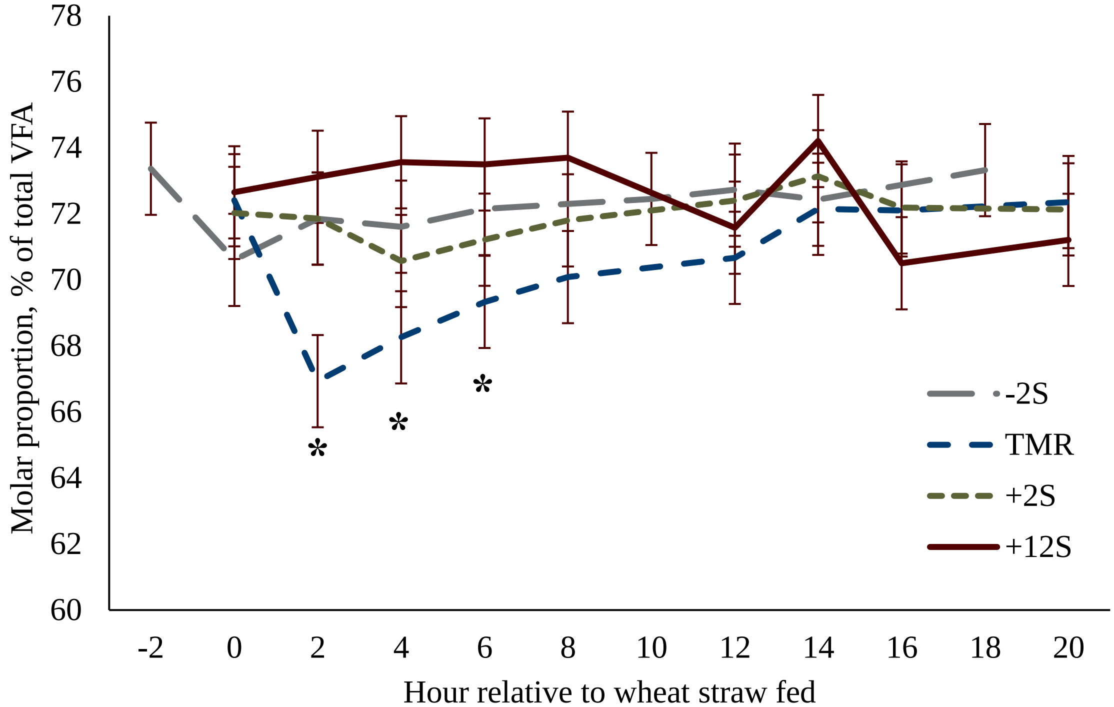

Figure 4. Effect of time of concentrate delivery on acetate production over time in steers consuming wheat straw. -2S = Concentrate fed 2 h before wheat straw; TMR = Concentrate and wheat straw fed as TMR; +2S = Concentrate fed 2 h after wheat straw; +12S = Conc fed 12 h after wheat straw. Significant effects of time (P = 0.04) and treatment × time (P = 0.01). * denotes time points where treatments differ.

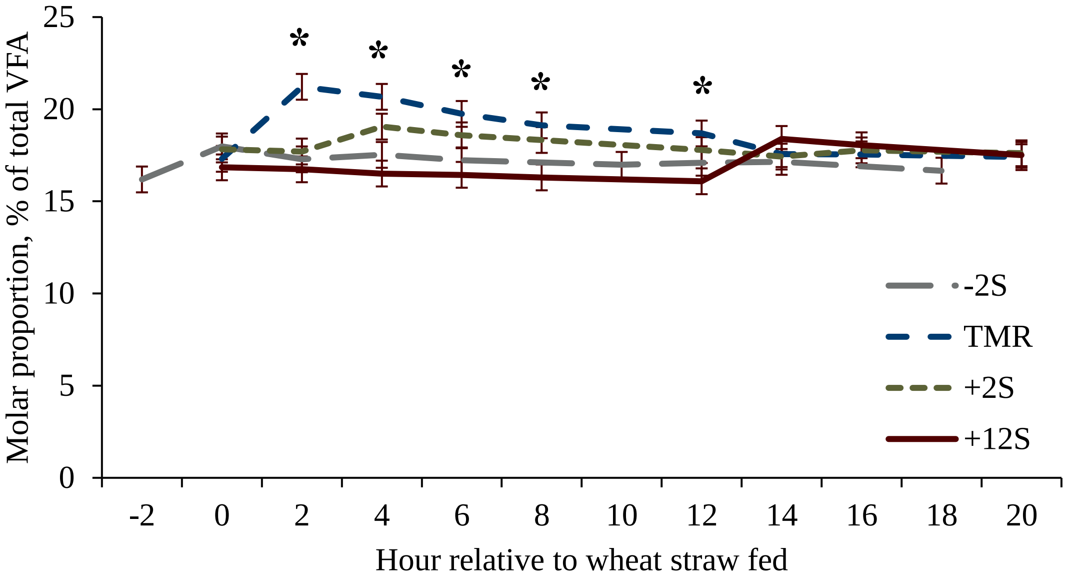

Figure 5. Effect of time of concentrate delivery on propionate production over time in steers consuming wheat straw. -2S = Concentrate fed 2 h before wheat straw; TMR = Concentrate and wheat straw fed as TMR; +2S = Concentrate fed 2 h after wheat straw; +12S = Concentrate fed 12 h after wheat straw. Significant effects of time (P = 0.08) and treatment × time (P = 0.04). * denotes time points where treatments differ.

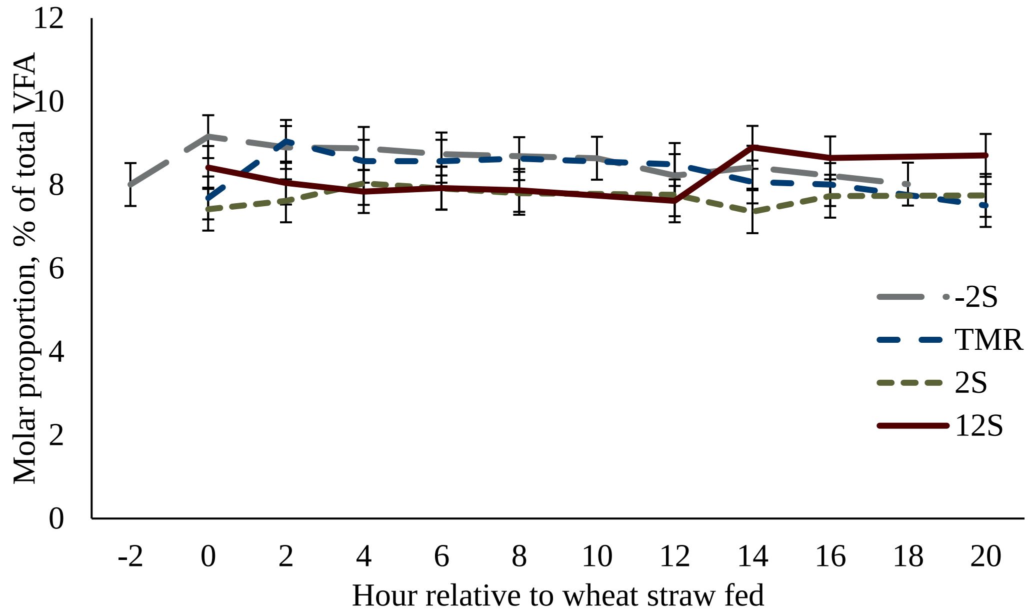

Figure 6. Effect of time of concentrate delivery on butyrate production over time in steers consuming wheat straw. -2S = Concentrate fed 2 h before wheat straw; TMR = Concentrate and wheat straw fed as TMR; +2S = Concentrate fed 2 h after wheat straw; +12S = Concentrate fed 12 h after wheat straw. Significant effects of treatment × time (*P* = 0.01).

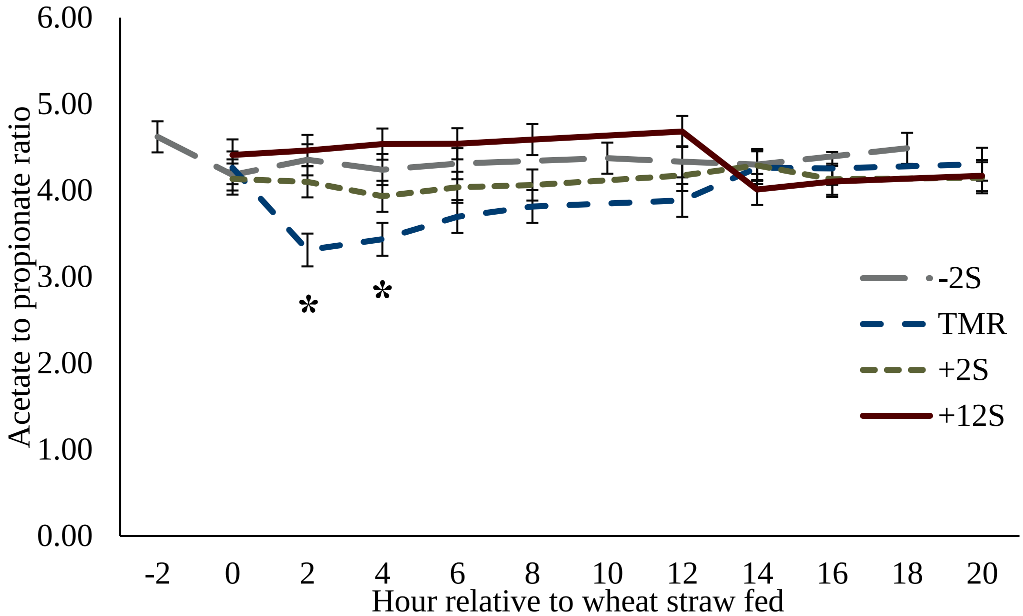

Figure 7. Effect of time of concentrate delivery on acetate to propionate ratio over time in steers consuming wheat straw. -2S = Concentrate fed 2 h before wheat straw; TMR = Concentrate and wheat straw fed as TMR; +2S = Concentrate fed 2 h after wheat straw; +12S = Concentrate fed 12 h after wheat straw. Significant effects of time ($P = 0.31$) and treatment × time ($P = 0.08$). * denotes time points where treatments differ.

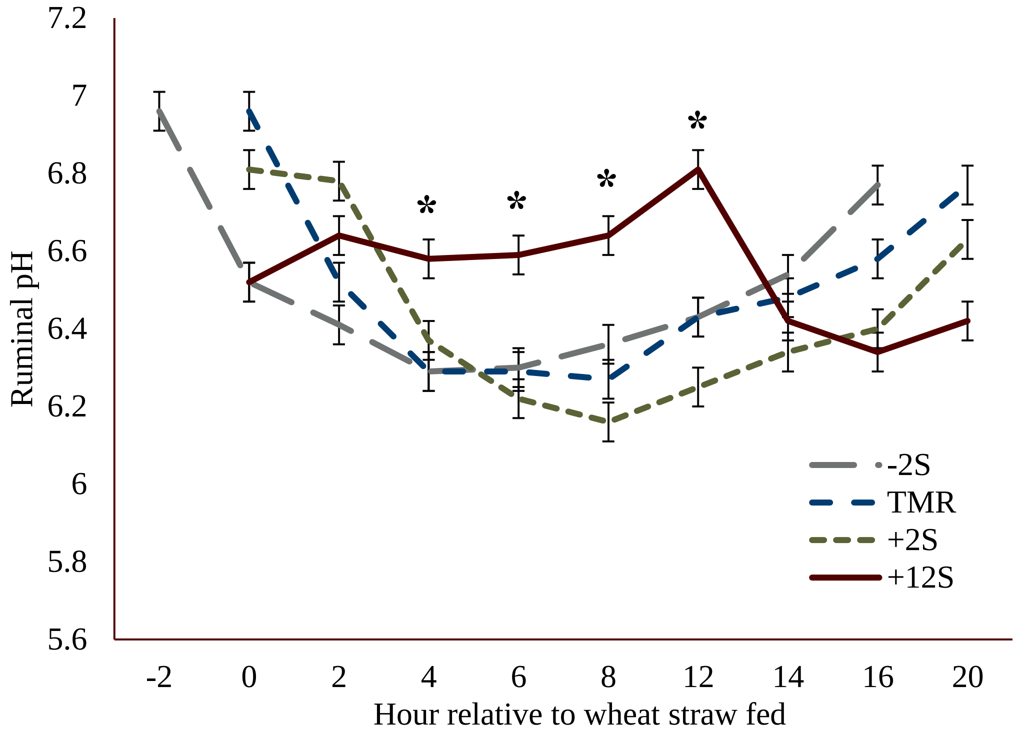

Figure 8. Effect of time of concentrate delivery on ruminal pH over time in steers consuming wheat straw. -2S = Concentrate fed 2 h before wheat straw; TMR = Concentrate and wheat straw fed as TMR; +2S = Concentrate fed 2 h after wheat straw; +12S = Concentrate fed 12 h after wheat straw. Significant effects of time ($P < 0.01$) and treatment × time ($P < 0.01$). * denotes time points where treatments differ.

for each treatment, but treatment means for ruminal pH were not significantly different (*P* = 0.22). There was a significant effect of time and treatment × time interaction for ruminal pH (*P* < 0.01; Figure 8). Ruminal fill of DM or ADF was not significantly different between treatments (*P* > 0.19; Table 3). Passage rates were similar between treatments as well (*P* = 0.55), with 12S treatment numerically lower than other treatments.

Table 3. Effect of time concentrate is offered on rumen fill and passage in steers consuming wheat straw.

	Treatment[1]					
Item	-2S	TMR	+2S	+12S	SEM	*P*-value
No. of observations	4	4	4	4		
Fill, kg/d						
DM	3.45	3.71	3.78	4.10	0.27	0.24
ADF	1.49	1.58	1.64	1.77	0.14	0.19
Passage Rate, %/hr	2.33	2.23	2.31	2.06	0.14	0.55

[1] -2S = Concentrate fed 2 h before wheat straw; TMR = Concentrate and wheat straw fed as TMR; +2S = Concentrate fed 2 h after wheat straw; +12S = Concentrate fed 12 h after wheat straw.

Experiment 2: Cow performance

Feeding system did not affect initial (d 0) or final BW (d 112) (Table 4; *P* ≥ 0.22), which averaged 502.5 and 518.4 kg, respectively. During the first 28 d, HAY cattle gained 6.8 kg while SEP and TMR lost 12.4 and 5.1 kg, respectively. Weight change in HAY from d 0 to 28 was significantly different than SEP and TMR system (*P* < 0.01) and SEP tended to be different than TMR (*P* = 0.08). In the first 28 d, HAY and SEP had weight changes that were different from 0 (*P* ≤ 0.03) while TMR tended to

Table 4. Effect of feeding method on cumulative and period body weight and subjective body condition score (BCS)[1] in mid- to late-gestation cows.

	Treatment[2]				
Item	HAY	SEP	TMR	SEM	*P*-value[3]
No. of observations	32	31	32		
Initial BW (d 0), kg	518.6	496.6	492.4	10.72	0.22
Period weight changes, kg					
d 0 - 28	6.8[a*]	-12.4[b*]	-5.1[b]	2.66	<0.01
d 29 - 56	7.6[*]	7.4[*]	6.8[*]	2.12	0.96
d 57 - 84	-7.3[a]	5.6[b]	7.8[b]	3.59	0.03
d 85 - 112	1.0[a]	16.0[b*]	13.5[b*]	3.82	<0.01
Change from initial body weight, kg					
d 28	6.8[a*]	-12.4[b*]	-5.1[b]	2.66	<0.01
d 56	14.4[a*]	-4.9[b]	1.7[b]	3.33	<0.01
d 84	7.1	0.6	9.5	4.36	0.37
d 112	8.1	16.6[*]	22.9[*]	5.15	0.17
Final BW (d 112), kg	526.7	513.1	515.3	12.69	0.72
Initial BCS (d 0)	5.71	5.45	5.47	0.09	0.14
Period BCS changes					
d 0 – 28	-0.04	-0.13	-0.07	0.08	0.73
d 29 - 56	-0.01	0.15[*]	0.07	0.06	0.21
d 57 - 84	-0.14[*]	-0.01	0.02	0.05	0.07
d 85 - 112	-0.06	0.11	0.07	0.07	0.24
Change from initial BCS					
d 28	-0.04	-0.13	-0.07	0.08	0.73
d 56	-0.05	0.02	-0.01	0.09	0.88
d 84	-0.19[*]	0.01	0.02	0.08	0.19
d 112	-0.25[a*]	0.12[b]	0.09[b]	0.07	0.01
Final BCS (d 112)	5.46	5.58	5.56	0.09	0.67

[1]Body condition score: 1 = emaciated ; 9 = obese.
[2]HAY = cows fed ad libitum hay; SEP = cows limit fed concentrate 12 h after wheat straw; TMR = cows limit fed total mixed ration once daily
[3]Treatments with differing superscripts differ (P < 0.05)
*Treatment is significantly different from zero (P < 0.05)

differ from 0 ($P = 0.08$). Weight change from d 29 to 56 was not significantly different between treatments ($P = 0.96$), but period weight changes were significantly different from zero ($P < 0.01$) for all treatments (7.6, 7.4, and 6.8 kg for HAY, SEP, and TMR, respectively). From d 57 to 84, HAY (-7.3 kg) was significantly different from SEP (5.6 kg) and TMR (7.8 kg; $P \leq 0.03$). Treatments, HAY and TMR, tended to be different from 0 ($P = 0.06$) for weight change between d 57 and 84, but SEP did not differ from zero ($P = 0.15$). In the final 28 d period, SEP gained 16.6 kg, TMR gained 13.5 kg, and HAY gained 1.0 kg. Period weight change was greater from d 85 to 112 for SEP and TMR than HAY ($P < 0.01$). Additionally, SEP and TMR were significantly different from zero ($P < 0.01$), but HAY did not differ ($P = 0.72$).

On d 56, weight change from initial weight (d 0) for HAY (Table 4; 14.4 kg) was significantly different from SEP (-4.9 kg) and TMR (1.7 kg; $P \leq 0.02$). Additionally, HAY was significantly greater than zero ($P < 0.01$). Change from d 0 to 84 and total change (d 0 to 112). By d 84, total weight change was similar between treatments ($P = 0.37$) which averaged 5.7 kg, but TMR (9.5 kg) tended to be different from zero ($P = 0.06$). Weight changes from d 0 to 112 did not differ ($P = 0.17$) and were 8.1, 16.6 and 22.9 kg for HAY, SEP, and TMR, respectively. However, total change in weight for SEP and TMR were significantly different from zero ($P \leq 0.01$) whereas HAY did not differ ($P = 0.15$).

Initial subjective BCS were 5.7, 5.5, and 5.5 (Table 4; $P = 0.14$) and final subjective BCS were 5.5, 5.6, and 5.6 for HAY, SEP and TMR, respectively ($P = 0.67$). For each period (d 0 to 28, d 29 to 56, d 57 to 84, and d 85 to 112), changes in subjective

Table 5. Effects of feeding method on cumulative and period back fat thickness and predicted body condition score (PBCS)[1] in mid- to late-gestation cows.

	Treatment[2]				
Item	HAY	SEP	TMR	SEM	*P*-value[3]
No. of observations	32	31	32		
Initial Back fat thickness (d 0), cm	0.73	0.86	0.77	0.07	0.91
Period back fat changes, cm					
d 0 – 28	0.05[*]	0.05[*]	0.10[*]	0.02	0.23
d 29 – 56	-0.02	-0.08[*]	-0.02	0.02	0.11
d 57 – 84	-0.08[a*]	0.01[b]	-0.03[ab]	0.02	0.02
d 85 – 112	-0.03	-0.06[*]	-0.03	0.02	0.52
Change from initial back fat, cm					
d 28	0.05[*]	0.05[*]	0.10[*]	0.02	0.23
d 56	0.03[a]	-0.04[b]	0.07[a*]	0.02	0.01
d 84	-0.04[a]	-0.03	0.04[b]	0.02	0.05
d 112	-0.08[a*]	-0.08[a*]	0.01[b]	0.02	0.05
Final back fat thickness (d 112), cm	0.65	0.68	0.78	0.07	0.45
Initial PBCS (d 0)	5.80	5.86	5.94	0.25	0.91
Period PBCS changes					
d 0 – 28	0.18[*]	0.20[*]	0.39[*]	0.08	0.16
d 29 - 56	-0.04	-0.32[*]	-0.07	0.09	0.09
d 57 - 84	-0.31[a*]	0.00[b]	-0.15[ab*]	0.07	0.03
d 85 - 112	-0.14	-0.24[*]	-0.14	0.07	0.56
Change from initial PBCS					
d 28	0.18[*]	0.30[*]	0.39[*]	0.08	0.16
d 56	0.14[a]	-0.12[b]	0.32[a*]	0.08	0.01
d 84	-0.18[a]	-0.12[a]	0.17[b]	0.08	0.03
d 112	-0.32[a*]	-0.36[a*]	0.04[b]	0.10	0.03
Final PBCS (d 112)	5.48	5.50	5.98	0.26	0.35

[1]Predicted body condition score: 1 = emaciated ; 9 = obese.
[2]HAY = cows fed ad libitum hay; SEP = cows limit-fed concentrate 12 h after wheat straw; TMR = cows limit-fed total mixed ration once daily
[3]Treatments with differing superscripts differ (P < 0.05)
*Treatment is significantly different from zero (P < 0.05)

BCS were not significantly different between treatments ($P \geq 0.07$). However, from d 29 to 56 change in subjective BCS was significantly greater from zero for SEP (0.15; P = 0.03), but HAY (-0.01) or TMR (0.07) was not different from zero ($P > 0.26$). During the next period (d 57 to 84), HAY was significantly lower than zero (-0.14; P = 0.01), but TMR (0.02) and SEP (-0.01) were not different from zero ($P > 0.66$). On d 28, 56, and 84, changes in subjective BCS from initial subjective BCS (d 0) were similar between treatments ($P \geq 0.19$). However, total change in subjective BCS (d 0 to 112) for HAY (-0.25) was significantly different from SEP (0.12) and TMR (0.09; $P < 0.01$). Additionally, HAY was significantly lower than zero (P = 0.01), but SEP and TMR were not (0.12 and 0.09, respectively; $P > 0.13$).

Back fat thickness was not different between treatments throughout the feeding period (Table 5; $P \geq 0.45$). Initial back fat thickness (d 0) averaged 0.79 cm whereas final back fat thickness (d 112) averaged 0.70 cm. During the first 28 d, period change in back fat thickness was similar between treatments (P = 0.23). Additionally, HAY (0.05 cm), SEP (0.05 cm), and TMR (0.10 cm) gained back fat thickness and were significantly greater than zero ($P < 0.03$). Treatments lost back fat thickness (-0.02, -0.08, and -0.02 cm for HAY, SEP, and TMR, respectively) between d 29 and 56 (P = 0.11), but the only treatment significantly less than zero ($P < 0.01$) was SEP. Between d 57 and 84, HAY (-0.08 cm) lost more back fat than SEP (0.01 cm; $P < 0.01$) and TMR tended to lose more back fat than SEP (P = 0.09). Period back fat change for HAY during this period (d 57 to 84) was significantly less than zero ($P < 0.01$). During the final period (d 85 to 112), all treatments lost between 0.03 and 0.06 cm of back fat (P = 0.52), and SEP (-0.06 cm) was significantly different from zero (P < 0.01).

Change from initial back fat on d 56, was significantly different for HAY (0.03 cm) and TMR (0.07 cm) when compared to SEP (-0.04 cm; P < 0.03), however the only treatment to differ from zero was TMR (P < 0.01). By d 84, HAY (-0.04 cm) was significantly different from TMR (0.04 cm; P = 0.02), and SEP (-0.03 cm) tended to lose more back fat than TMR (P = 0.06). Change from initial back fat was not significantly different than zero ($P \geq 0.07$). Total change from initial back fat thickness on d 112 was significantly different for HAY (-0.08 cm) and SEP (-0.08 cm) compared to TMR (P < 0.03). Additionally, total change in back fat thickness for HAY and SEP were significantly less than zero (P < 0.01).

Predicted body condition scores (PBCS) were estimated from back fat thickness (Table 5). No treatment differences for PBCS were observed during the trial ($P \geq 0.33$). Initial PBCS were 5.80, 5.86, and 5.94 for HAY, SEP, and TMR, respectively (P = 0.91), and final PBCS were 5.48, 5.50, and 5.98 for HAY, SEP, and TMR, respectively (P = 0.35). During the first 28 d, period change in PBCS was 0.27 on average (P = 0.16) and treatments were significantly greater than zero (P = 0.04). Between d 29 and 56, period change in PBCS averaged -0.14 and was not different between treatments (P = 0.09). Period change in PBCS (d 29 to 56) for SEP was significantly lower than zero (P = 0.01). From d 57 to 84, period change in PBCS was significantly different for HAY (-0.31) and SEP (0.00; P = 0.03). Additionally, HAY and TMR (-0.15) were significantly lower than zero (P < 0.04). Although in the last 28 d (d 85 to 112) period change in

PBCS was not different between treatments (*P* = 0.56) and averaged -0.17, SEP (-0.24) was the only treatment significantly lower than zero (*P* < 0.01).

Total change from initial PBCS on d 56 was significantly different for HAY (0.14) and TMR (0.32) when compared to SEP (-0.12; *P* ≤ 0.04), and TMR was significantly different from zero (*P* < 0.01). On d 84, change from initial PBCS for TMR (0.17) was significantly different from HAY (-0.18) and SEP (-0.12; *P* < 0.03). There was tendency (*P* = 0.06) for change from initial PBCS on d 84 to be different from zero for TMR and HAY. Total change (d 0 to 112) in PBCS was -0.32, -0.36, and 0.04 for HAY, SEP, and TMR, respectively. Change in PBCS for HAY and SEP was significantly lower than zero (*P* < 0.01) and TMR (*P* < 0.03).

Retained energy was estimated using subjective and predicted BCS (Table 6). Retained energy calculated using subjective BCS will be discussed first. During the first 28 d of the trial, HAY (28.6 Mcal) retained more energy than SEP (-103.5 Mcal) and TMR (-46.8 Mcal; *P* ≤ 0.05). Additionally, RE for SEP was significantly less than zero (*P* < 0.01). Retained energy was greater for all treatments on d 56 and were 65.5, -17.8 and 13.0 Mcal for HAY, SEP, and TMR, respectively (*P* = 0.26). However, no treatment was different from zero (*P* ≥ 0.08). On d 84, RE averaged 30.77 Mcal (*P* = 0.65) and was not significantly different from zero (*P* >0.13). No treatment differences were observed in RE on d 112 (*P* = 0.06). Although RE on d 112 for HAY (-14.6 Mcal) was not different from zero (*P* = 0.72), SEP (98.9 Mcal) and TMR were significantly greater than zero (*P* ≤ 0.04).

Table 6. Effect of feeding method on total retained energy estimated from subjective and predicted body condition score (BCS)[1] in mid- to late-gestation cows.

	Treatment[2]				
Item	HAY	SEP	TMR	SEM	*P*-value[3]
No. of observations	32	31	32		
RE from Subjective BCS, Mcal					
d 28	28.58[a]	-103.53[b*]	-46.76[b]	23.97	0.01
d 56	65.54	-17.77	13.01	33.79	0.26
d 84	24.79	11.16	56.36	34.97	0.65
d 112	-14.61	98.86[*]	137.05[*]	40.01	0.06
RE from Predicted BCS, Mcal					
d 28	100.18[a*]	-12.26[b]	84.68[a*]	28.97	0.04
d 56	125.43[a*]	-67.87[b]	109.58[a*]	32.60	<0.01
d 84	-10.21[a]	-35.77[a]	115.68[b*]	39.66	0.05
d 112	-50.00[a]	-13.28[a]	159.26[b*]	49.80	0.03

[1] Body condition score: 1 = emaciated; 9 = obese.
[2] HAY = cows fed ad libitum hay; SEP = cows limit-fed concentrate 12 h after wheat straw; TMR = cows limit-fed total mixed ration once daily
[3] Treatments with differing superscripts differ (P < 0.05)

Table 7. Effect of feeding method on standard deviation of performance characteristics in mid- to late-gestation cows.

Item	Treatment[3] HAY	SEP	TMR	SEM	*P*-value[4]
No. of observations	4	4	4		
Standard deviation of body weight					
d 0	55.6	65.3	66.2	3.20	0.08
d 28	61.3	66.9	68.9	3.23	0.28
d 56	60.7[a]	69.7[b]	75.3[b]	2.58	0.01
d 84	62.9[a]	62.5[a]	79.3[b]	3.50	0.01
d 112	62.3[a]	71.4[ab]	83.3[b]	5.05	0.05
Standard deviation of change from initial body weight					
d 28	13.2	11.6	12.9	1.16	0.61
d 56	15.5	19.0	19.5	2.78	0.57
d 84	16.0[a]	23.5[ab]	26.1[b]	2.58	0.05
d 112	18.8	29.6	31.3	3.55	0.07
Standard deviation of BCS[1]					
d 0	0.52	0.48	0.54	0.08	0.87
d 112	0.47	0.50	0.57	0.08	0.72
Change	-0.05	0.02	0.02	0.06	0.62
Standard deviation of PBCS[2]					
d 0	1.40	1.50	1.30	0.15	0.66
d 112	1.45	1.65	1.36	0.20	0.60
Change	0.05	0.15*	0.06	0.07	0.51

[1] Body condition score: 1 = emaciated; 9 = obese.
[2] Predicted body condition score: 1 = emaciated; 9 = obese.
[3] HAY = cows fed ad libitum hay; SEP = cows limit-fed concentrate 12 h after wheat straw; TMR = cows limit-fed total mixed ration once daily
[4] Treatments with differing superscripts differ
*Treatment is significantly different from zero ($P < 0.05$)

Retained energy calculated from PBCS on d 28 was greater for HAY (100.2 Mcal) and TMR (84.7 Mcal) than SEP (-12.3 Mcal; $P \leq 0.04$). Additionally, HAY and TMR were greater than zero ($P \leq 0.02$) on d 28. Greater RE was observed for HAY (125.4 Mcal) and TMR (109.6 Mcal) than SEP (-68.9 Mcal; $P < 0.01$) on d 56 as well. Both, TMR and HAY, were greater than zero ($P < 0.01$). On d 84 and 112, RE for TMR (115.7 and 159.3 Mcal, respectively) was significantly greater than HAY (-10.2 and -50.0 Mcal, respectively), SEP (-35.8 and -13.3, respectively; $P \leq 0.04$), and zero ($P < 0.02$).

Standard deviation is presented as a method of quantifying variation within treatment for BW and BCS (Table 7). There was a tendency for less standard deviation in initial BW (d 0) for SEP (55.5 kg) than TMR (65.3 kg) and HAY (66.2 kg; $P = 0.08$). By d 28, this tendency disappears and no significant differences in BW standard deviation between treatments was observed ($P = 0.28$). However, by d 56, standard deviation of BW was greater for SEP (69.7 kg) and TMR (75.3 kg) than HAY (60.7 kg; $P \leq 0.04$). Similarly, TMR (79.3 kg) had a greater standard deviation of BW on d 84 than HAY and SEP and (62.9 and 62.5 kg, respectively; $P \leq 0.01$). Final standard deviation of BW (d 112) was greater for TMR (83.3 kg) than HAY (62.3 kg; $P = 0.02$), but SEP (71.4 kg) was not significantly different for HAY or TMR ($P \geq 0.13$). Standard deviation was calculated for the change in BW from initial BW (Table 7). On d 28 and 56, standard deviation of BW change from initial BW was not significantly different between treatments ($P > 0.57$) and averaged 12.59 and 18.01 kg, respectively. Standard deviation of BW change from initial BW on d 84 was significantly greater for TMR

(26.10 kg) than HAY (16.01 kg; $P = 0.02$). There was a tendency on d 112 for standard deviation of BW change from initial BW to differ between HAY (18.8 kg) and TMR (31.34 kg; $P = 0.03$).

Standard deviations of subjective BCS on d 0 and 112 for were not significantly different between treatments ($P > 0.72$) and averaged 0.51 and 0.51, respectively. Change in the standard deviations of subjective BCS from d 0 to 112 averaged 0.00 kg ($P = 0.62$). On d 0 and 112, standard deviations of PBCS were similar between treatments averaged 1.40 and 1.49, respectively ($P > 0.60$). Change between standard deviations on d 0 and 112 did not differ ($P = 0.51$) and were -0.10, -0.02, and 0.09 for HAY, SEP, and TMR, respectively.

Cows started calving approximately 45 days after the feeding trial ended, and average cow BCS and calf birth weights were reported (Table 8). No differences were observed between treatments for cow BCS at calving (5.0 on average; $P = 1.00$) or calf birth weight (33.7 kg on average; $P = 0.36$). Approximately 45 d after calving, cow BW, cow BCS, and calf BW were not significantly different ($P > 0.66$) and averaged 486.4 kg, 4.8, and 74.2 kg, respectively.

Table 8. Effect of feeding method on cow body weight, cow body condition score (BCS)[1], and calf performance after limit-feeding period.

Item	Treatment[2] HAY	SEP	TMR	SEM	*P*-value[3]
No. of observations	29	30	30		
At calving					
Cow BCS	5.0	5.0	5.0	0.13	1.00
Calf birth weight, kg	32.7	35.0	33.5	1.05	0.36
45 d after calving					
Cow body weight, kg	481.9	491.5	486.0	11.27	0.83
Cow BCS	4.7	4.8	4.8	0.11	0.74
Calf body weight, kg	71.8	76.5	74.2	3.56	0.66

[1] Body condition score: 1 = emaciated; 9 = obese.
[2] HAY = cows fed ad libitum hay; SEP = cows limit-fed concentrate 12 h after wheat straw; TMR = cows limit-fed total mixed ration once daily
[3]Treatments with differing superscripts differ

Discussion

To facilitate implementation of limit-fed production systems to all sizes of cow-calf producers, experiment 1 was designed to evaluate the effects of alternative feeding methods on nutrient utilization and fermentation in limit-fed steers. Treatments were designed to imitate a producer without the capabilities to feed a TMR. Therefore, a producer would feed one component and then the other (-2S or +2S) or feed one component in the morning and the other in evening (+12S).

No differences in digestion of DM, OM, NDF, or ADF were found in our study. Contrarily, Gordon et al. (1995) reported significantly lower total DM digestion for cows fed *ad libitum* complete diets than when separately *ad libitum* fed. When cows were intake restricted at 2.5% BW, digestibility of DM and OM were increased in cows fed ingredients separately than when fed in a TMR (Phipps et al., 1984). Cattle cannot selectively consume feed when fed at a restricted intake, likely no differences to be observed in our trial unlike what Gordon et al. (1995) and Phipps et al. (1984) found. Differences were not observed between treatments for GE digestibilities, and DE and ME were calculated from digestibilities of GE. When this diet was fed at the same level of restriction, Trubenbach (2014) and Boardman (2015) found similar digestibilities of OM (71.7 and 76.7%, respectively) and GE (68.6 and 75.2%, respectively). In experiment 1, energy availability was not altered by the time concentrate was delivered (2.54 Mcal ME/kg DM), but it was slightly greater than energy availabilities observed by Trubenbach (2014) and Boardman (2015), 2.18 and 2.38 Mcal ME/kg DM, respectively. The NRC (2000) predicts ME availability to be 2.45 Mcal/kg DM, which is lower than the observed ME availability in this experiment. This and the work done by Trubenbach (2014) and Boardman (2015), suggests the NRC (2016) is not able to accurately predict ME available to cattle in confined systems.

Increasing energy supplementation to grazing cattle in the form of barley can cause a linear decrease in ADF digestion (Lardy et al., 2004). Furthermore, Poore et al. (1990) reported potentially digested fiber (as % of NDF) decreases from 92.4 to 48.0% concentrate increases from 30 to 90% of the ration, (Poore et al., 1990). Observed NDF digestibilities averaged 62.1% in experiment 1, but this could be from increased digestibilities from restricting intake. A decrease in fiber digestion could occur, but because of the low amount of readily fermentable carbohydrates (approximately 36% of DMI according to NRC, 2000) fed in the concentrate portion and the degree of intake restriction this was not observed in our study.

It is known feeding large quantities of concentrates can cause acidosis and other metabolic issues (Tremere et al., 1968; Krouse, and Oetzel, 2006), however when fed in limited quantities these negative impacts may be diminished. An indicator of risk for acidosis is ruminal pH Ruminal pH fluctuations are reduced by offering more meals throughout the day (Kaufmann, 1976), and when a ration was separated into forage and concentrate fed at the same time, ruminal pH was not different from cattle consuming a total mixed ration (Yan et al., 1998). Similarly, +12S compared to all other treatments had reduced pH variation throughout the day, with lower peak and greater nadir pH time points. In experiment 1, mean pH was not different when comparing treatments, this may be attributed to limit feeding diets instead of *ad libitum*. The interaction between treatment and time was primarily driven by the time concentrate was delivered, which caused a decline in ruminal pH after the concentrate was delivered. Also, it is important to note is pH was never less than 6 for any treatment or time point, suggesting acidosis is not a high concern when feeding the two components separately.

Although total VFA production was not affected by treatments, the proportion of total VFA for acetate numerically decreased 2 h after delivery of the concentrate component of the diet. This resulted in the treatment × time interaction that was observed in experiment 1. However, when concentrate was fed for +12S, acetate proportion was numerically increased. Proportions of propionate for all treatments numerically increased when concentrate was delivered 2 h after concentrate was delivered. Similar to our results, Phipps et al. (1984) reported no differences in proportions of acetate, propionate or butyrate when ingredients were combined or separated at restricted intake levels for dairy cattle. Also in agreement with our results, Yan et al. (1998) found no differences in proportions of VFA or total VFA concentration when cows were fed a complete diet or separately fed that diet. When cows were separately fed in that study the roughage was offered once daily and the concentrate was offered in equal amounts 4 times throughout the day. The treatment × time interaction for acetate:propionate ratios were driven by time of concentrate delivery as well. Mean acetate:propionate ratio (4.18) was greater in experiment 1 than those observed by Trubenbach (2014) and Boardman (2015), 2.38 and 3.07, respectively. This may be a results of greater mean ruminal pH in our study creating a more conducive environment for the rumen microbial population to ferment and digest more substrate.

Boardman (2015) reported slower solid passage rates (%/h) when intake was reduced from 100 to 80% of NRC predicted NE_m requirements, 2.44 and 1.88 %/h, respectively. However, in our experiment, passage rates were slightly higher than that observed by Boardman (2015) when the diet was fed at the same level of energy restriction. Differences were not found between passage rates, DM fill or ADF fill likely because intake and digestion coefficients were similar in this trial.

Experiment 1 found there to be no detrimental effects on digestion or ruminal fermentation from separating a TMR into a concentrate and roughage component. As a result, a trial (experiment 2) was designed to compare performance of cows in alternative feeding methods for limit-fed cow-calf production systems to a conventional cow-calf system fed hay. Separated concentrate and roughage components were fed 12 h apart for SEP because this treatment (+12S) tended to be more different from TMR in experiment 1.

Although differences in fill had been accounted prior to starting experiment 2, initial body weights were similar among treatments. However, limit-fed treatments were numerically lower than HAY by approximately 24 kg. Body weight losses in limit-fed treatments were expected in the first 28 d. It has been well documented restricting intake decreases splanchnic tissue mass causing the decrease in BW observed during this period (Ferrell et al., 1986; Ortigues and Doreau, 1995; Chilliard et al., 1998). Since the gastrointestinal tract is a major contributor to maintenance energy requirements, requirements for limit-fed dry cows was likely lower than what the NRC predicted for maintenance (Trubenbach, 2014; Boardman, 2015). Trubenbach (2014) predicted ME_m requirements to be 41% below that predicted by NRC (2000) estimated ME_m requirements, and Boardman (2015) reported a 18% reduction. Once limit-fed cattle (TMR and SEP) reached a new maintenance energy equilibrium, cattle started to regain weight, ultimately gaining more weight over the 112 d trial than HAY. When Boardman (2015) limit-fed cattle a TMR at the same level of restriction, change in BW decreased in the first 28 d, but never returned to zero within 56 d like observed by TMR in experiment 2. Cows consuming *ad limitum* hay (HAY) were expected to maintain BW as our results show, which is similar to results reported by Loerch (1996).

There were no differences in initial or final BCS between treatments were observed, which is similar to results found for PBCS and back fat thickness. In a trial feeding limit-fed corn or *ad libitum* hay to cows during winter (November to April), BCS was not different between treatments, but the decrease in BCS was greater for hay than cows limit-fed corn (Loerch, 1996). Similar to BW results of TMR and SEP, when a new maintenance equilibrium was reached, limit-fed cattle regained condition when BCS was recorded through visual observation. In contrast to BCS, PBCS increased over the first 28 d then declined for all treatments during the rest of the feeding period. Body condition scores observed by Camacho et al. (2014) when cattle were limit-fed at 60% of NRC predicted maintenance energy requirements continued to decrease throughout the entire experiment, which is in contrast to both methods of estimating body condition in this experiment. Additionally, Camacho et al. (2014) fed cattle at 100% NRC required NE_m and found body condition score was not affected. However, in our experiment, cattle on HAY maintained condition until after d 56 where subjective BCS started to decline. There was a similar trend with PBCS for HAY. Predicted body condition score increased significantly in the first 28 d for HAY, however after d 28 PBCS continued to decrease throughout the trial. Trend over time was similar for PBCS and back fat thickness since PBCS was estimated from back fat thickness. Although Boardman (2015) did not report PBCS, it can be inferred PBCS was not affected during the 56 d feeding period with a change in back fat of 0.01 cm. In experiment 2 at d 56, results from SEP agreed with results by Boardman (2015), but TMR had a significant increase in both back fat thickness and PBCS.

Body condition scores were the average of scores from 3 trained personnel. Cattle were assessed for BCS in the pen in an effort to avoid bias observations when cattle left the chute. Because of this, trained personnel were aware of what cattle were on

HAY yet limit-fed treatments were not differentiable, possibly causing bias in each system throughout the trial. Whereas estimates of PBCS were obtained from estimated back fat thickness through ultrasound and were not biased from knowledge of treatment. In previous studies (Trubenbach, 2014; Boardman, 2015), BCS predicted from back fat was primarily used to quantify RE at the end of the feeding period, not to detect changes in BCS over time which was an objective of experiment 2. Additionally, cattle in those studies had a lower back fat thickness initially (0.50 cm thinner) than cattle used in our study. The equation from Herd and Sprout (1998) is a quadratic equation causing greater changes in BCS when back fat is less than about 0.7, but as back fat thickness continues to increase past this changes in BCS are not as pronounced. This equation may have been good at predicting BCS of thinner cattle, but possibly it was a less reliable equation when cattle have more back fat. Throughout our trial, cattle visually scored as a BCS 6 or 7 were greater than a PBCS 8 using the equation from Herd and Sprout (1998). Visual observation took in the overall condition of the whole cow, whereas PBCS only took into account fat deposition on the back.

Hay wastage was approximated at 10% of hay offered to the system. Cattle consumed approximately 11.83 kg DM/d of hay throughout the trial (Table 9). One reason HAY lost BCS in the later part of the trial could be intake decreased, but the day each bale of hay was fed was not recorded so this cannot be substantiated. Additionally, this trial was conducted over the winter from October 8 to February 3 which could possibly account for why cattle fed *ad libitum* hay had decreasing subjective BCS in the colder and rainier months of the trial. This time period also corresponds to the beginning of the third trimester, which is a time when the fetus experiences rapid growth. It is likely Bermudagrass hay alone was not sufficient to maintain BW, BCS or RE estimated from BCS.

Table 9. Intake, energy intake and feed costs per cow of each cow-calf production system.

	Treatment[2]		
Item	HAY	SEP	TMR
Feed offered, kg AF/d	14.85	5.58	5.58
Feed cost, $/kg	0.14	0.17	0.17
Total feed cost, $/d	2.10	0.99	0.99
Feed waste, kg AF/d	1.48		
Estimated DMI	11.83	4.97	4.97
ME consumed, Mcal/d	24.13[a]	12.62[b]	12.62[b]
Feed cost, $/Mcal consumed	0.09	0.08	0.08

[a] Calculated from estimated DMI and BCNRM (2016) ME concentration for bermudagrass.
[b] Calculated from estimated DMI and ME concentration found in experiment 1.

Retained energy was estimated according to NRC (2000) equations using BCS and BW which caused RE to follow pattern similar to those variables. Energy required to move from a BCS 4 to a BCS 5 would be approximately 207 Mcal according to the NRC (2000), and RE (Mcal) is a good indicator of maintenance equilibrium. No treatments resulted in biologically significant changes in BCS. Cattle on HAY gained body energy in the first 56 d then RE became negative in the following 56 d, indicating cattle were losing energy reserves. Although RE was only numerically lower than maintenance, however it could be inferred from the trend of RE that energy reserves may continue to decline if treatments were continued. Freetly and Nienaber (1998) fed cattle brome hay 135% above maintenance energy requirements and did not see BW, BCS or RE losses like observed in this trial. Limit-fed cattle were in a negative energy balance during the first 28 d, then continued to gain body energy for the next 84 d when RE was estimated from BCS. Although cattle in limit-fed systems were fed below NRC (2000) predicted estimates for NE_m, TMR had RE values greater than zero, whereas cattle fed *ad libitum* hay were losing energy reserves according to both methods of predicting RE even though cattle likely fed above maintenance requirements (Table 9). Limit-fed treatments (TMR and SEP) were numerically greater than HAY but not significantly different, yet energy reserves were different by approximately 135 Mcal. Boardman (2015) estimated RE to be negative (-7.17 Mcal) after 56 d of limit-feeding this diet. Retained energy estimated from both BCS and PBCS on d 56 was negative for SEP but positive for TMR. Both treatments were different from zero implying cattle were either maintained energy reserves or had reached a new maintenance equilibrium and started to gain body energy. This is similar to findings by Trubenbach (2014) and Boardman (2015) which reported cattle had reached a new maintenance equilibrium. Retained energy estimated from BCS returned to zero between d 42 and 84 for limit-fed treatments (TMR and SEP), indicating maintenance requirements had decreased and excess energy was available to be stored in the body. This is slightly sooner than the 112 d Freetly and Nienaber (1998) observed when cattle were restricted to 65% of *ad libitum* intake of brome hay.

When considering cow-calf production systems, variation of the herd is an important consideration. It becomes more difficult to meet nutrient requirements of all cows in the herd without overfeeding some when there is large variation in BCS and BW and this causes feed costs to increase. Due to social dominance that exists within herds (Grant and Albright, 2001), less aggressive cattle may not be ideally suited for an intensified feeding system because subordinate cows will not consume the same amount of feed. Standard deviation was measured to estimate variability differences within each system. Initial variability in BW did not exist, but final BW standard deviations were greater for TMR than HAY. Additionally, TMR had a significant increase in standard deviation indicating intensified systems cause increased variation within the herd and possibly cause more cattle to leave the system. Increased variation was caused from the competitive environment that was created through limiting feed availability. Feed was typically completely consumed within an hour of it being delivered. It was hypothesized there would be more variation for SEP because the concentrate containing most of the nutrients was consumed much quicker than the TMR. However, this was not substantiated by the results found in this experiment. Further work is needed in group fed intensified systems for understanding bunk space requirements at various levels of feed intake and impacts on DMI variation within the herd.

Conclusions

Producers, who lack the capability to deliver a mixed ration, are not able to capitalize on benefits from an intensified limit-fed system. Findings from experiment 1 suggest delivering forage and concentrate separately will not change digestion, and timing of concentrate delivery has little impact on ruminal fermentation. Additionally, experiment 2 found limit-feeding a TMR or separate delivery of roughage and concentrate sustained cow performance compared to *ad libitum* hay consumption. Together these findings demonstrate cow-calf producers can choose how an intensified system is implemented to best fit their capabilities so that profitability can be continued in times of limited forage availability. Furthermore, development of sustainable intensified cow systems for different sized operations like those proposed in this study helps to improve the long-term sustainability of beef as a global protein source.

CHAPTER III

AN ECONOMIC COMPARISON BETWEEN LIMIT-FED AND CONVENTIONAL COW-CALF PRODUCTION SYSTEMS DURING PERIODS OF REDUCED FORAGE AVAILABILITY

Overview

Drought and land values challenge the economic sustainability of cow-calf production. Creating an intensified cow-calf system reduces a producer's dependence on sufficient forage production and (or) allows them to more efficiently use available forage resources. However, delivery of limit-fed, total mixed rations brings greater fixed costs and creates logistical challenges, preventing smaller producers from capturing benefits associated with intensified systems. Therefore, we evaluated three management scenarios: 1) *ad libitum* Bermudagrass hay (HAY), representing conventional management during times of limited forage availability in Southeast Texas; 2) a limit-fed total mixed ration (TMR) which requires significant investment in equipment; and 3) a management system where the forage and concentrate found in the TMR are not mixed but rather fed separately (SEP), decreasing the need for initial investment in equipment. Additionally, in the limit-fed systems four different levels of energy intake 70, 85, 100, and 115% of NRC requirements (NRC, 1996) based on experimental observations in previous studies were considered. To evaluate net returns of alternative feeding systems, a stochastic simulation model was developed based on a 200 cow operation. Stochastic variables in the model included weaning weights, prices of weaned steers and heifers, and feed ingredient prices. To estimate ingredient and cattle prices, multivariate empirical distributions were used, which incorporate historical variability and correlations in stochastic forecasted prices. A budget for each system was developed to incorporate stochastic variables in the model. Net returns for both limit-fed systems at intake levels of 70, 85 and 100%, which ranged from $93.00 to $155.30 per cow, were greater than the HAY ($72.41 per cow). However, HAY had greater net returns than TMR at 115% intake level ($62.95 per cow), but HAY had lower net returns compared to SEP at 115% intake level ($95.58 per cow). Reductions in feed costs ranged from $29.90 to $116.59 per cow for limit fed systems compared to HAY, and these reductions offset the increases in costs from labor, fuel and repairs, operating interest, and new fixed costs (mixer depreciation and bunks). The probability of negative net returns was 0.35 for the HAY scenario, slightly smaller than the probability observed in the 115% TMR (0.37). All other probabilities of negative returns ranged from 0.13 (SEP at 70%) to 0.30 (TMR at 115%). Additionally, the net returns coefficient of variation for HAY ($271.50 per cow) was greater than all limit fed systems, which averaged $143.75 per cow. Economic analysis suggests limit-feeding cattle is preferred to hay feeding, and that separate delivery of forage and concentrate would be most profitable and least risky for the enterprise tested.

Introduction

In regions where cow-calf producers are primarily dependent on grazing forage, drought and other periods of reduced forage availability consistently challenges the long-term sustainability of the operation (Foran and Smith, 1991; Bahre and Shelton, 1993;

Coppock, 2011). Most producers purchase hay when pastureland is no longer meeting the herd's energy requirements or they are forced to liquidate their herd. Hay is a common feed purchased when grazing lands are limited. However, hay tends to be overpriced ($/lb of TDN) compared to other sources of TDN, such as corn, and the price difference observed is further distorted in areas of regional droughts. In times of limited forage availability, producers are forced to purchase exogenous feed calories. An additional challenge facing cow/calf operations is the capital required to acquire land for grazing. Ultimately, high capital costs can prevent herd expansion, which is required after recent droughts in Texas and the Midwest. Farm real estate, cropland and pastureland values have steadily increased over the last decade (USDA, 2015), increasing the difficulty for new producers to enter the industry and likely decreasing land available for lease.

Limit-feeding cattle improves nutrient utilization (Galyean et al., 1979; Zinn and Owens, 1983; Boardman, 2015). Reductions in maintenance energy requirements (NE_m) of cattle have been observed (Trubenbach, 2014; Boardman, 2014) when cattle are limit-fed while cow performance has not been affected (Chapter II and unpublished data). Therefore, the objective was to compare the economic sustainability of *ad libitum* hay and intensified limit-fed systems. However, production systems that incorporate limit-feeding a total mixed ration (TMR) bring greater fixed costs to cow-calf production, which may prevent small producers from capturing the benefits of increased energy density in limit-fed rations. Thus, the effect of offering limit-fed diets as a TMR or as separate components, concentrate and roughage, at differing levels of dietary energy intake was evaluated to determine profitability of limit-fed systems.

Methodology

Scenario comparisons were based on an enterprise budget presented by Sawyer and Wickersham (2013) which included limit-feeding cows for four months of the year in confinement because forage is limiting the operation. Three management scenarios were evaluated: 1) *ad libitum* Bermudagrass hay (HAY), representing conventional management during times of limited forage availability in Southeast Texas; 2) a limit-fed total mixed ration (TMR) which requires significant investment in equipment; and 3) a management system where the forage and concentrate found in the TMR are not mixed but rather fed separately (SEP), decreasing the need for initial investment in equipment. Dry cows would be placed in one of the production systems on the day of weaning. Limit-fed systems, SEP and TMR, were fed at 4 levels of dietary energy intake (70, 85, 100 and 115% of predicted NE_m requirements; Table 10) based on experimental observations in previous studies.

A stochastic simulation model using empirical distributions was used to estimate net returns for an operation that calves in the spring of 2017. Stochastic variables in the model included weaning weights, price of weaned steers and heifers, and input prices of feed ingredients. A budget for each system was developed to include these stochastic variables in the model. Stochastic feed prices were linked to intake and days on feed to develop a total feed cost for each system. Costs for labor, fuel and repairs, as well as ration mixing and delivery were calculated from feed intakes and machinery capacity

Table 10. Formulated ingredient and nutrient composition of treatment diets.[1]

	Treatment[2]			
	70	85	100	115
Ingredient	% As fed			
Wheat straw	44.84	39.06	34.52	31.04
Cracked corn	24.81	27.40	29.46	28.92
Dried distillers' grains	23.13	25.60	27.46	31.02
Urea	0.93	1.00	1.10	1.16
Molasses	4.21	4.70	5.00	5.27
Mineral premix	2.07	2.30	2.46	2.59
Diet components	DM basis			
CP, %	14.47	15.62	16.53	17.20
TDN, %	53.28	56.36	58.70	60.62
ME, Mcal/kg	2.32	2.40	2.47	2.52
NE_m, Mcal/kg	1.42	1.50	1.56	1.61

[1]According to NRC (2000) model estimates

[2] 70 = 70% NRC requirements; 85 =d 85% NRC requirements; 100 = 100% NRC requirements; 115 = 115% NRC requirements

(Boardman, 2015) to reflect changes required by each limit fed system. Each limit fed system had 4 separate budgets to reflect differing levels of energy intake. Additionally, the TMR system had added fixed costs for a mixer wagon and concrete bunks which were needed to produce and deliver the TMR, whereas the SEP system only had increased fixed costs for concrete bunks. Bunks were accounted for using straight line depreciation and a useful life of 10 years with no salvage value. Straight line depreciation was used for the mixer wagon with a useful life of 15 years and a $2,000 salvage value.

Simulated probability distributions of net returns for each system for the 2016-2017 production year were used to determine which production system provided the least risk with greatest chance of profitability. Average net return for each system provides little information on the risk associated with each system. To choose, or to evaluate, the best option among risky alternatives, stochastic efficiency with respect to a negative exponential utility function (SERF) was used to rank these alternatives while accounting for differing levels of risk aversion of the decision maker (Ribera et al., 2004). This simulation was based on an annual enterprise budget; therefore, a negative exponential function was used instead of a power utility function. Certainty equivalence at differing levels of risk aversion can be used to determine the best alternative for individual producers, and the alternative with the greatest certainty equivalence will be preferred over all others at a given risk aversion coefficient.

Data

Production data

Brangus cattle with an average weight of 503 kg were used in this study. A previous experiment was conducted to determine the effects of these three production systems on cow performance (Chapter II). Because calf data was not available, weaning weights were used from a prior trial conducted investigating the effect dietary energy supplied (70, 85, 100, and 115% of NE_m requirements) to cows on calf performance in a spring calving herd (Early, 2016). Weaning weights for each dietary energy treatment were used to estimate parameters in an empirical distribution of weaning weights. A contemporary herd to the cows on that trial grazed a nearby pasture during the same time, and weaning weights from those calves were used to estimate parameters for an empirical distribution of weaning weights for the HAY system. Both herds were bred to calve at the same time and all calves were weaned in October of 2015 at Beef Cattle Systems in Burleson County, Texas. For each of the 5 weaning weight distributions, a mean weaning weight of steers (261 kg) and heifers (215 kg) and the percent deviation from the mean of experimental data were used as parameters in the empirical distribution. Previous research shows no changes in digestion and ruminal fermentation of cattle when feeding a TMR or separated ration, therefore, we assumed production data of cows and calves are similar.

Feed intake data

For each limit-fed system, the NRC (2000) was used to predict NE for maintenance requirements for the average weight of the cow herd (10.9 Mcal/d). One of four levels of concentrate were fed in the limit-fed systems: 0.69, 0.88, 1.06, and 1.25% of BW corresponding to 70, 85, 100, and 115% of NRC predicted NE_m requirements. Cows in each limit-fed system were fed a constant amount of wheat straw (0.56% of BW). The concentrate fed consisted of dry rolled corn (45%), dried distillers' grains (42%), and a premix (13%; Table 10). For the conventional system (HAY), hay wastage was included in the DMI and based off a previous experiment, DMI was 16.33 kg/d per cow (Chapter II).

Price data

Monthly historical prices from the USDA for corn, dried distillers' grains (DDG), and hay were used to estimate parameters for prices using multivariate empirical (MVE) distributions. To estimate a stochastic forecasted wheat straw price, the stochastic forecasted hay price was discounted based on a TDN adjustment factor. Monthly historical prices were detrended using a linear regression, and fractional deviations from trend were calculated from residuals then used to simulate risk about the forecasted monthly mean prices for October 2016. Our model was developed to assume that all feed would be purchased at the start of the feeding period and feed would be delivered monthly in truck loads. Monthly historical price data for urea and molasses were also obtained from the USDA. These prices were not included in MVE simulated prices mentioned previously due to lack of data and of linear trend in the historical data ($P > 0.85$). Both urea and molasses price distributions were simulated empirically using historical 5 year averages and fractional deviations from the average as the parameters. Monthly historical prices from USDA Livestock Market News for steers and heifers at auctions in Texas were used to estimate parameters for MVE distribution of prices. Steer and heifer prices were detrended using linear regression, and fractional deviations from trend were calculated from residuals then used to simulate risk about the forecasted mean prices for October of 2017, which is based on when calves would be weaned and sold. Multivariate empirical distributions were chosen for estimating ingredient prices and cattle prices to ensure that historical variability and price correlations were reflected in the stochastic forecasted prices (Richardson et al., 2000).

Results and discussion

Deterministic results

Average gross revenues for each alternative were similar ranging from $738.38 to $740.19 per cow (Table 11). Gross revenues slightly differed due to differences in weaning weight distributions even though average weaning weights were not different in previous studies. Feed costs increased for limit-fed systems from $144.08 to $230.77 per cow as net energy intake increased from 70% to 115% of NRC requirements for maintenance, respectively. All levels of limit-fed intake had lower feed costs than the conventional system (HAY) which had a feed cost of $260.67 per cow for the feeding period. Labor costs were less for the SEP systems and HAY system compared to the TMR systems ($13.50 vs $14.40 per cow when wage rate was estimated at $15/hr). Fuel and maintenance costs were greatest for TMR systems ($15.38 and $1.70 per cow, respectively) followed by HAY ($8.87 and $0.98 per cow, respectively) and SEP ($3.20 and $0.36 per cow, respectively). New fixed costs were the depreciation expense associated with the bunks for SEP and TMR systems and mixer wagon required by TMR

Table 11. Simulated means for revenues, costs and net cash income associated with each alternative system in dollars per cow.

	HAY	TMR				SEP			
	Ad Libitum	70	85	100	115	70	85	100	115
Intake, kg/d	1,959.54	748.44	862.20	969.97	1,083.73	748.44	862.20	969.97	1,083.73
Gross Revenues	738.51	739.33	740.19	739.77	738.38	739.36	739.66	739.36	738.53
Costs									
Feed	260.67	144.08	173.49	201.36	230.77	144.08	173.49	201.36	230.77
Mixing/delivery						14.32	14.32	14.32	14.32
Labor	13.50	14.40	14.40	14.40	14.40	13.50	13.50	13.50	13.50
Fuel and lube	8.87	15.38	15.38	15.38	15.38	3.20	3.20	3.20	3.20
Repairs and maintenance	0.98	1.70	1.70	1.70	1.70	0.36	0.36	0.36	0.36
Interest on loans	28.46	34.05	36.05	37.95	39.95	21.08	23.08	24.98	26.98
Total variable costs	460.25	357.37	388.78	418.54	449.96	344.29	375.71	405.47	436.88
New Fixed Costs		19.80	19.80	19.80	19.80	2.80	2.80	2.80	2.80
Other production costs	147.76	147.76	147.76	147.76	147.76	147.76	147.76	147.76	147.76
Total fixed costs	205.85	225.65	225.65	225.65	225.65	208.65	208.65	208.65	208.65
Net Cash Income	*72.41*	*155.31*	*125.76*	*95.58*	*62.95*	*185.45*	*155.30*	*125.25*	*93.00*

Table 12. Summary statistics for net cash income of each alternative production system in dollars per cow.

	HAY	TMR				SEP			
	Ad Libitum	70	85	100	115	70	85	100	115
Mean	72.41	155.31	125.76	95.58	62.95	185.43	155.30	125.25	93.00
Standard Deviation	196.61	159.76	161.22	168.17	161.98	154.46	158.98	161.70	158.94
Coefficient of variation, %	271.50	102.86	128.20	175.95	257.32	83.297	102.37	129.10	170.90
Minimum	-407.59	-181.75	-227.60	-297.00	-332.42	-124.97	-185.85	-291.01	-265.28
Maximum	722.50	688.32	649.23	619.60	598.46	693.69	635.31	605.23	668.36

systems. As such, HAY had no new fixed costs, but TMR and SEP had additional fixed costs of $19.80 and $2.80 per cow, respectively. Net return was greatest for SEP at 70% energy intake level ($185.43 per cow) than all other alternatives. Net cash income decreased from $185.43 to $93.00 per cow as the level of energy intake increased from 70 to 115% for the SEP system. As the level of energy intake increased for TMR systems, net returns were decreased from $115.31 to $62.95 per cow. The conventional HAY system had net returns of $72.41 per cow which is less than all alternatives except the 115% level of energy intake in the TMR system.

Stochastic results

Summary statistics for net returns are presented in Table 12. As previously stated, the SEP at 70% intake had the highest mean net return, but this does not account for risk. This alternative had the lowest standard deviation ($154.46 per cow) and coefficient of variation (83.30%) compared to the other alternatives, which depending on risk aversion of the decision maker makes this a more favorable alternative. Coefficient of variation (271.50%) and standard deviation ($196.61 per cow) were greatest for HAY. At the 70% intake level, there was a 19.56 unit difference in the coefficient of variation between TMR and SEP systems ($102.86 and $83.30, respectively). However, at the 115% intake level, the difference increased to $86.46 ($257.32 and $170.90 per cow for TMR and SEP systems, respectively). It is difficult to compare alternatives using coefficient of variation when means vary and standard deviation remains constant. This is observed when comparing the limit-fed systems at the greatest intake level; thus, another way of ranking, or choosing among, risky alternatives is needed.

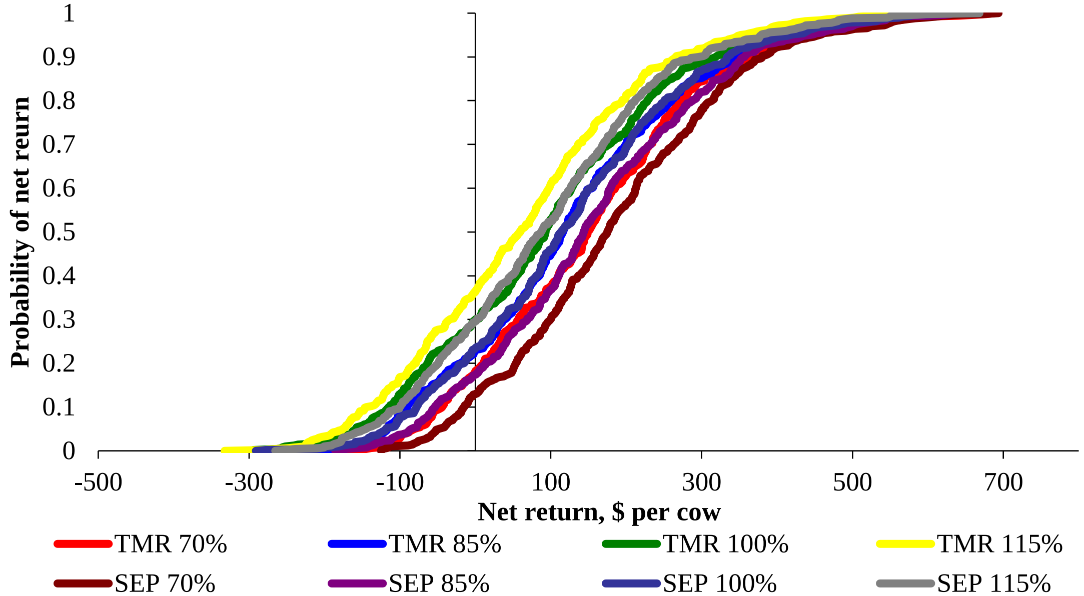

Figure 9. Cumulative distribution function of net returns for limit-fed cow-calf production systems during periods of reduced forage availability.

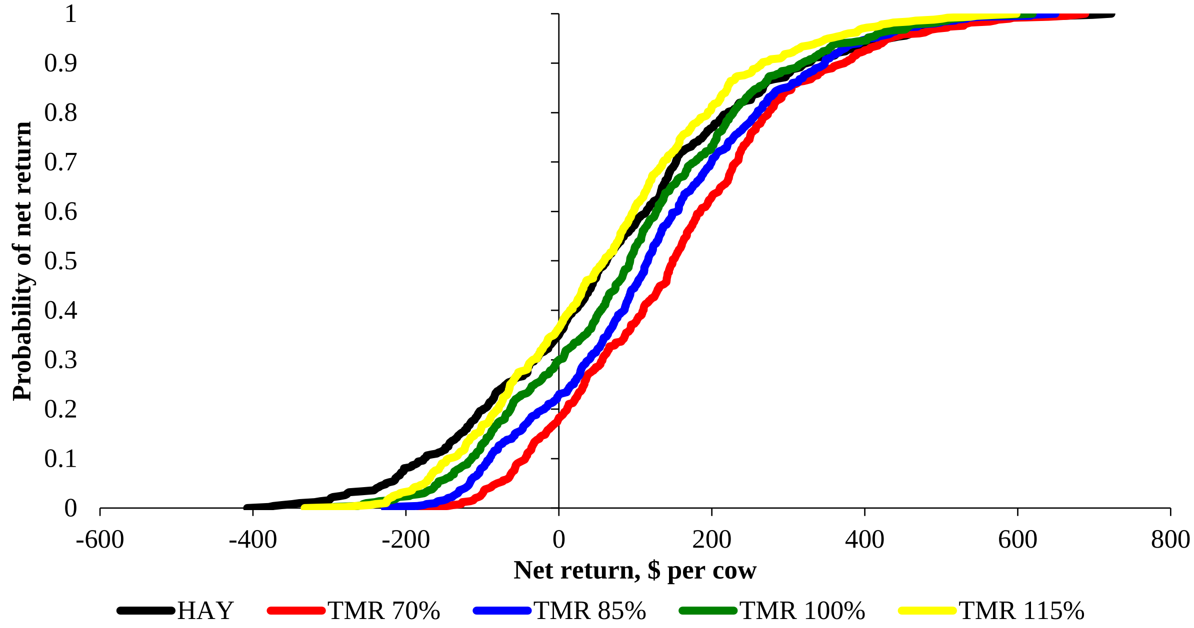

Figure 10. Cumulative distribution functions of net returns for limit-fed production systems fed a TMR and conventional hay fed production system.

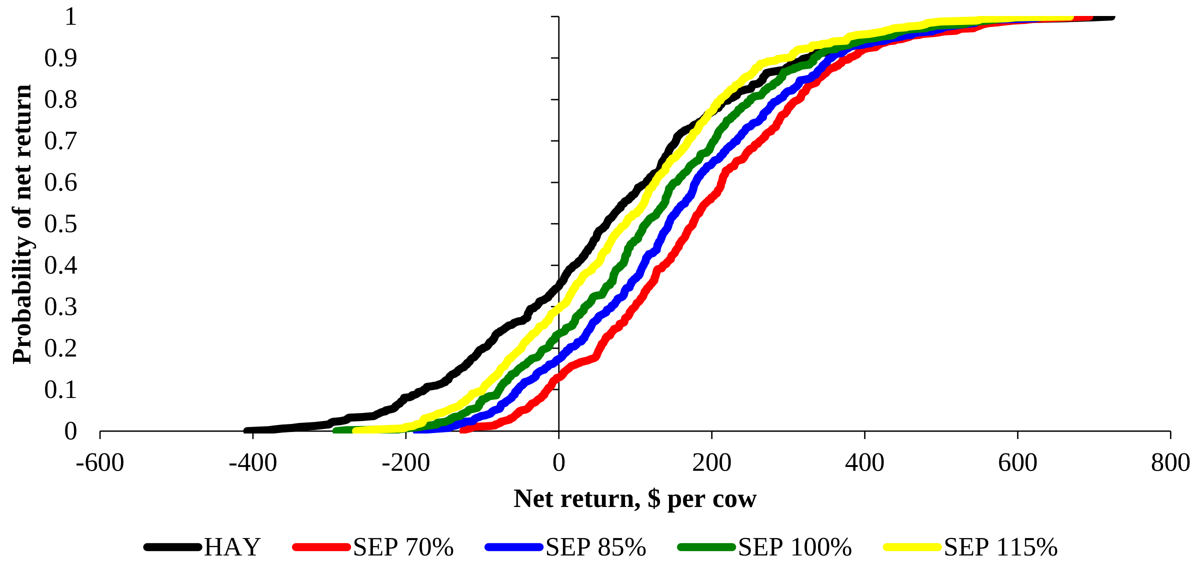

Figure 11. Cumulative distribution functions of net returns for limit-fed production systems separately fed components of a TMR and conventional hay fed production systems.

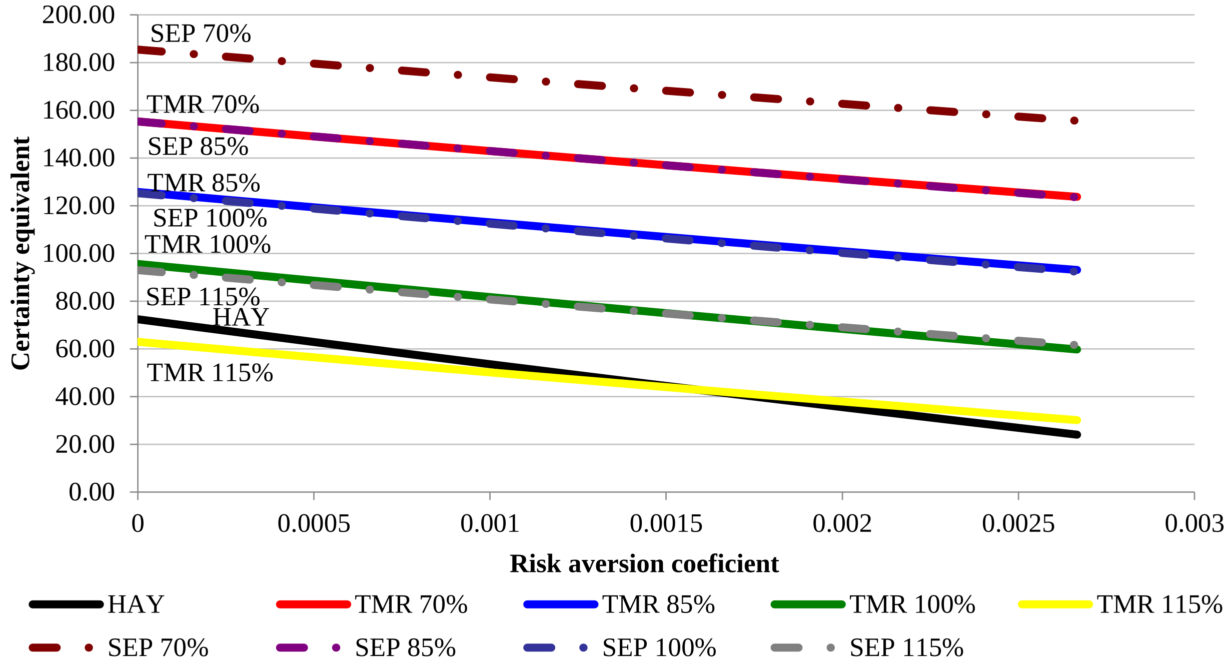

Figure 12. Certainty equivalents of net returns for limit-fed and conventional hay fed cow-calf production systems during times of reduced forage availability.

Simulated net return results are presented as cumulative distribution functions (CDFs) in Figures 9 to 11 for all systems. The CDF graph illustrates the probability (y-axis) of an alternative being equal to or below a particular level of net return (x-axis). At any given level of return the alternative with the lowest probability is the preferred alternative. Probability of net returns being negative ranged from about 0.10 (SEP at 70%) to 0.34 (TMR at 115%). It is difficult to rank the alternative systems from this figure because the CDF lines cross meaning there is no first-order stochastic dominance when comparing scenarios. For example, in figure 10, at zero net return HAY (0.35) is preferred to TMR at 115% intake (0.37), but when net returns are -$100 per cow TMR at 115% (0.03) is preferred to HAY (0.08). However, at all levels of probability SEP at 70% has the greatest net return and is easily ranked as the best choice among risk outcomes.

One way to choose among risky alternatives is to calculate the certainty equivalent (CE), which is an estimated value of one alternative versus another. It is explained as the amount of dollars a person would accept to make them indifferent among the choices. The CE at all levels of risk version for SEP at 70% intake was greater than all other alternatives when evaluated using the stochastic efficiency with respect to a function (SERF; Figure 12) making this the preferred system for all cow-calf producers. The next best alternatives were the TMR at 70% intake and SEP at 85% intake which were equally preferred (CE of $138.94) when the decision maker was moderately risk averse. Rankings for the remaining risky alternatives and corresponding CEs for a moderately risk averse producer were as follow: TMR at 85% ($108.94), SEP at 100% ($108.33), TMR at 100% ($77.21), SEP at 115% ($76.76), HAY ($47.49), TMR at 115% ($46.03). For an extremely risk averse cow-calf producer, TMR at 70% becomes the preferred option over SEP at 85% with CE of $123.73 and $123.52, respectively. Remaining CE of alternatives at an extreme risk aversion level are ranked as follows: TMR at 85% ($93.08), SEP at 100% ($92.34), TMR at 100% ($59.76), SEP at 115% ($61.59), TMR at 115% ($30.14), and HAY ($24.05). When comparing TMR and SEP at 115% intake level, a moderately risk averse producer would prefer the TMR system, but an extremely risk averse producer would prefer the SEP system. Additionally, at a moderately risk averse level HAY was preferred to TMR at 115%, but an extremely risk averse cow-calf producer prefers TMR at 115% intake over HAY.

To predict ranking preferences of limit-fed systems when compared to conventional systems, risk premiums (CE of limit-fed system minus CE of HAY) were determined at three levels of risk (risk neutral, moderately risk averse, extremely risk averse; Table 13). Risk premiums for all systems increased as producers became more risk averse. When producers were risk neutral, a risk premium of $113.02 per cow is placed on SEP at 70%. Thus, the producer would need to be paid $113.02 to choose HAY over SEP at 70%. As the producer becomes moderately risk averse, this premium increases to $122.55, and an extremely risk averse producer places a $131.55 per cow premium on SEP at 70% intake. Comparing limit-fed alternatives with similar mean net returns to HAY, such as TMR and SEP at 115%, risk premiums are lower than SEP at 70% when the producer was risk neutral (-$9.59 and $20.59 per cow, respectively). Risk premium for TMR at 115% was still unfavorable (-$1.47 per cow) for a moderately risk averse producer, but risk premium for an extremely risk averse producer was \$6.09 per cow.

Table 13. Risk premiums between limit-fed production systems and conventional hay systems at varying levels of risk preference.[a]

	Level of risk aversion		
Production system	Risk neutral	Moderately risk averse	Extremely risk averse
TMR at 70%	82.90	91.45	99.68
TMR at 85%	53.35	61.45	69.03
TMR at 100%	23.17	29.72	35.71
TMR at 115%	-9.46	-1.47	6.09
SEP at 70%	113.02	122.55	131.55
SEP at 85%	82.88	91.45	99.46
SEP at 100%	52.83	60.83	68.29
SEP at 115%	20.59	29.27	37.54

[a] A positive value indicates a dollar per cow benefit of limit-fed over hay systems.
A negative value indicates a dollar per cow benefit of hay over limit-fed systems.

Figure 13 presents the probability of net returns being negative and the probability of net returns be greater than \$225 per cow (average of top 25th percentile of simulation returns for all systems). Decision makers who are risk averse would minimize the probability of net returns being negative, making SEP at 70% intake the most preferred choice. Order of preferred alternative follows level of intake (70, 85, 100, and 115%). As level of intake increases for SEP and TMR, the probability of negative returns increases from 0.13 to 0.30 and from 0.18 to 0.37, respectively. The average difference between SEP and TMR for negative net returns was approximately 0.05, with

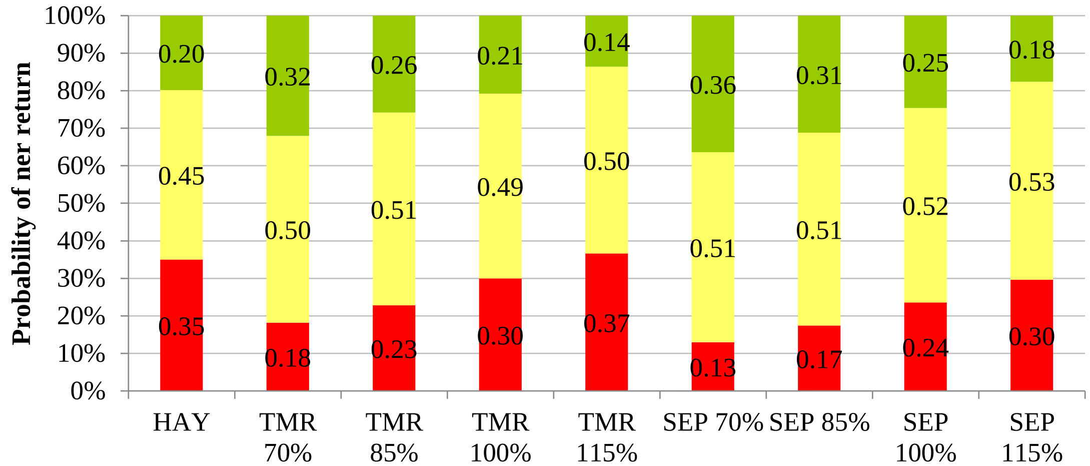

Figure 13. Probabilities of net returns for limit-fed and conventional hay fed cow-calf production systems in times of reduced forage availability. (red is return < $0 per cow; green is return > $225 per cow).

SEP preferred over TMR. The conventional production system, HAY, was only preferred over TMR at 115% intake, with probabilities of 0.35 and 0.37, respectively, for returns being negative. If decision makers were risk accepting, decision makers would look to maximizing net returns. The most preferred system, SEP at 70%, has a 0.36 probability of making more than $225 per cow. Similar to probability of negative returns, probability of returns greater than $225 per cow decreased as level of intake was increased for SEP (0.36 to 0.18) and TMR (0.32 to 0.14). The least preferred system, TMR at 115% intake, had the greatest chance of net returns being negative (0.14), and HAY was slightly greater than TMR at 115% with a probability of 0.20.

Conclusions

Limit feeding systems allow cow-calf producers to reduce the costs of feed during a drought and furthermore, corn and DDG are usually cheaper than hay ($/Mcal of NE). Thus, restricting rations containing inexpensive feedstuffs while still meeting energy requirements of the cow is economically beneficial to the operation. Rankings according to SERF are similar for risk neutral and moderately risk averse producer, but HAY become the least preferred alternative for an extremely risk averse producer. The SEP system was preferred to the TMR system at all intake levels evaluated. This was due to increased fixed costs of the mixer associated with the TMR system. A producer with a herd size of 200 cows, as in this example, would realize a higher net return having a feed store mix and deliver a concentrate in bulk than buy a mixer to feed cattle with during limited forage availability. Increasing energy density of the ration increased net returns for both limit-fed systems.

One of the limitations to this study was for a set herd size of 200 cows was evaluated. Increasing this herd could potentially cause the TMR system to be more competitive with the SEP system since fixed costs could be spread over a greater number of cows. Decreasing herd size may cause HAY to be preferred over the TMR system because fixed costs would increase per cow for the TMR system.

Little research is available evaluating the effects of limit-feeding energy dense diets on reproduction and calf performance. Variables not included in the model, such as conceptions rates, need to be characterized. If the most preferred alternative according to this model causes lower reproductive performance, risk associated with this alternative increases and likely changes the ranking of the systems simulated. An expansion of the model over multiple years is needed to fully assess the impacts of limit-feeding on net returns and cash flows, especially during times when forage availability is not limited.

CHAPTER IV

CONCLUSIONS

During times of limited forage availability, many small producers choose to exit the industry entirely. Perceived costs and managerial requirements may prevent some producers from capturing benefits associated with intensified systems because intensification strategies have utilized a feedlot setting or large investments in equipment. Results from this study indicate restricting intake and separating a TMR into a forage and concentrate component does not impact digestion or fermentation. Additionally, pH and VFA proportions are driven by time concentrate is delivered and Cow performance in this study gives further evidence that limit-feeding cows results in lower maintenance requirements because reductions in gastrointestinal mass likely occur. Producers can adapt intensified systems to fit their capabilities so cow efficiency captured. Limit-feeding allows producers to minimize nutritional inputs compared to conventionally feeding *ad libitum* hay creating a more efficient production system. Visual assessment of BCS in limit-fed cows disagrees with BCS predicted from back fat thickness. Further investigation is needed to determine the effects of separating components in a wider range of intake levels on digestion, ruminal fermentation, and cow performance.

Results from the economic analysis demonstrate separately feeding forage and concentrate is the most profitable and least risky system for producers to limit-feed 200 cows. When intake is increased, returns decrease in limit-fed systems and conventional production systems feeding hay become more competitive. Reproduction performance should be considered when economically evaluating limit-fed systems in the long run. Further research is required to determine at what level of production a TMR is preferred to separately feeding forage and concentrate.

LITERATURE CITED

Adams, D., and R. Kartchner. 1984. Effect of level of forage intake on rumen ammonia, pH, liquid volume and liquid dilution rate in beef cattle. J. Anim. Sci. 58:708-713.

Adams, D. C., R. T. Clark, S. A. Coady, J. B. Lamb, and M. K. Nielsen. 1994. Extended grazing systems for improving economic returns from Nebraska sandhills cow/calf operations. J. Range Manage. 47:258-263.

Andersen, P., J. Reid, M. Anderson, and J. Stroud. 1959. Influence of level of intake upon the apparent digestibility of forages and mixed diets by ruminants. J. Anim. Sci. 18:1299-1307.

Anderson, D. P., J. G. Robb, and J. Mintert. 1996. The cattle cycle. Managing for Today's Cattle Market and Beyond.

Anderson, V. L., B. R. Ilse, and C. L. Engel. 2013. Drylot vs. pasture beef cow-calf production: Three-year progress report. NDSU Beef Report. 13-16.

Bahre, C. J., and M. L. Shelton. 1993. Historic vegetation change, mesquite increases, and climate in southeastern Arizona. J. Biogeogr. 20:489-504.

Boardman, C. J. 2015. Effects of monensin and dietary energy intake on maintenance requirements in beef cows. M. S. Thesis. Texas A&M Univ., College Station, TX.

Breimyer, H. F. 1955. Observations on the cattle cycle. Agricultural Economics Research 7:1-11.

Brink, D., and R. Steele. 1985. Site and extent of starch and neutral detergent fiber digestion as affected by source of calcium and level of corn. J. Anim. Sci. 60:1330-1337.

Broderick, G. A., and J. H. Kang. 1980. Automated simultaneous determination of ammonia and total amino acids in ruminal fluid and in vitro media. J. Dairy Sci. 63:64.75.

Brody, S. 1945. Bioenexgetics and growth, with special reference to the efficiency complex in domestic animals. Bioenexgetics and growth, with special reference to the efficiency complex in domestic animals.

Camacho, L. E. et al. 2014. Effects of maternal nutrient restriction followed by realimentation during midgestation on uterine blood flow in beef cows. Theriogenology. 81:1248-1256.

Chilliard, Y., F. Bocquier, and M. Doreau. 1998. Digestive and metabolic adaptations of ruminants to undernutrition, and consequences on reproduction. Reprod. Nutr. Dev. 38: 131-152.

Close, D. L. 2015. Outside in – confined cow-calf production is a viable model for rebuilding the U.S. cow herd numbers. Dr. Kenneth S. and Caroline McDonald Eng Foundation Symposium, Oklahoma City, OK. p 17-24.

Coppock, C. E. 1977. Feeding Methods and Grouping Systems. J. Dairy Sci. 60: 1327-1336.

Coppock, D. L. 2011. Ranching and multiyear droughts in Utah: production impacts, risk perceptions, and changes in preparedness. Rangeland Ecology & Management. 64:607-618.

Darnhofer, I., J. Fairweather, and H. Moller. 2010. Assessing a farm's sustainability: insights from resilience thinking. International Journal of Agricultural Sustainability. 8:186-198.

De Vries, M., and R. Veerkamp. 2000. Energy balance of dairy cattle in relation to milk production variables and fertility. J. Dairy Sci. 83:62-69.

DeRouen, S. M. et al. 1994. Prepartum Body Condition and Weight Influences on Reproductive-Performance of First-Calf Beef-Cows. J. Anim. Sci. 72:1119-1125.

Dhuyvetter, K., and K. Herbel. 2012. Differences between high-, medium-, and low-profit producers: an analysis of the Kansas Farm Management Association Beef Cow-Calf Enterprise. Department of Agricultural Economics, Kansas State University.

Dijkstra, J., J. L. Ellis, E. Kebreab, A. B. Strathe, S. Lopez, J. France, and A. Bannink. 2012. Ruminal pH regulation and nutritional consequences of low pH. Anim. Feed Sci. Tech. 172:22-33.

Du, M., J. Tong, J. Zhao, K. R. Underwood, M. Zhu, S. P. Ford, and P. W. Nathanielsz. 2010. Fetal programming of skeletal muscle development in ruminant animals. J. Anim. Sci. 88:E51-E60.

Dunn, T. G., and C. C. Kaltenbach. 1980. Nutrition and the postpartum interval of the ewe, sow and cow. J. Anim. Sci. 51:29-39.

Dunn, T. G., and G. E. Moss. 1992. Effects of Nutrient Deficiencies and Excesses on Reproductive Efficiency of Livestock. J. Anim. Sci. 70:1580-1593.

Erickson, G. E. et al. 2003. Interaction between bunk management and monensin concentration on finishing performance, feeding behavior, and ruminal metabolism during an acidosis challenge with feedlot cattle. J. Anim. Sci. 81:2869-2879.

Falconer, L. L., J. Parker, and J. McGrann. 1999. Cost of production analysis for the Texas cow-calf industry. Texas Journal of Agriculture and Natural Resources 12:7-13.

Featherstone, A. M., M. R. Langemeier, and M. Ismet. 1997. A nonparametric analysis of efficiency for a sample of Kansas beef cow farms. Journal of Agricultural and Applied Economics. 29:175-184.

Ferrell, C. L., L. J. Koong, and J. A. Nienaber. 1986. Effect of previous nutrition on body composition and maintenance energy costs of growing lambs. Br. J. Nutr. 56:595-605.

Foran, B., and D. S. Smith. 1991. Risk, biology and drought management strategies for cattle stations in central Australia. J. Environ. Manage. 33:17-33.

Freetly, H. C., C. L. Ferrell, and T. G. Jenkins. 2000. Timing of realimentation of mature cows that were feed-restricted during pregnancy influences calf birth weights and growth rates. J. Anim. Sci. 78:2790-2796.

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

Funston, R. N., D. M. Larson, and K. A. Vonnahme. 2010. Effects of maternal nutrition on conceptus growth and offspring performance: Implications for beef cattle production. J. Anim. Sci. 88:E205-E215.

Gadberry, M. et al. 2010. Effect of dried distillers' grains supplementation on calves grazing bermudagrass pasture or fed low-quality hay. Prof. Anim. Sci. 26:347-355.

Galyean, M., E. Hatfield, and T. Stanton. 1999. Review: restricted and programmed feeding of beef cattle—definitions, application, and research results. Prof. Anim. Sci. 15:1-6.

Galyean, M. L., D. G. Wagner, and F. N. Owens. 1979. Level of Feed-Intake and Site and Extent of Digestion of High Concentrate Diets by Steers. J. Anim. Sci. 49:199-203.

Gordon, F. J. et al. 1995. The Influence of Genetic Index for Milk-Production on the Response to Complete Diet Feeding and the Utilization of Energy and Nitrogen. J. Anim. Sci. 61:199-210.

Hardaker, J. B., J. W. Richardson, G. Lien, and K. D. Schumann. 2004. Stochastic efficiency analysis with risk aversion bounds: a simplified approach. Aust. J. Agric. Resour. Econ. 48:253-270.

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

Hess, B. et al. 2005. Nutritional controls of beef cow reproduction. J. Anim. Sci. 83:E90-E106.

Hicks, R., F. Owens, D. Gill, J. Martin, and C. Strasia. 1990. Effects of controlled feed intake on performance and carcass characteristics of feedlot steers and heifers. J. Anim. Sci. 68:233-244.

Hoover, W. 1986. Chemical factors involved in ruminal fiber digestion. J. Dairy Sci. 69:2755-2766.

Hough, R. L., F. D. Mccarthy, H. D. Kent, D. E. Eversole, and M. L. Wahlberg. 1990. Influence of Nutritional Restriction during Late Gestation on Production Measures and Passive-Immunity in Beef-Cattle. J. Anim. Sci. 68:2622-2627.

Jenkins, K., S. Furman, J. Hansen, and T. Klopfenstein. 2015. Limit feeding high-energy, by-product–based diets to late-gestation beef cows in confinement. Prof. Anim. Sci. 31:109-113.

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

Kaufmann, W. 1976. Influence of the composition of the ration and the feeding frequency on ph-regulation in the rumen and on feed in-take in ruminants. Livest. Prod. Sci. 3:103-114.

Krause, K. M., and G. R. Oetzel. 2006. Understanding and preventing subacute ruminal acidosis in dairy herds: A review. Anim. Feed Sci. Tech. 126:215-236.

Lardy, G. P., D. N. Ulmer, V. L. Anderson, and J. S. Caton. 2004. Effects of increasing level of supplemental barley on forage intake, digestibility, and ruminal fermentation in steers fed medium-quality grass hay. J. Anim. Sci. 82:3662-3668.

Larson, D. M., J. L. Martin, D. C. Adams, and R. N. Funston. 2009. Winter grazing system and supplementation during late gestation influence performance of beef cows and steer progeny. J. Anim. Sci. 87:1147-1155.

Loerch, S. C. 1990. Effects of Feeding Growing Cattle High-Concentrate Diets at a Restricted Intake on Feedlot Performance. J. Anim. Sci. 68:3086-3095.

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

Maekawa, M., K. Beauchemin, and D. A. Christensen. 2002. Effect of concentrate level and feeding management on chewing activities, saliva production, and ruminal pH of lactating dairy cows. J. Dairy Sci. 85:1165-1175.

May, G. J., L. W. Van Tassell, J. W. Waggoner, and M. A. Smith. 1999. Relative costs and feeding strategies associated with winter/spring calving. J. Range Mangage. 6:560-568.

Miller, A. et al. 2001. Critical control points for profitability in the cow-calf enterprise. Prof. Anim. Sci. 17:295-302.

Murphy, T., and S. Loerch. 1994. Effects of restricted feeding of growing steers on performance, carcass characteristics, and composition. J. Anim. Sci. 72:2497-2507.

Murphy, T. A., F. L. Fluharty, and S. C. Loerch. 1994a. The influence of intake level and corn processing on digestibility and ruminal metabolism in steers fed all-concentrate diets. J. Anim. Sci. 72:1608-1615.

Murphy, T. A., S. C. Loerch, and B. A. Dehority. 1994b. The influence of restricted feeding on site and extent of digestion and flow of nitrogenous compounds to the duodenum in steers. J. Anim. Sci. 72:2487-2496.

Murphy, T. A., S. C. Loerch, and F. E. Smith. 1994c. Effects of feeding high-concentrate diets at restricted intakes on digestibility and nitrogen metabolism in growing lambs. J. Anim. Sci. 72:1583-1590.

Nixon, J. 2013. The Drought of 2012. Online. Available: https://dnr.mo.gov/pubs/TheDroughtOf2012.pdf.

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

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

Ortigues, I., and M. Doreau. 1995. Responses of the splanchnic tissues of ruminants to changes in intake: Absorption of digestion end products, tissue mass, metabolic activity and implications to whole animal energy metabolism. In: Annales de Zootechnie. p 321-346.

Ozturk, A. 2016. Examining the economic growth and the middle-income trap from the perspective of the middle class. Int. Bus. Rev. 25:726-738.

Owens, F., J. Hill, D. Secrist, and D. Gill. 1995. Intake by feedlot cattle. In: Proceedings: 56th Minnesota Nutrition Conference and Alltech, Inc. Technical Symposium. p 97. Univ. of Minnesota, St. Paul, MN.

Patrick, G. R., P. N. Wilson, P. J. Barry, W. G. Boggess, and D. L. Young. 1985. Risk perceptions and management responses: producer-generated hypotheses for risk modeling. Southern Journal of Agricultural Economics 17:231-238.

Phipps, R. H., J. A. Bines, R. F. Weller, and J. Thomas. 1984. Complete Diets for Dairy-Cows - the Effect of Energy Concentration and Change in Energy Concentration of a Complete Diet on Intake and Performance of Lactating Dairy-Cows. J. Agr. Sci. 103:323-331.

Poore, M. H., J. A. Moore, and R. S. Swingle. 1990. Differential Passage Rates and Digestion of Neutral Detergent Fiber from Grain and Forages in 30-Percent 60-Percent and 90-Percent Concentrate Diets Fed to Steers. J. Anim. Sci. 68:2965-2973.

Ramsey, R. et al. 2005. Factors Affecting Beef Cow-Herd Costs, Production, and Profits. Journal of Agricultural and Applied Economics. 37:91-99.

Raun, N. S., and W. Burroughs. 1962. Suction Strainer Technique in Obtaining Rumen Fluid Samples from Intact Lambs. J. Anim. Sci. 21: 454-&.

Ribera, L. A., F. M. Hons, and J. W. Richardson. 2004. An Economic Comparison between Conventional and No-Tillage Farming Systems in Burleson County, Texas. Agron. J. 96:415.

Richards, M., J. Spitzer, and M. Warner. 1986. Effect of varying levels of postpartum nutrition and body condition at calving on subsequent reproductive performance in beef cattle. J. Anim. Sci. 62:300-306.

Richardson, J. W., S. L. Klose, and A. W. Gray. 2000. An applied procedure for estimating and simulating multivariate empirical (MVE) probability distributions in farm-level risk assessment and policy analysis. Journal of Agricultural and Applied Economics 32:299-315.

Richardson, J. W., and H. P. Mapp, Jr. 1976. Use of probabilistic cash flows in analyzing investments under conditions of risk and uncertainty. Southern Journal of Agricultural Economics 8:19-24.

Rossi, J., S. Loerch, S. Moeller, and J. Schoonmaker. 2001. Effects of programmed growth rate and days fed on performance and carcass characteristics of feedlot steers. J. Anim. Sci. 79:1394-1401.

Sainz, R. D., F. Delatorre, and J. W. Oltjen. 1995. Compensatory Growth and Carcass Quality in Growth-Restricted and Refed Beef Steers. J. Anim. Sci. 73:2971-2979.

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

Schoonmaker, J. P., S. C. Loerch, J. E. Rossi, and M. L. Borger. 2003. Stockpiled forage or limit-fed corn as alternatives to hay for gestating and lactating beef cows. J. Anim. Sci. 81:1099-1105.

Selk, G. E. et al. 1988. Relationship among weight change, body condition and reproductive performance of range beef cows. J. Anim. Sci. 66: 3153-3159.

Short, R. E., and D. Adams. 1988. Nutritional and hormonal interrelationships in beef cattle reproduction. Can. J. Anim. Sci. 68:29-39.

Short, S. D. 2001. Characteristics and Production of U.S. Cow-Calf Operations. In: U. S. D. o. Agriculture (ed.), Economic Research Service.

Stalker, L. A., L. A. Ciminski, D. C. Adams, T. J. Klopfenstein, and R. T. Clark. 2007. Effects of weaning date and prepartum protein supplementation on cow performance and calf growth. Rangeland Ecology & Management. 60:578-587.

Tokgoz, S. et al. 2008. Bottlenecks, drought, and oil price spikes: Impact on US ethanol and agricultural sectors. Appl. Econ. Perspect. Policy. 30:604-622.

Tremere, A. W., W. G. Merrill, and J. K. Loosli. 1968. Adaptation to high concentrate feeding as related to acidosis and digestive disturbances in dairy heifers. J. Dairy Sci. 51:1065-1072.

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

Trostle, R., and R. Seeley. 2013. USDA Economic Research Service-Developing Countries Dominate World Demand for Agricultural Products.

Underwood, K. R. et al. 2010. Nutrition during mid to late gestation affects growth, adipose tissue deposition, and tenderness in cross-bred beef steers. Meat Sci. 86:588-593.

United States Department of Agriculture. 2015. National Resources Inventory Summary Report August 2015. National resources conservation service. Online. Available: http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcseprd396218.pdf.

United States Department of Agriculture. 2016. Land Values 2016 Summary. National agricultural statistics service. Online. Available: http://usda.mannlib.cornell.edu/usda/current/AgriLandVa/AgriLandVa-08-05-2016.pdf.

United States Department of Agriculture National Agricultural Statistics Service. Quick Stats. Online. Available: http://quickstats.nass.usda.gov.

Van Tassell, L. W., S. M. McNeley, M. D. MacNeil, R. E. Short, and E. E. Grings. 1997. Retained ownership of beef cattle when considering production and price risk. In: annual meeting of the Western Agricultural Economics Association, Reno/Sparks, NV.

Vanzant, E. S., and R. C. Cochran. 1994. Performance and forage utilization by beef cattle receiving increasing amounts of alfalfa hay as a supplement to low-quality, tallgrass-prairie forage. J. Anim. Sci. 72:1059-1067.

Warner, J. M., L. M. Kovarik, M. K. Luebbe, G. E. Erickson, and R. J. Rasby. 2011. Limit feeding nonlactating, nonpregnant beef cows with bunkered wet distillers grains plus solubles or distillers solubles. Prof. Anim. Sci. 27:456-460.

Warner, J. M. 2015. Production and economic efficiencies of intensified cow-calf production management systems. Ph. D. Dissertation. Univ. Nebraska, Lincoln, NE.

Wheeler, W., C. Noller, and C. Coppock. 1975. Effect of forage-to-concentrate ratio in complete feeds and feed intake on digestion of starch by dairy cows. J. Dairy Sci. 58:1902-1906.

Yan, T., D. C. Patterson, and F. J. Gordon. 1998. The effect of two methods of feeding the concentrate supplement to dairy cows of high genetic merit. Anim. Sci. 67:395-403.

Zinn, R. A., C. F. Adam, and M. S. Tamayo. 1995. Interaction of feed intake level on comparative ruminal and total tract digestion of dry-rolled and steam-flaked corn. J. Anim. Sci. 73:1239-1245.

Zinn, R. A., and F. N. Owens. 1983. Influence of Feed-Intake Level on Site of Digestion in Steers Fed a High Concentrate Diet. J. Anim. Sci. 56:471-475.

Zinn, R. A., A. Plascencia, and R. Barajas. 1994. Interaction of forage level and monensin in diets for feedlot cattle on growth performance and digestive function. J. Anim. Sci. 72:2209-2215.

APPENDIX A

Table 14. Effect of time concentrate of delivery on ruminal pH and fermentation profile in steers consuming wheat straw.

	Treatment[1]					
Item	-2S	TMR	+2S	+12S	SEM	*P*-value[2]
No. of observations	4	4	4	4		
Total VFA, m*M*	81.11	83.97	81.28	78.05	3.18	0.65
Molar percentages						
Acetate[3]	72.28	70.48	71.93	72.67	1.10	0.53
Propionate[4]	17.12	18.81	18.01	16.99	0.70	0.26
Butyrate	8.55	8.28	7.71	8.22	0.42	0.55
Isobutyrate	0.73	0.77	0.83	0.76	0.06	0.67
Isovalerate	0.74	1.00	0.95	0.82	0.12	0.26
Valerate	0.58	0.66	0.58	0.55	0.04	0.48
A:P Ratio[5]	4.35	3.91	4.11	4.38	0.19	0.23
pH[6]	6.51	6.51	6.44	6.55	0.06	0.21

[1]-2S = Concentrate fed 2 h before wheat straw; TMR = Concentrate and wheat straw fed as TMR; +2S = Concentrate fed 2 h after wheat straw; +12S = Concentrate fed 12 h after wheat straw

[2]Treatments with differing superscripts differ ($P < 0.05$)

[3]Treatment × Time: $P < 0.01$, effect of time: $P < 0.05$

[4]Treatment × Time: $P < 0.05$, effect of time: $P = 0.08$

[5]Treatment × Time: $P = 0.08$

[6]Treatment × Time: $P < 0.01$, effect of time: $P < 0.01$

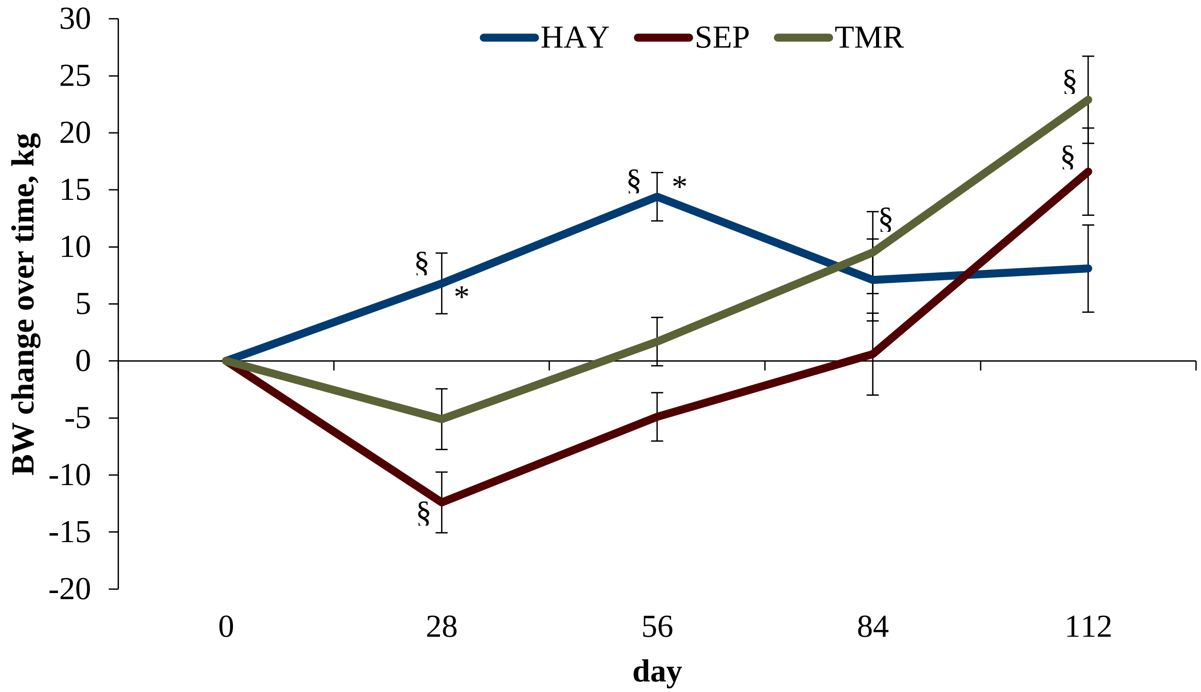

Figure 14. Effect of feeding method on body weight change from initial body weight of limit-fed mid- to late-gestation cows. HAY = cows fed *ad libitum* hay; SEP = cows limit fed concentrate 12 h after wheat straw; TMR = cows limit fed total mixed ration once daily; * denotes significant difference between treatments; **§** denotes significant difference from zero

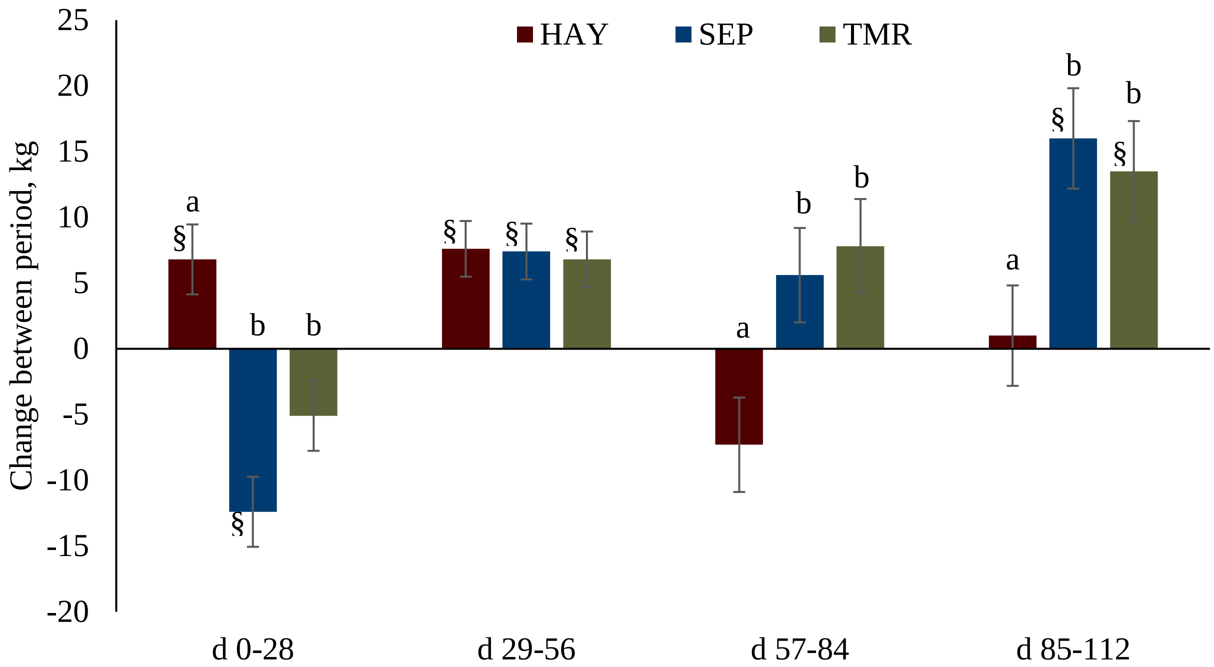

Figure 15. Effect of feeding method on between period body weight change in limit-fed mid- to late-gestation cows. HAY = cows fed *ad libitum* hay; SEP = cows limit fed concentrate 12 h after wheat straw; TMR = cows limit fed total mixed ration once daily; **§** denotes significant difference from zero

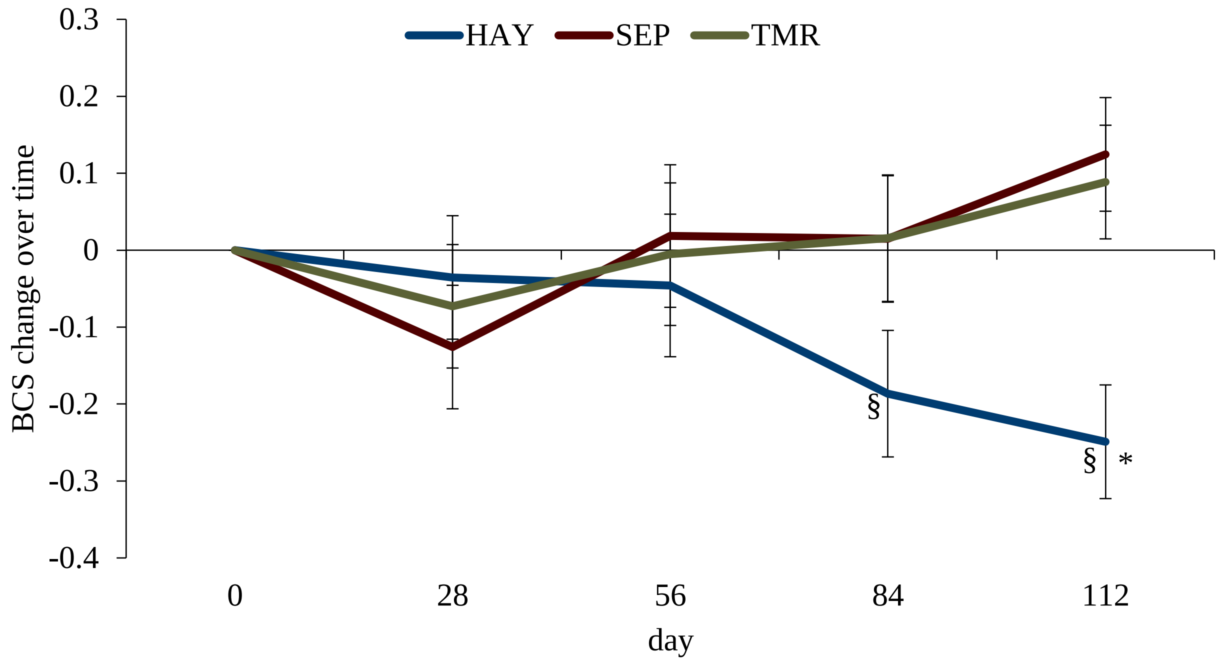

Figure 16. Effect of feeding method on body condition score (BCS) change from initial BCS in limit-fed mid- to late-gestation cows. HAY = cows fed *ad libitum* hay; SEP = cows limit fed concentrate 12 h after wheat straw; TMR = cows limit fed total mixed ration once daily; * denotes significant difference between treatments; **§** denotes significant difference from zero

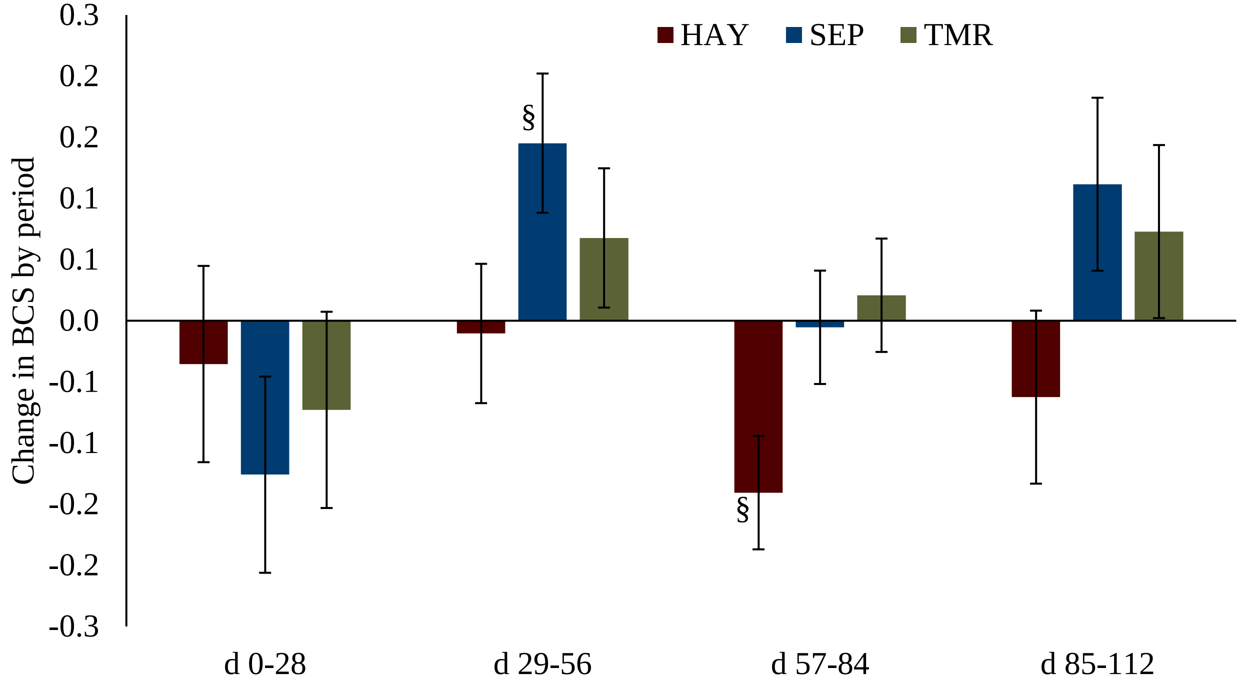

Figure 17. Effect of feeding method on period body condition score change (BCS) in limit-fed mid- to late-gestation cows. HAY = cows fed ad libitum hay; SEP = cows limit fed concentrate 12 h after wheat straw; TMR = cows limit fed total mixed ration once daily; **§** denotes significant difference from zero

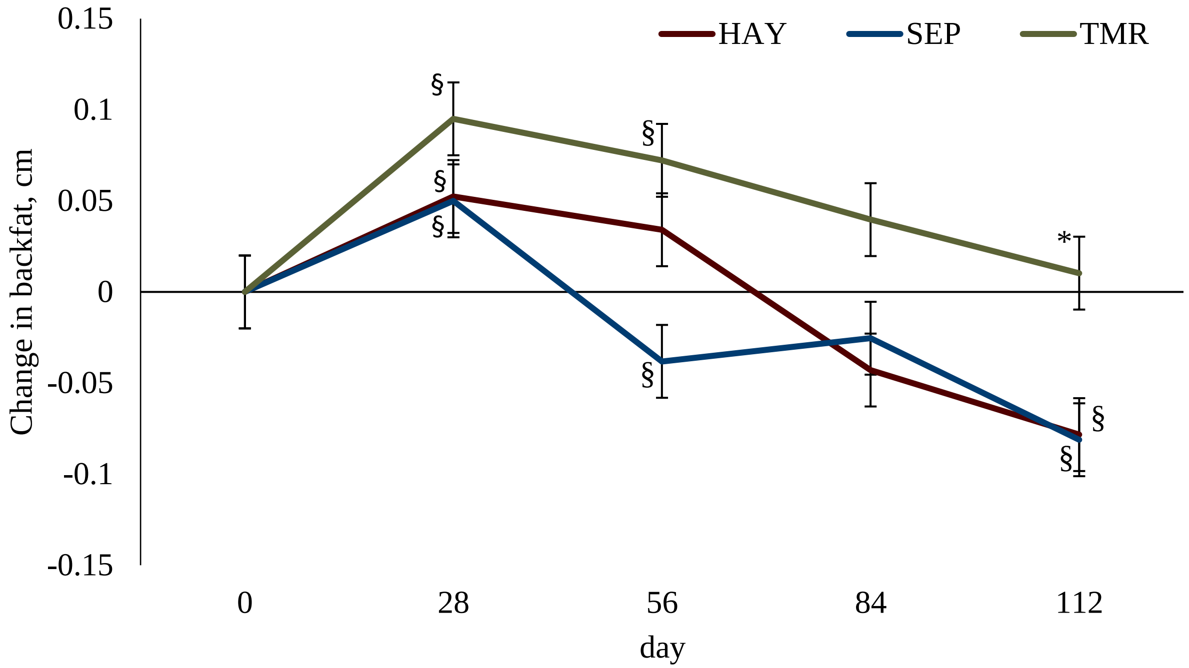

Figure 18. Effect of feeding method on backfat change in limit-fed mid- to late-gestation cows. HAY = cows fed *ad libitum* hay; SEP = cows limit fed concentrate 12 h after wheat straw; TMR = cows limit fed total mixed ration once daily; * denotes significant difference between treatments; **§** denotes significant difference from zero

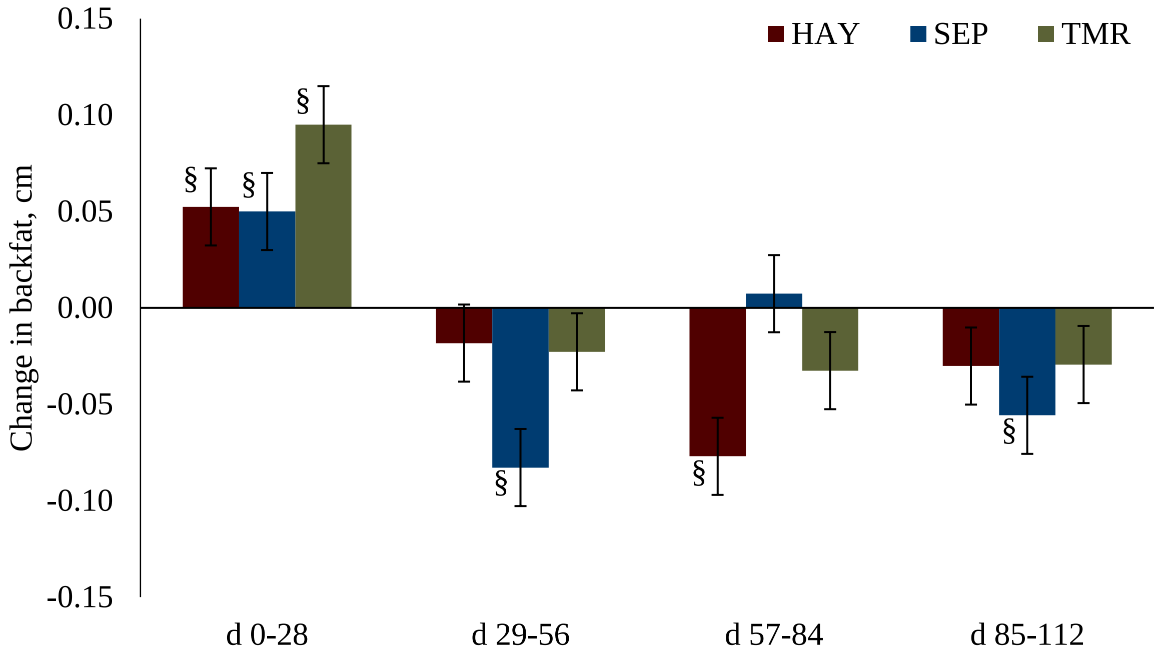

Figure 19. Effect of feeding method on period change of back fat thickness in limit-fed mid- to late-gestation cows. HAY = cows fed *ad libitum* hay; SEP = cows limit fed concentrate 12 h after wheat straw; TMR = cows limit fed total mixed ration once daily; * denotes significant difference between treatments; **§** denotes significant difference from zero

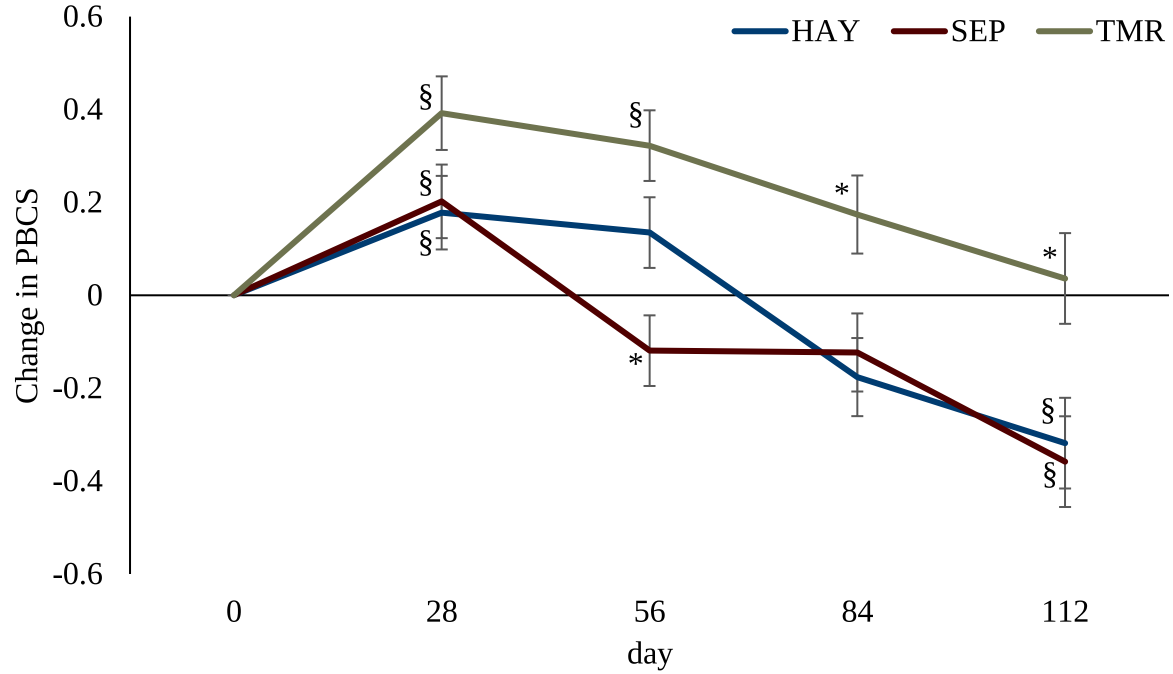

Figure 20. Effect of feeding method on predicted body condition score (PBCS) of limit-fed mid- to late-gestation cows. HAY = cows fed *ad libitum* hay; SEP = cows limit fed concentrate 12 h after wheat straw; TMR = cows limit fed total mixed ration once daily; * denotes significant difference between treatments; + denotes significant difference from zero

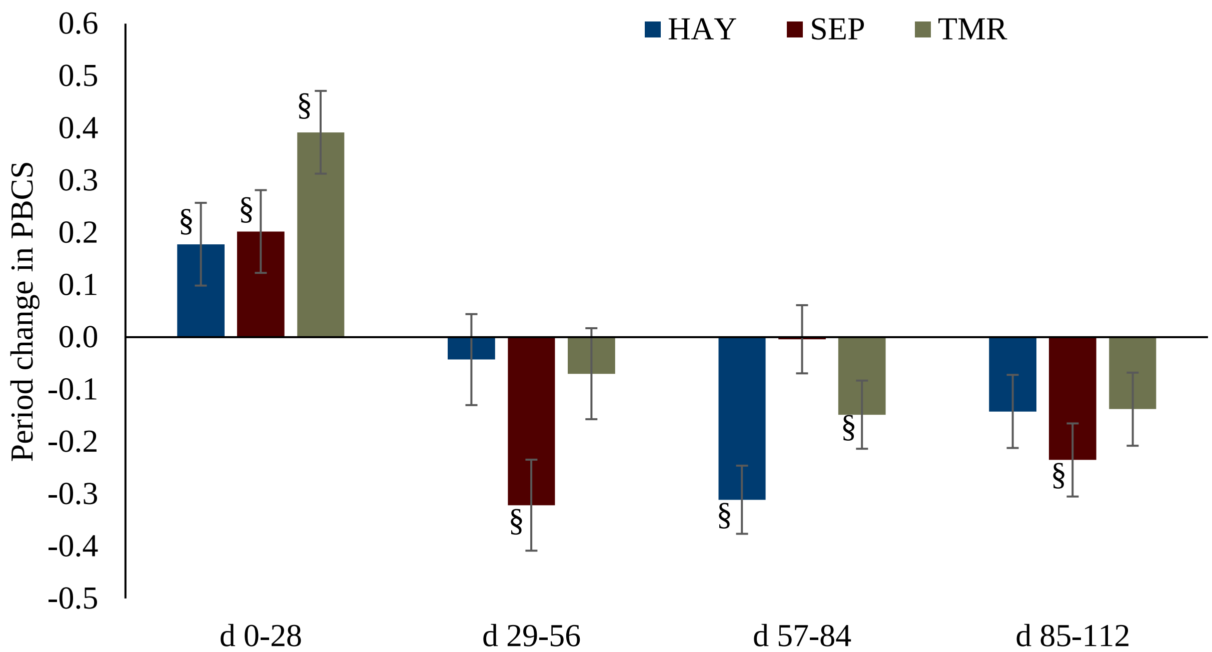

Figure 21. Effect of feeding method on period changes of predicted body condition score (PBCS) in limit-fed mid- to late-gestation cows. HAY = cows fed *ad libitum* hay; SEP = cows limit fed concentrate 12 h after wheat straw; TMR = cows limit fed total mixed ration once daily; § denotes significant difference from zero

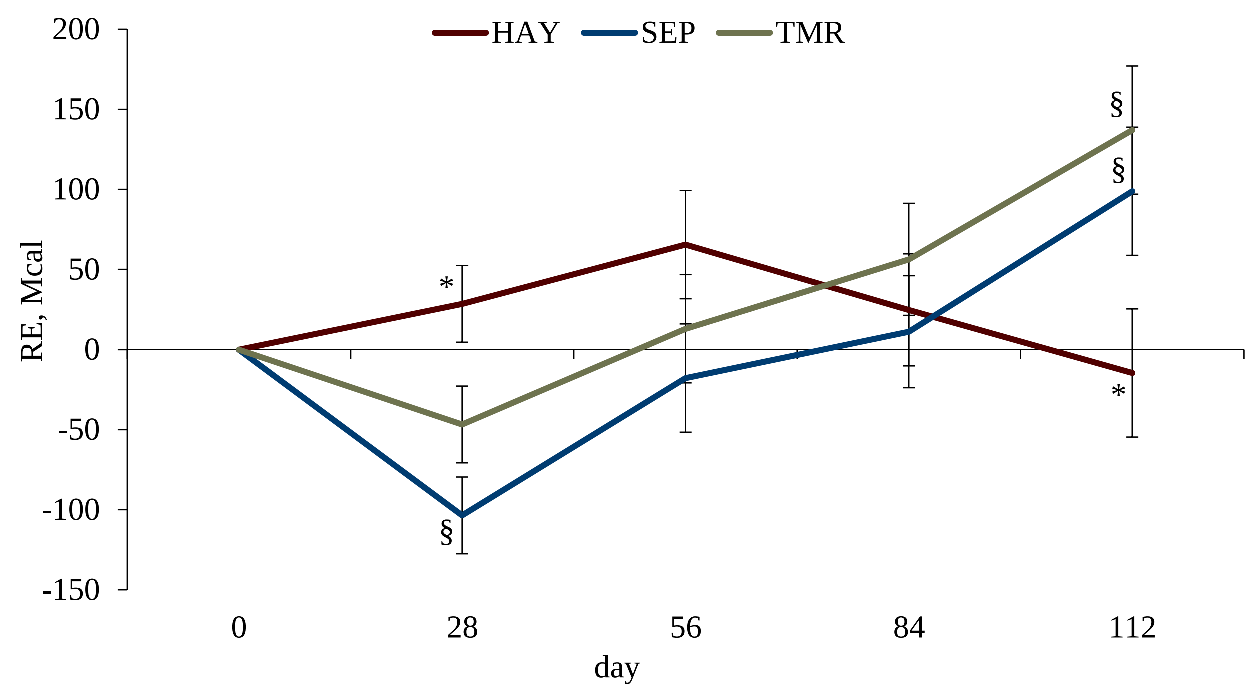

Figure 22. Effect of feeding method on retained energy (RE) in limit-fed mid- to late-gestation cows. HAY = cows fed *ad libitum* hay; SEP = cows limit fed concentrate 12 h after wheat straw; TMR = cows limit fed total mixed ration once daily; * denotes significant difference between treatments; § denotes significant difference from zero

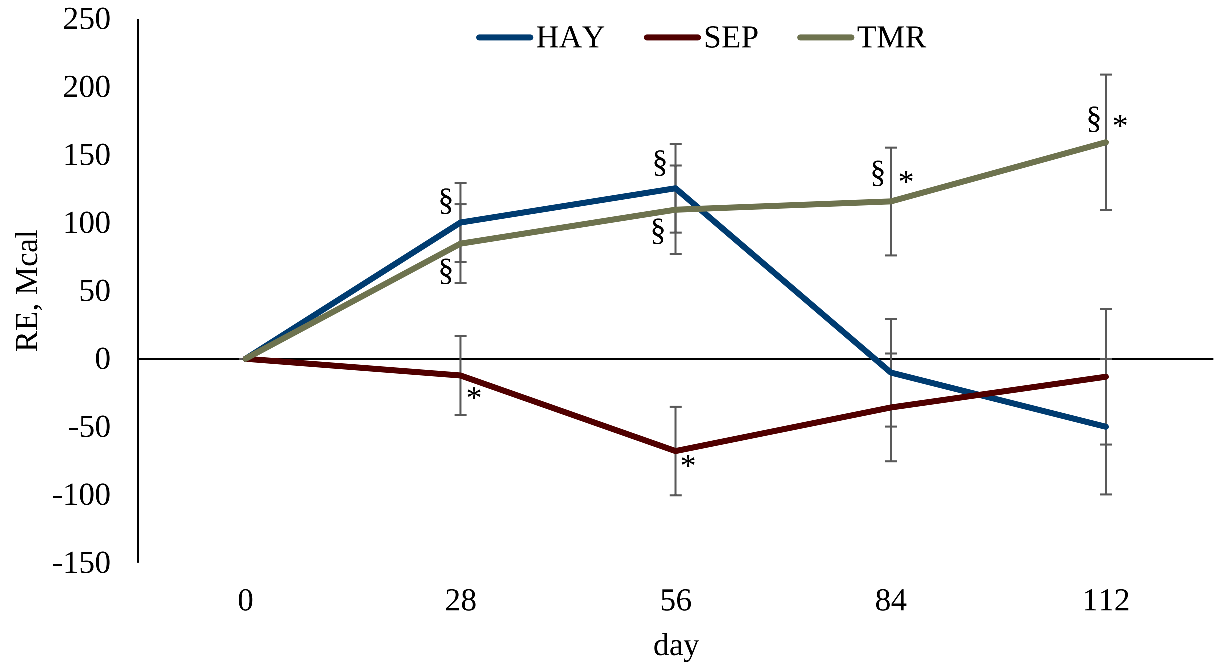

Figure 23. Effect of feeding method on retained energy (RE) estimated from predicted body condition score (PBCS) in limit-fed mid- to late-gestation cows. HAY = cows fed *ad libitum* hay; SEP = cows limit fed concentrate 12 h after wheat straw; TMR = cows limit fed total mixed ration once daily; * denotes significant difference between treatments; § denotes significant difference from zero

Table 15. Effect of feeding method on standard deviation change from initial standard deviation for body weight of mid- to late-gestation cows.

	Treatment[1]				
	HAY	SEP	TMR	SEM	*P*-value
No. of observations	4	4	4		
Change from initial standard deviation					
d 28	5.8*	1.7	2.7	1.92	0.33
d 56	5.3	4.4	9.2*	2.94	0.50
d 84	7.4	-2.7	13.2*	4.29	0.07
d 112	6.8	6.1	17.1*	5.43	0.32

[1] HAY = cows fed *ad libitum* hay; SEP = cows limit-fed concentrate 12 h after wheat straw; TMR = cows limit-fed total mixed ration once daily
*Treatment is significantly different from zero ($P < 0.05$)

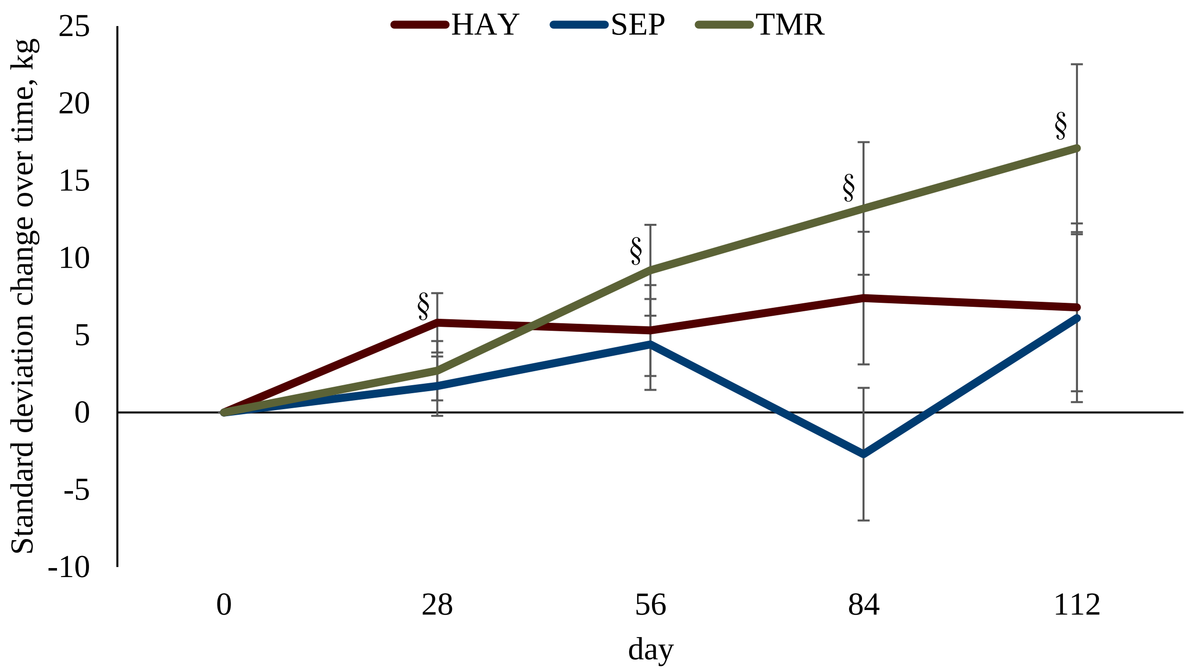

Figure 24. Effect of feeding method on standard deviation change over time. HAY = cows fed *ad libitum* hay; SEP = cows limit fed concentrate 12 h after wheat straw; TMR = cows limit fed total mixed ration once daily; § denotes significant difference from zero