EFFECT OF LEVEL OF INTAKE AND ENERGY CONCENTRATION ON DIET UTILIZATION AND RUMINAL FILL IN BEEF STEERS

An Undergraduate Research Scholars Thesis

by

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ABSTRACT

Effect of Level of Intake and Energy Concentration on Diet Utilization and Ruminal Fill in Beef Steers. (May 2015)

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Intensification of cow-calf production by limit-feeding high-energy diets could increase beef production per acre and returns to cow-calf enterprises while reversing the decline in beef cow numbers. To determine the impact of level of intake and dietary energy concentration on digestion, 16 steers (kg BW) fitted with ruminal cannulae were used in a 2×2 factorial experiment. The first factor consisted of ration energy density: high-energy (H; 2.45 Mcal ME/kg) and low-energy (L; 1.94 Mcal ME/kg). The second factor was level of intake 80% (80) or 120% of predicted NRC requirements (120). Intake was assigned individually based on mean treatment intake (g/kg BW.75) of gestating cows from a previous completed project. The experiment consisted of 14-d for adaptation to treatments, 4-d for measurement of intake and digestion, 1-d for determination of ruminal fermentation, and 1-d to determine ruminal fill. There was an energy density by intake level interaction ($P = 0.05$) for OM intake resulting from a smaller increase in intake for L steers moving from 80 to 120, than the H steers. Organic matter intake was 11.96 and 14.93 g/kg BW for L 80 and L 120, respectively. Steers fed H had OM intakes of 9.06 and 13.71 g/kg BW for 80 and 120, respectively. An energy density by level interaction was observed for digestibility of OM ($P < 0.01$) and GE ($P = 0.02$). These interactions result from consistent digestion of L across the two intakes (59 and 61% for 80 and

120, respectively) and a sizeable reduction in H as intake increased (69 and 61% for 80 and 120, respectively). Intake of DE was different between intake level (P < 0.01) and energy density (P < 0.01) with steers offered L consuming 0.138 and 0.178 Mcal/kg BW.75 in 80 and 120, respectively. Steers fed H consumed 0.120 and 0.161 Mcal/kg BW.75 for 80 and 120, respectively. Ruminal fill was greater (P < 0.01) in steers fed L vs. H diets (4.75) versus 3.90 kg DM and for steers consuming 80 versus 120 (P < 0.01, 3.98 versus 4.67 kg DM, respectively). Solid rate of passage was greater (P < 0.01) in steers offered L (2.65) than H (2.20 %/h) and was not significantly different between levels of intake (P = 0.11). Steers responded to dietary energy density and level of intake as expected with the exception of digestion being greater with the low-energy diet than anticipated.

NOMENCLATURE

ADIA	Acid Detergent Insoluble Ash
ADF	Acid Detergent Fiber
CP	Crude Protein
DM	Dry Matter
DMD	Dry Matter Digestibility
DMI	Dry Matter Intake
mM	Millimoles
N	Nitrogen
NDF	Neutral Detergent Fiber
NEm	Net Energy Maintenance
OM	Organic Matter
OMD	Digestibility
VFA	Volatile Fatty Acid

CHAPTER I

INTRODUCTION

Over the past several decades, beef cow numbers in the United States have declined and continue to contract in the presence of an ever growing world population (NASS, 2014). Population growth is predominantly occurring in developing counties, where per capita incomes are simultaneously increasing. Ultimately, these increases in population and affluence correspond to increased global demand for animal protein. An increase of 70% above 2010 levels in the year 2050 is anticipated and this coincides with an expected global population of 9.6 billion people (Gerber, 2013). In order to accommodate the demand from a larger population, production efficiency increases are needed to balance the decreasing cow inventory of the United States. While the U.S. trails other top exporters of beef in terms of total cow numbers, countries such as Brazil and India continue to be exceeded by United States commercial beef production by at least 20% (AgMRC). Due to advancements in genetics, management, nutrition, and animal health, the amount of beef produced per cow in the U.S. has increased from 400 pounds in the 1960s to 632 pounds in 2009 (USDA). While this increase if impressive, additional advancements will be needed in order to match growing global beef consumption.

These challenges are further complicated by increasing competition for land between urban development, recreation, green space and cow-calf enterprises. According to NASS, a 98% increase in average pastureland value has been observed since 2003. To meet the growing demand for animal protein with a limited land base creates a challenge and requires beef producers to investigate strategic intensification allowing for expansion of our capacity to produce beef in concurrence with economic and environmental sustainability. Placing cows in confinement would allow for a concentrated diet to be fed for either a portion of the production cycle, or for the entirety of the process. Possible benefits include lower feed inputs, reduced feed cost per unit of gain, reduced manure production and handling, and potentially less feed wastage (Lake, 1986). Intensification strategies would allow the beef industry to cope with these trends and increase beef production per acre while simultaneously increasing returns to commercial enterprises.

Diet Digestion and Energy Availability

Energy retention is promoted at an increased level for high-concentrate, energy dense (NEm Mcal/kg) diets versus those of lower energy density (NRC, 2000). This is due to greater urinary, gaseous, and fecal losses from a diet with a low concentration NEm, typically low-quality forage based diets. There is a critical level of ME density which adjusts to an animal's varying energy requirements over time; as energy density increases overall feed intake will decrease (Montgomery & Baumgardt, 1965). It is this principle that forms the foundation for the idea of programmed feeding, to meet energy requirements for maintenance while doing so at a lower intake level.

Intake level influences nutrient digestion of a given diet with a general trend of decreasing digestion as intake increases. It is known that the level of intake has an effect on a ruminant's ability to metabolize the diet (Garrett, 1987; Johnson, 1987). As level of intake increases, the rate of passage in the digestive tract increases as well to utilize the diet efficiently, which decreases the amount of time for digestion and thus the energy availability for materials slowly fermented in the rumen (Owens, 1986). This implies that a diet fed at a low intake would be digested to a greater extent, and therefore an increased amount of the total nutrients fed would be absorbed and subsequently utilized. However, it must be considered that excessively high concentrate levels fed to ruminants will have detrimental effects on rumen health as well as digestibility in some cases. The implications of this information in an applicable format become evident when the effects of energy density on digestion parameters are also considered.

Supplementing predominantly hay-based diets with grain reduced forage utilization, measured as digestible organic matter intake (Kartchner, 1980). They determined this by supplementing cracked barley or soybean meal to cows grazing native fall-winter range forage, and found decreases in forage dry matter digestion of 6.3% compared to cows not supplemented. Despite this observation, total DMD values were not as varied, with only a 1.8% decrease in digestibility between grazing cows and those supplemented with grain. This negative associative effect is terminated when the practice of programmed feeding is used, however, since only small amounts of forage are fed in a concentrate based diet.

Greater DMD (66.2% versus 63.2%) was observed when a high energy diet (1.80 Mcal NEm/kg, 70% concentrate) versus a low energy diet(1.48 Mcal NEm/kg, 45% concentrate), were fed ad libitum (Fluharty et al., 1994). Dry matter intake ($P < 0.05$) was 0.5 kg/d lower for steers fed the high energy diet than the low energy diet. Despite this difference in DMI, the steers fed the high energy diet consumed 39.5% more NEg than the low steers. A portion of this response resulted from greater digestion (5% more) for the high-energy diet. In total, greater energy availability produced an 8.7% increase in feed efficiency. In following with these observations, a trial in sheep compared isoenergetic rations (Murphy et al., 1994). One of four diets was fed containing increasing levels of concentrate (22, 39, 61, and 92%) with the lowest level of concentrate being fed *ad libitum* whereas the remaining diets were fed at 90, 80 and 70% of *ad libitum* intake such that all diets were fed on as an equal amount of metabolizable energy. For the 92% concentrate treatment, OMD was 82.16%, which was 18% more than the 61 % concentrate diet. In Trial 2, they fed the 92% concentrate diet was fed at four levels ad libitum intake, 90, 80, and 70% of ad libitum intake. For each 1% reduction in DM intake there was a 0.14, 0.42, 0.50, and 0.05 percent increase in DM, ADF, CP and starch digestion, respectively.

These results are in concurrence with steers fed 84% corn diets at maintenance level intake displaying increased starch digestion as well as total tract DMD and OM digestion versus steers with intake levels 1.67 and 2.00 times maintenance level (Galyean, 1979). Similar studies have found that adding corn to a ruminant's diet can increase overall DMD by 13.3% while decreasing cellulose digestibility almost 6% (Montgomery, Baumgardt, 1965). A diet consisting solely of long-alfalfa hay had a DMD coefficient of 55.9, while long-alfalfa hay supplemented with corn had a value of 69.2 when fed to Holstein heifers. Grubb and Dehority (1975) fed diets containing 60% concentrate to sheep and observed an increase in rumen bacterial populations compared to all-forage diets. Increased bacterial populations aid in the digestions of ADF and NDF, which may account for some increase in digestibility observed in the limit fed diets. Feeding a high concentrate diet at a high intake level, however, will actually decrease the digestibility of the diet being fed (Colucci et al., 1989). This study found a linear relationship between the proportion of concentrate in a diet and OMD, as also illustrated by the experiments previously mentioned, however the slope of the line relating these parameters decreased for cows fed at a high intake level. Additionally, percentage of concentrate at low intake levels was linearly and negatively related to rate of passage in the reticulorumen ($P < 0.005$). This trend was also observed at high intake levels, however not at significant values. Contradicting results have been observed, stating that intake level (*ad libitum*, 85% of *ad libitum*, or 70% of *ad libitum*) has no effect on the digestibility of high concentrate diets (Old and Garrett, 1987). These findings may be the result of a small sampling size (eight steers) being used to determine digestible and metabolizable energy (Mcal/kg). It has also been stated that limit feeding diets of increasing protein content will not improve digestibility (Hart and Glimp, 1991). While clarification is needed to determine the cause of these discrepancies, the vast majority of work done in this subject matter has found effects between intake and energy availability.

Evidence has been presented that limit feeding high-concentrate diets to beef cattle will increase feed efficiency (Hicks et al., 1990). This conclusion comes from a study consisting of three trials investigating the effect of limit feeding on the performance of feedlot cattle. One of these trials, conducted over 149 days, illustrated that a high wheat diet fed at 85% *ad libitum* versus *ad libitum* improved the feed required per unit of live weight gain by 8.4% ($P < 0.03$). Additional trials have seen increases in feed efficiency up to 8.7% (Fluharty et al., 1994). Despite the lack of ADG improvement, increasing feed efficiency alone is still economically advantageous to the producer. This benefit is amplified when utilizing limit feeding due to the fact that hay generally costs 50-100% more per unit of energy than corn, in addition to higher digestibilities generally being observed when restricted intake is utilized. Loerch (1996) reported lower daily feed costs for cows limit fed compared to ad libitum hay consumption, with corn diets costing $0.81 per cow per day and hay costing $1.37 per cow per day. The cost of feeding hay ad libitum to cows in mid-gestation was almost double that of limit feeding, with few differences observed in overall cow performance regarding birth and weaning weights as well as conception rates (Schoonmaker et al., 2003). These results present implications that programmed feeding is an economically feasible management practice that should be further considered.

Solid Passage Kinetics

Retention time and digesta passage kinetics are important to fully understanding the mechanisms of feed utilization and degradation in the rumen. Additional information regarding the interactions of forage to concentrate ratios is needed to fully interpret how these parameters effect feed utilization, as well as how these interactions are affected by varying intake levels. Montgomery and Buamgardt (1965) presented data stating that as DMI increases, gastrointestinal fill in cattle increases as well through a direct relationship. This study compared eight rations with various energy concentrations and physical forms. From this information, it has been speculated that ruminants can regulate their energy intake based on the amount of digesta present in the gastrointestinal tract. This is significant when considering differing effects regarding isoenergetic intake levels and diets. Increasing ruminant feed intake generally increases digesta passage rate and frequency of reticular contractions (Grovum, 1986). Owens and Zinn (1986) reported increasing passage rate decreased DMD results in reduced nutrient utilization and an expected increase in fecal excretion. Faichney (1980) proved this principle by finding the digestibility of dietary components in the rumen is a function of the rate of passage of the component as well as the rate at which is digested.

Robsinson et al. (1986) performed a study with lactating dairy cows which illustrated that as intake decreased, rumen content of total digesta including non-DM and DM components decreased as well. Additionally, as intake level declined, rumen passage rate of NDF linearly declined at an increasing rate and rumen rate of NDF digestion increased linearly. This experiment was conducted using 66% concentrate diets. Rumen capacity physiologically adapted to reductions in intake. Ruminal DM components are disproportionately decreased while only a moderate depression is observed in relation to total rumen volume. They postulated that rate of digestion may be decreased at high levels of intake because of subprime conditions for ruminal bacterial growth. When employing restricted intake of a high concentrate ration on sheep, it was observed that fecal DM was reduced, but even more so than expected due to the increased digestibility of the diet (Murphy, Loerch, Smith, 1994). Limit-fed steers had a 17% increase in ruminal retention time compared to steers consuming ad libitum hay (Chaot et al. 2002). This study also illustrated that after 21 days limit-feeding a finishing diet reduced fecal OM and N excretion by 50 and 35%, respectively.

Research has found differing results regarding solid passage kinetics. In a study of 3 trials, all related to restricted intake of a high concentrate diet, ruminal metabolism was not significantly affected, with digesta kinetics following the same trend (Choat et al. 2002). The objective of this study was to determine how restricted dietary adaptation would affect feedlot performance, in relation to a conventional adaptation method. However, an important aspect to note for this study is the decreased length of restriction in comparison to other literature concerning limit feeding. The shorter duration of restrictive feeding could have an influence on the metabolism parameters observed over the 21 d period. Gaylean (1979) saw no effects regarding gastrointestinal fill when restricted intake was used as a feeding tactic.

Volatile Fatty Acids

Organic volatile fatty acids are the products of fermentation in the rumen, and supply a significant amount of energy to the animal once absorbed by the gastrointestinal epithelium. For this reason, determining dietary effects on VFA production is important to determine how ruminal fermentation will be affected. Literature has reported that individual VFA levels vary in relation to certain intake levels (Bath & Rook, 1963). Furthermore, as intake decreases, ruminal pH will increase and total VFA concentrations in the rumen will decrease (Davey, 1965). This observation was verified by those seen by Rumsey (1970), where intake increase caused an increase in total VFA production. Murphy et al. (1994a) compared VFA concentrations of steers fed *ad libitum* versus 70% *ad libitum* and observed greater concentrations at 3 and 4 hours after feeding when intake was limited. This observation was attributed to the fact that a smaller ruminal volume was present in the limited intake steers. However, it must be emphasized that these implications were not developed while considering varying energy densities. Robinson et al. (1986) also reported that a decrease in intake caused a linear decrease in total rumen VFA concentrations for acetate, propionate, butyrate, and valerate. When the study examined the effects of varying starch proportions in the diet, no effect was seen for either VFA concentrations or ammonia levels in the rumen, with the exception of valerate, which increased linearly as starch increased. The rumen evacuation-derived rate of digestion for NDF proved to be highly correlated to rumen pH, with an r^2 value of .86. The total VFA concentration was less highly correlated, with r^2 = .62. Despite these correlations, the changes observed in pH and total VFA concentration failed to predict a decline in NDF rate of digestion for a shift from 10.5 to 6.0 kg of intake, inducing speculations that these parameters may not be the causative factors for rate of digestion.

Based on the review of literature, it is hypothesized that increasing the intake level of a diet will decrease the digestion and nutrient availability of the ration. It is also predicted that ruminal pH will increase in response to a decreased intake level, while total VFA concentrations will decrease. The rate of solid passage is figured to increase in correlation to increased feed intake. Ruminal dry matter fill is expected to increase with intake as well as with a lower quality, less energy dense ration.

CHAPTER II

METHODOLOGY

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

Material and Methods

Sixteen Angus × Hereford steers (287 ± 37 kg BW) fitted with ruminal cannulae were used in an experiment designed to examine the effects of dietary energy concentration and intake on digestibility, ruminal fermentation, and gut fill. Treatments were arranged as a 2 × 2 factorial with the first factor consisting of one of two rations (Table 1): high-energy (H; 2.45 Mcal ME/kg) and low-energy (L; 1.94 Mcal ME/kg). The levels of intake were designed to correspond to the level of intake required to meet either 80 or 120% of NRC NEm requirements for mature cows used in a previous experiment. For the duration of the experimental period, steers were housed in individual stalls (2.1 m × 1.5 m) in an enclosed barn. Daily feeding time was at approximately 0700 h, with orts, when present, being collected and weighed just prior to feeding. *Ad libitum* access to fresh water was supplied throughout the course of the experiment.

Experimental periods proceeded as follows: 1) 14-d for adaptation to treatments, 2) 4-d for measurement of intake and digestion, 3) 1-d for determination of ruminal pH, RAN and VFA concentrations, and 4) 1-d for determination of gut fill. Feed and ort samples were collected on d 14 through 17 to correspond with fecal samples collected on d 15 through 18. Feces were collected in a staggered pattern across the 4-d period, representing 12 different h, and were stored at -20°C following collection.

On d 19, ruminal fermentation parameters, including pH level, RAN and VFA concentration were measured. A suction strainer (Raun and Burroughs, 1962; 19 mm diameter, 1.5 mm mesh) was utilized to collect rumen fluid samples immediately before feeding (0 h) and at 2, 4, 6, 9, 12 and 16 h after feeding. At the time of sampling, determination of pH for each sample was completed with a portable pH meter including a combined electrode (VWR SympHony). Rumen fluid subsamples of 8 mL were combined with 2 mL of 25% m-phosphoric acid for future VFA analysis, and 9 mL of rumen fluid were combined with 1 mL of 1 N HCl for subsequent RAN analysis. Following this procedure, the subsamples were frozen at -20°C. Rumen fluid samples were thawed prior to being centrifuged at 20,000 X g for 20 min. Volatile fatty acid concentrations were measured using a gas chromatograph with methods described by Vanzant and Cochran (1994). Rumen ammonia nitrogen concentrations were measured using a UV-VIS with calorimetric procedures as described by Broderick and Kang (1980).

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

Ingredient	High Energy	Low Energy
	% As Fed	
Wheat straw	34.52	64.08
Corn	29.46	0
Distillers' grain	27.46	27.36
Urea	1.1	1.1
Molasses	5	5
Mineral	2.46	2.46
Ingredient Cost	157.33	129.52
Nutrient composition	% of Dm[a]	
ADF	29.4	45.92
Ash	8.13	10.11
ADIA	2.84	4.29
ME[b]	2.54	1.96
NEm[c]	1.64	1.12

[a]Dry matter contents: high energy, 89.9%; low energy, 90.6%.
[b,c]Mcal / kg as fed, estimated using NRC

Reticuloruminal fill was quantified via rumen evacuations completed at approximately 0700 h followed by another evacuation period at 1100 h. The reticulorumen contents were emptied through the cannula and subsequently placed into a barrel, where weight was recorded after a hand mixing of the contents had taken place. Samples of approximately 750 g were placed in tin pans for later drying. Following this procedure, rumen contents were immediately returned to the rumen of each animal.

Laboratory Analysis

Feed, fecal and rumen samples were dried in a forced-air oven for at least 96 h at 55°C and allowed to air equilibrate for determination of partial DM. Following partial DM determination, the remaining samples were composited and filtered through a 4-mm screen prior to a 1-mm screen using a Wiley mill, and then dried at 105°C for determination of DM. The loss in dry weight upon combustion in a muffle furnace for 8 h at 450°C was measured to determine organic matter content. ADF analysis was performed using an Ankom Fiber Analyzer (Ankom Technology Corp., Macedon, NY), and ADIA determination was achieved by loss in ADF DM weight upon combustion in a muffle furnace at 450°C. Energy content of each sample was determined using a bomb calorimeter (Parr adiabatic calorimeter; Parr Instruments Co., Moline, IL).

Calculations

Calculations of intake and digestion were constructed from observations of fecal samples on d 15 through 18. Fecal production was calculated by dividing ADIA consumption by fecal ADIA concentration: Fecal production, kg = $\frac{DMI \times ADIA_d}{ADIA_f}$

where:

DMI, kg

$ADIA_d$ = Dietary ADIA concentration (%DM)

$ADIA_f$ = Fecal ADIA concentration (%DM)

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

$$\text{Digestibility}_n, \% = \frac{Intake_n - Fecal_n}{Intake_n} \times 100\%$$

where:

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

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

Statistical Analyses

All data analyses were completed using PROC MIXED procedures in SAS 9.2 (SAS Inst. Inc., Cary, NC). The model effects included diet, intake and diet × intake.

CHAPTER III

RESULTS AND DISCUSSION

An intake level × energy density interaction was observed for DM intake (P = 0.06) due to incomplete consumption of feed offered for L steers when fed 120 versus 80, compared to the H steers. Dry matter intake was 13.32 and 16.69 g/kg BW for L 80 and L 120, and 9.86 and 14.93 g/kg BW for H 80 and H 120, respectively. This is in contrast to results observed from the mature cows in a previous study, which displayed no intake level × energy density interaction (Trubenbach, 2014). This discrepancy between data is the results of the incomplete consumption of the ration, as steers consuming the low energy ration had orts remaining after most feedings.

There was also an energy density × intake level interaction (P = 0.05) for OM intake again resulting from a smaller increase in intake for L steers moving from 80 to 120, than the H steers. Organic matter intake was 11.96 and 14.93 g/kg BW for L 80 and L 120, and 9.06 and 13.71 g/kg BW for 80 and 120, respectively. There was no significant intake level × energy density interaction for NDF and ADF intake. Intake of NDF for L steers was 8.33 and 9.99 g/kg BW for 80 and 120 and for H80 steers was 4.58 g/kg BW, while NDF intake for H 120 steers was 6.93 g/kg BW.

An energy density × intake level interaction was observed for digestibility of OM (P < 0.01) and GE (P = 0.02). These interactions result from consistent digestion of L across the two GE intakes (59 and 61% for 80 and 120, respectively) and a decrease in GED in H as intake increased (69 and 61% for 80 and 120, respectively). Digestibility of OM for L was 61.3 and

63.6% for the 80 and 120 intake levels, respectively. In contrast, the H diet OM digestibility was 71.7 and 64% for 80 and 120, respectively. The digestibility of the L diet for both intake levels was greater than expected when compared to results from the mature cow project at the McGregor Research Station, with no biological difference being observed between the 80 and 120 intakes. Trubenbach (2014) observed OM digestibility of 62.79 and 58.8% for 80 and 120, respectively, which are lower and more variant levels than those observed with the steers. However, the high energy digestibility of the steers was concurrent with the idea that increasing intake will decrease the digestibility of the diet fed. Colucci et al. (1989) found a linear relationship between the proportion of concentrate in the ration and OMD, which is consistent with results illustrated. Galyean (1979) also reported results of increased total tract DMD and OM digestion for steers fed diets at lower intake levels, specifically maintenance level intake versus 1.67 and 2 times maintenance requirements.

Table 2. Effect of diet energy concentration and level of intake on intake and ruminal digestibility[a]

	High Energy Diet		Low Energy Diet		SEM	Probability		
Item	Low intake	High intake	Low intake	High intake		Diet	Intake	Diet × Intake
Dry matter intake, g/kg MBW	13.32[a]	16.69[b]	9.86[c]	14.93[d]	41	<0.01	<0.01	0.06
Dry matter digestibility, %	57.5	59.1	68.1	60.5	1.6	<0.01	<0.01	0.01
OM digestibility, %	61.3	63.4	71.7	64	1.6	<0.01	<0.01	<0.01
ADF digestibility, %	50.9	52.3	49.7	44	1.8	<0.01	<0.01	0.08
GE digestibility, %	59	60.7	68.6	61.1	1.7	<0.01	<0.01	0.02
OM intake, g/kg MBW	11.96[a]	14.93[b]	9.06[c]	13.71[d]	38	<0.01	<0.01	0.05
Gross energy intake[b]	0.23[a]	0.30[b]	0.18[c]	0.26[d]	0.6	<0.01	<0.01	0.04
Digestible energy intake[b]	0.14[a]	0.18[b]	0.12[c]	0.16[d]	0.5	<0.01	<0.01	0.97

[a]Observed via feed and fecal analysis
[b]Mcal/kg MBW

An intake level × energy density interaction appeared for intake of GE (P = 0.04), which can again be attributed to incomplete consumption of the L ration. Intake of DE differed between intake level (P < 0.01) and energy densities (P < 0.01) with steers offered L consuming 0.14 and 0.18 Mcal/kg $BW^{\wedge.75}$ in 80 and 120, respectively. Steers fed H consumed 0.12 and 0.16 Mcal/kg $BW^{\wedge.75}$ for 80 and 120, respectively. These results are as expected due to fecal losses being accounted for in the measurement of DE, which are not taken into consideration in the measurement of GE intake.

Ruminal fill was greater (P < 0.01) in steers fed L vs. H diets (4.75) versus 3.90 kg DM and for steers consuming 80 versus 120 (P < 0.01; 3.98 versus 4.67 kg DM, respectively). Solid rate of passage was greater (P < 0.01) in steers offered L (2.65) than H (2.20 %/h) and was not significantly different between levels of intake (P = 0.11). While Grovum (1986) did find increased passage rate when increasing feed intake, the results observed with the steers are still consistent with literature regarding the decreasing digestibility of the low energy diet. Owens and Zinn (1986) reported an increasing passage rate was positively correlated to decreased DMD results, which is undeviating from the results observed in this trial.

Steers responded to dietary energy density and level of intake as expected with the exception of digestion being greater with the low-energy diet than anticipated.

Total VFA concentrations increased over the 16 h period regardless of treatment. An energy density × intake level interaction was observed for total VFA concentration (P = 0.03). Additionally, an energy density × hour interaction was observed as well (P < 0.01). Average concentration for steers fed the low energy diet was 66.48 mM and 62.33 mM for 80 and 120 consumptions, respectively. Steers consuming H had total VFA concentrations of 60.80 mM for the low intake level and 63.86 mM for the 120 intake level. These results are consistent with those reported by Robinson et al. (1986), of which total rumen VFA concentrations for acetate, propionate, butyrate, and valerate decreased linearly as intake level decreased.

An energy density × intake level interaction was seen for ruminal pH (P = 0.09) as well a diet × hour interaction being observed (P <0.01). Steers fed the low energy ration had slightly higher pH levels, with a pH of 6.35 and 6.41 being measured for 80 and 120, respectively. The high energy ration pH levels were observed to be 6.35 for low intake and 6.30 for high intake, with the H 120 treatment displaying the lowest pH over the 16 h period. In general, the high energy ration displayed lower pH values starting at h 5, which was expected.

Table 3. Effect of diet energy concentration and level of intake on intake and ruminal dry matter fill and solid passage rate

	High Energy Diet		Low Energy Diet			Probability	
Item	Low intake	High intake	Low intake	High intake	SEM[a]	Amount	Diet
Dry Matter Fill, kg	3.39	4.42	4.57	4.92	27.69	0.03	0.01
Solid Passage, %/hour	2.1	2.33	2.52	2.81	14.44	0.1	<0.01

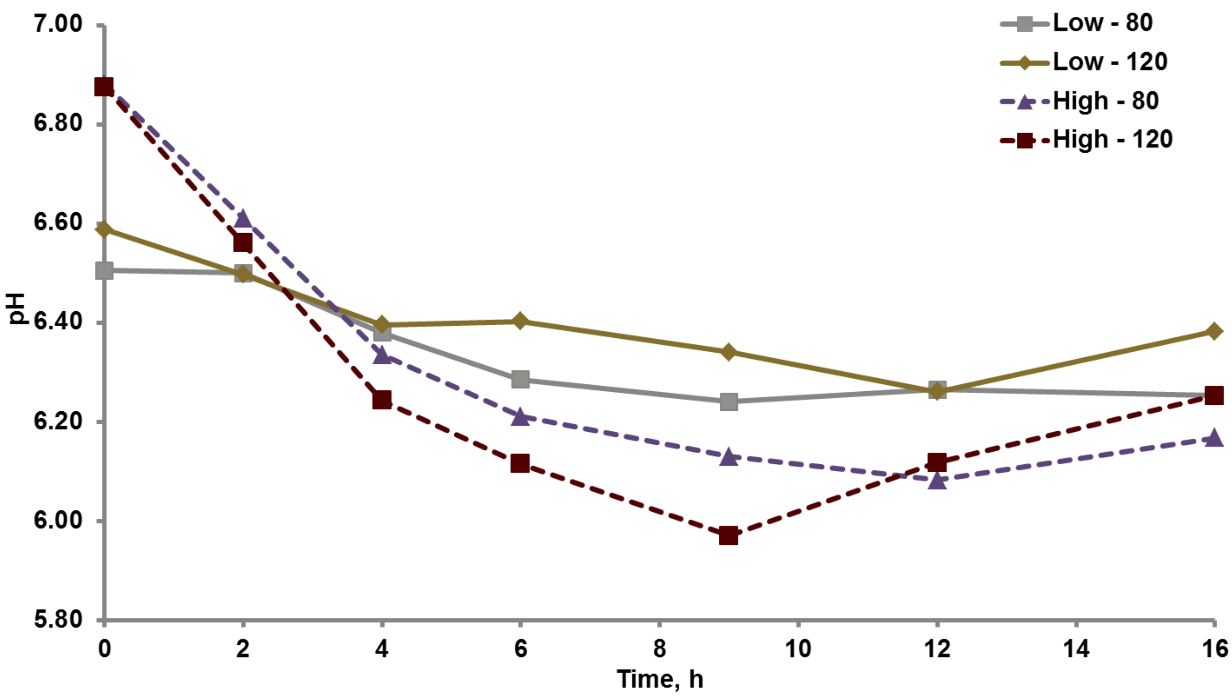
[a]Standard Error Mean

Table 4. Effect of diet energy concentration and level of intake on ruminal pH and VFA profile

	High Energy Diet		Low Energy Diet		SEM[a]	Amount	Diet	D[b] × A[c]	H[d]	A × h	D × h	A × D × h
Item	80	120	80	120								
pH	6.35	6.3	6.35	6.41	2.97	0.71	0.077	0.087	<0.01	0.86	<0.01	0.86
Total [VFA]	60.8	63.86	66.48	62.33	166	0.74	0.22	0.033	<0.01	0.99	<0.01	0.63
Acetate	63.37	65.18	0.68	0.67	0.36	0.23	<0.01	<0.01	<0.01	0.99	0.49	0.85
Propionate	21.73	20.34	0.20	0.19	0.24	<0.01	<0.01	0.54	<0.01	0.61	0.47	0.50
Butyrate	10.54	10.52	0.087	0.10	0.23	0.0032	<0.01	<0.01	<0.01	0.57	0.08	0.99
Isobutyrate	1.5	1.4	0.011	0.013	0.032	0.034	<0.01	<0.01	<0.01	0.81	<0.01	0.97
Isovalerate	1.85	1.56	0.011	0.015	0.045	0.68	<0.01	<0.01	<0.01	0.95	<0.01	0.81
Valerate	1.0	.99	0.0084	0.0091	0.029	0.23	<0.01	0.14	<0.01	0.95	0.03	0.97
Acetate: Propionate	3.0	3.23	3.4	3.52	5.038	<0.01	<0.01	0.18	<0.01	0.92	0.57	0.54

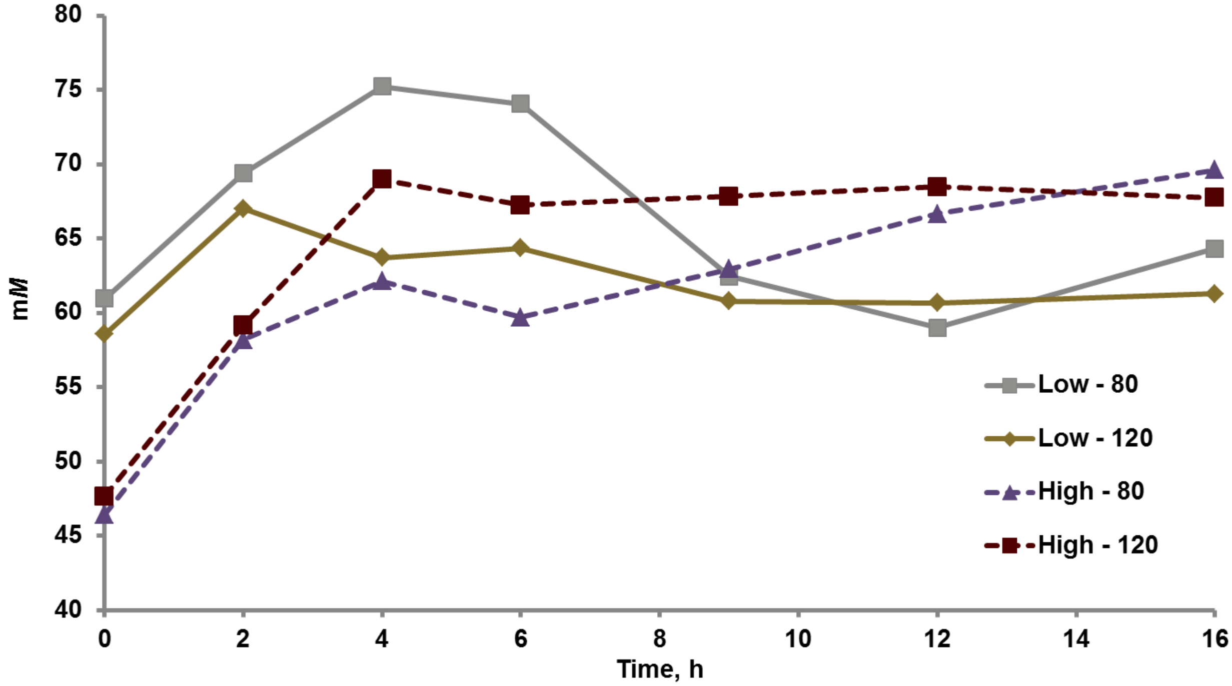
[a]Standard Error Mean
[b]Diet
[c]Amount
[d]Hour

Figure 1. Effect of diet energy concentration and level of intake on ruminal pH[a]



[a]Diet $P = 0.08$
Hour $P < 0.01$
Diet × Amount $P = 0.09$
Diet × Hour $P < 0.01$

Figure 2. Effect of diet energy concentration and level of intake on ruminal VFA profile[a]



[a]Diet $P = 0.22$
Amount $P = 0.74$
Hour $P < 0.01$
Diet × Amount $P = 0.03$
Diet × Hour $P < 0.01$

CHAPTER IV

CONCLUSION

Despite the elevated digestibility of the low-energy ration being observed, it is clear that decreasing the intake level of a diet increases digestibility. Incomplete consumption of the low-energy ration resulted in no significant difference between intake levels for the low-energy diet. However a difference was observed between the low and high intakes when the high-energy ration was fed, as expected. This data verifies the idea that limit-feeding high-energy diets increases the digestibility of the ration when compared to *ad libitum* consumption. Increased passage rate for the low-energy diet further supports this idea, as the passage rate is inversely related to digestibility. While further research is needed to investigate how intensification strategies would allow the beef industry to adapt to changes in economic and environmental sustainability, the results of this study verify the benefits of limit-feeding in regards to nutrient utilization.

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