EFFECTS OF RESTRICTED VS CONVENTIONAL DIETARY ADAPTATION ON PERFORMANCE, CARCASS TRAITS AND DIGESTA KINETICS BY FEEDLOT CATTLE

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NOMENCLATURE

ADG	average daily gain
DOF	days on feed
BW	body weight
KPH	kidney, pelvic and heart fat
CP	crude protein
ME	metabolizable energy
MP	metabolizable protein
NEm	net energy for maintenance
NEg	net energy for gain
DM	dry matter
DMI	dry matter intake
GAIN	individual animal weight gain
h	hour
d	day
cm	centimeter
kg	kilogram
°C	degrees centigrade
n	sample size

CHAPTER I

INTRODUCTION

Many important advances in technology have occurred in the beef cattle industry, which has allowed beef to remain a competitive protein source in today's market. Great strides have been made in improving the efficiency of beef production, from the development of growth promoting compounds such as oral diethylstilbesterol (DES) in 1954 to the development of feed additives such as Rumensin® in 1975. Products such as these and others have contributed a great deal to the efficiencies we have in beef production today, and are necessary in order for beef to remain competitively priced with other protein sources, namely pork and poultry. However, competing protein sources have made even greater strides in terms of production efficiencies, where as a plethora of inefficiencies remain for beef production. These inefficiencies include such things as industry segmentation, biological and product inconsitency, and long generation turnover to mention a few. Thus it is very important for producers and researchers in the beef industry to strive for increased efficiencies in production of their product in order for it to remain competitively priced and profitable to produce. Such improvements can be made in one of two ways; either by developing new innovative products, which improve performance and lower costs, or by changing management strategies to achieve similar goals. The former may be the more difficult of the two, due to increased consumer awareness and more stringent FDA regulations. Thus if beef is to remain a competitively priced protein source we must strive to develop new and innovative management tools to improve the efficiency of beef production with the resources at hand. One area of management in the feedlot production segment that has consistently proven to be an affective means of improving performance is the use of restricted or programmed feeding of high-concentrate diets. Restricted or programmed feeding has resulted in a 0.4 to 0.6 % improvement in feed efficiency for each 1.0% in restriction below ad libitum. This management tool can be used in a number of ways and offers several benefits other than improved efficiency. These benefits may include, but are not limited to, decreased use of expensive energy sources such as roughage, more predictable performance, and less nutrient excretion which is becoming more and more important to sustaining our natural resources. With these things in mind the objective of the research contained in this thesis was to adapt beef steers of different initial weights to high-concentrate diets with the use of restricted feeding of the finishing diet as opposed to altering the roughage to concentrate ratio and evaluate its effects on feedlot performance, carcass characteristics and ruminal metabolism.

CHAPTER II

REVIEW OF LITERATURE

<u>Growth Management</u>

Introduction

The management of calves from the point of weaning until fattening can vary greatly based upon frame size and (or) breed (i.e., genetic) makeup, the availability of resources, the price of cereal grains, location, economics and many other factors. Although there are many factors that are involved, the many methods of growth management can be generalized into either extensive programs where calves are grown at low to moderate rates of gain, or intensive management programs, which usually involves placing calves directly into the feedlot and on to a finishing program.

Extensive Programs

Extensive growing programs or back-grounding periods as stated by Vaage et al. (1998) involves raising weaned calves on a low-energy, typically forage-based ration for a variable period of time prior to fattening on a high-energy ration. Restricting feed intake or reducing the energy content of the diet prolongs skeletal and muscle growth while delaying the onset of fat deposition (Solomon and Elasser, 1991; Yambayamba and Price, 1991). This system of production is important for earlier maturing biological types due to lighter carcass weights at similar compositions and fatter carcasses at similar body weights compared with later maturing biological types under similar finishing conditions. In support of the previous statement, Coleman et al. (1993) reported that when Angus and Charolais steers were fed to a common backfat endpoint of 12 mm, Angus steers had lighter carcass weights and more carcass fat compared with Charolais steers under similar management. The authors also recommended that moderate growth through approximately seventy five percent of slaughter weight be used for earlier maturing types, and that those types which mature more slowly be placed directly on high-energy diets in order to achieve an acceptable USDA quality grade at a live weight suitable for packers.

Extensive programs include, but are not limited to, grazing calves on cool- and(or) warm-season pasture, stockpiled forages, winter wheat pasture, crop residues, etc. These programs can also include a dry-lot growing phase prior to finishing. The traditional feedlot growing diet typically contains a high percentage of roughage and is offered ad libitum to calves for a specified number of days prior to finishing on a high-concentrate diet. The intent of this type of growing program is to restrict energy intake and consequently body weight gain by offering a low-energy diet, by which intake is limited by physical factors. However the relatively high cost of forages as a source of energy has caused increasing interest in restricting feed intake of high-concentrate diets for growing calves. The objective of these two types of management (i.e., high-roughage and restricted intake of high-grain) is to grow calves at a low to moderate rate of gain in order to achieve a similar on feed physiological stage of maturity to those calves developed under grazing conditions.

Intensive Programs

While it is becoming more difficult in the year 2001 to define a typical system of beef cattle production, based on averages we can say that typically calves in the United

States are born in the spring, weaned in the fall, and grazed on forages for varying lengths of time prior to fattening on a high-concentrate diet. However, with less profitability in beef production and the importance of cost of gain and interest prices in the breakeven price of cattle, it has become a more common place for calves to be placed into the feedlot at 205 days of age or earlier. In support of the economic advantages of intensive management, Vaage et al. (1998) reported that crossbred beef steers derived from Charolais, Simmental, Angus, and Hereford breeding and adapted to high-concentrate diets directly after weaning had faster rates of gain and required less days on feed to reach a common back-fat depth compared with their contemporaries which were backgrounded on a barley silage-based diet for 85 days and grazed on cool season species for a subsequent 89 days prior to finishing under similar conditions.

Limit Feeding Effects on Performance

Galyean (1999) described intake management as either restricted (or limit) feeding or programmed feeding. Restricted feeding, according to Galyean (1999), is the method of feed intake management with which intake is restricted relative to actual or anticipated ad libitum intake and is most often applied to starting cattle on feed and to finishing cattle. Conversely, he defined programmed feeding, frequently used in growing programs, as a method in which net energy equations are used to calculate the quantities of feed required to meet the needs for maintenance and a specific rate of gain.

Finishing Cattle Experiments

Limit feeding as a method of feed intake management is less common than programmed feeding, however restricting intake of finishing cattle has shown some improvement in feed efficiency. Plegge (1987) conducted two experiments to evaluate the effects of slight restrictions in feed intake on feedlot performance of yearling steers. In experiments one and two, steers were either fed to appetite or fed 96 or 92% respectively, of the intake offered to steers consuming to appetite. He observed that steers fed 92% of appetite had lower overall daily gains than steers fed 96% of appetite and steers fed to appetite. While no differences were observed in efficiency, limit-fed steers tended to require less feed per unit of gain than steers fed to appetite. In contrast to percentage restrictions, Zinn (1987) fed an 80% concentrate diet at 110% of ad libitum or programmed intake to achieve 1.27 kg/d of weight gain. All calculations for intake were based on the intake equations of Lofgreen and Garret (1968). Daily gains of the ad libitum and programmed steers were 1.25 and 1.24 kg/d respectively, supporting the applicability of the intake equations. Intake of steers fed ad libitum was 6.2% greater which caused feed conversions to be 4.6% poorer. Percentage restrictions vs programmed feeding of finishing cattle were evaluated by Hicks et al. (1990). In yearling steers, restricting intake to 85% of ad libitum resulted in more efficient conversion of feed to gain with lower daily gains and intakes compared with ad libitum fed steers when adjusted for a common dressing percentage. Restricting intake also resulted in a decrease in the percentage of choice carcasses from 60.8 to 41.7%. In a second trial using yearling heifers, restricting intake to 89% of ad libitum tended to improve feed:gain by 10.9% and did not have an effect on overall daily gain. Percentage of choice carcasses for ad libitum and limit-fed heifers were 47.3 and 37.7%, respectively. In a third trial, restricting intake and programming gain were evaluated against ad libitum feeding. The treatments included ad libitum intake for the entire 138 d trial, 80% of ad libitum for the first 56 d followed by ad libitum feeding to d 138, or programmed gain at either 1.50 (high) or 1.35 kg/d (low). The actual gains for the two programmed groups averaged 1.25 (high) and 1.17 kg/d (low). Overall daily gains for the ad libitum group were greater than those for the 80% restricted group and the low programmed gain group. The high-programmed gain appeared to be the most beneficial with steers having similar daily gains and percentage of choice carcasses with improved feed efficiencies compared with ad libitum fed steers, which is in support of the data from Zinn (1987). Despite the potential for improved feed efficiency, restricting intake of finishing steers offers other appealing advantages to the cattle feeding industry, such as simplified bunk management, advanced knowledge of feed milling needs, and the potentional for decreased manure and nutrient output. Still, this type of management is reluctantly used on a large scale, due to the problem of decreased choice carcasses. Moreover, if restriction is severe enough, increased days on feed or lighter carcass weights might result as observed in the trial by Hicks et al. (1990), where the low programmed group had lighter carcass weights compared with ad libitum fed steers in the third experiment. Finally, the large degree of with in pen variation in biological type found in many commercial feedlots limits the use of the energy equations.

To date only one experiment has been conducted to evaluate the applicability of limit feeding the finishing diet as opposed to using step-up diets to adapt cattle to high-grain diets. Weichenthal et al. (1999) started 384 kg Angus crossbred yearling steers on a finishing program with either diets increasing in grain over 23 days or with limit feeding of the final diet over three weeks. Limit feeding during the start-up improved overall feed efficiency, carcass dressing percentage, and fat thickness, but did not affect daily gain or carcass quality and yield grades. The authors noted that ad libitum intake was reached using limit feeding without major problems from acidosis or related intake variation. This method of adaptation appears to offer all the advantages associated with limit feeding during the finishing phase without the negative effects such as decreased quality grade and carcass weight.

Growing Cattle Experiments

A much more widely used and accepted method of intake management is that used in growing cattle. In extensive growth management which was discussed previously, cattle are grown at low to moderate rates of gain. Usually, earlier maturing biological types are extensively grown in order to prolong skeletal and muscle growth while delaying the onset of fat deposition (Yambayamba and Price, 1991) so that carcass weights are heavier at the point of grading choice. This has historically been accomplished by either ad libitum feeding of high-roughage, low-energy rations or by placing calves into a stocker phase, where calves harvest the forage in a grazing situation. However, with the development of the net energy equations it has become more feasible to grow calves by restricting intake of high-energy diets. This type of intake management was referred to as 'programmed feeding' in the review of restricted and programmed feeding of beef cattle (Galyean, 1999). The many advantages to this type of management over ad libitum feeding of high-roughage diets are discussed in a review by

Lake (1987) and include decreased feed cost per unit of gain, reduced feed and waste handling, simplified bunk management, and more rapid adaptation to the finishing ration. Lake (1987) also stressed many management considerations that must be taken into consideration when limit-feeding high-energy diets. These considerations included such things as care in adapting calves to limit-feeding in timing of meals, calculating and adjusting feed supply for changes in animal weights, the ability to visually appraise the cattle, an understanding of the net energy system, and knowledge of the number of cattle currently in each pen.

In support of the advantages of limit-feeding high-energy diets to growing cattle, Loerch (1990) conducted three trials to compare the effects of restricted intake of high-concentrate diets vs ad libitum intake of corn silage diets during the growing phase on feedlot cattle performance. In Trial 1, one hundred twenty medium-framed steers were allotted to one of three dietary treatments for an 85-d growing period: 1) ad libitum access to a corn-silage diet; 2) a whole-shelled corn, high-moisture corn, corn-silage based diet restricted to a level 20% below that of steers on the corn-silage diet; or 3) a whole-shelled, high-moisture-corn diet restricted to a level 30% below that of steers on the corn silage diet. Nutrient and feed additive intakes were equal for all treatments. Daily gains during the growing phase were equal for all treatments and steers from the 30% restricted group were more efficient than the corn-silage-fed steers or the 20% restricted group. Restriction had no subsequent effects on feedlot performance. In Trial 2, ad libitum consumption of corn silage vs 30% restriction and equal nutrient and feed additive consumption resulted in an 18% decrease in daily gains and a 22.6% improvement in feed efficiency by restricted steers. In Trial 3, ad libitum consumption of corn silage vs 28% restriction and equal nutrient and feed additive intake during an 84-d growing period resulted in a 4.3% improvement in daily gain and a 44% improvement in feed efficiency for restricted steers. Growing and finishing performance combined in Trial 3 showed the same results as those observed in the growing phase. Moreover, final weights as well as hot carcass weights were greater for steers limit fed during the growing phase compared with steers fed ad libitum corn silage. Similar to Trial 1 of Loerch (1990), Sip and Pritchard (1991) found that feed efficiency was improved by 18%, but gain by steer calves was not affected by restricting intake of a high-moisture ear corn diet to approximately 87% of the intake of a corn-silage-based diet fed ad libitum during an 85-d growing period. Sainz et al. (1995) fed British breed steers on three different growing programs from 237 to 327 kg before a subsequent finishing period. Growing period treatments were an alfalfa-based, high-forage diet fed ad libitum, an 85% concentrate diet fed ad libitum, or an 85% concentrate diet fed at a restricted intake so as to equal the daily gain of the ad libitum forage diet group. Nutrient and feed additive concentrations of the limit-fed 85% concentrate diet were not increased in this experiment. Calves fed the restricted high-concentrate diet during the growing period were more efficient on an empty BW basis ($P < 0.05$) during the growing period than those fed the high-forage diet ad libitum during the growing period with no difference in daily gain. Subsequently, feedlot empty BW daily gain and gain : feed was greater for steers fed the restricted high-concentrate diet during the growing phase compared with steers fed the ad libitum high-roughage diet during the growing phase, and accordingly required 22 less days on feed.

In two trials Gunter et al. (1996) evaluated the effects of programming intake of three different diets containing three different concentrate levels to achieve the same level of gain (1.02 kg/d) on growing phase performance and subsequent finishing performance. Sixty, 75, or 90% concentrate diets were fed in Trials 1 and 2 for 84 to 92 d, followed by finishing on a common 90% concentrate diet. Feed efficiency improved in a linear fashion with increasing concentrate levels in both experiments. Restriction had little effect on subsequent finishing performance.

One potentional problem sometimes associated with limit or programmed feeding is that of manger or bunk space. The question that sometimes arises is do limit-fed cattle require greater manger space than conventional-fed cattle? This problem was addressed in a third experiment conducted by Gunter et al. (1996) where bunk space allowances of 12.7, 20.3, 27.9, 35.6 cm/steer were compared for steers programmed to gain 1.07 kg/d during an 84-d growing period. Decreasing bunk space allowance did not affect daily gain, efficiency or within pen variation in BW or daily gain. These findings are supported by similar studies conducted by Zinn (1989).

Mechanisms by which limit feeding may improve feed efficiency

Whether limit feeding is used in a growing or finishing program, it usually results in improved feed efficiency. Although no single explanation for this improvement in efficiency exists, several mechanisms have been proposed. However, due to the wide range in limit-feeding applications, no single mechanism may be active in every scenario. Instead, some combination of factors may be involved in any given system with certain factors being more important than others.

Digestibility, Digesta Kinetics, and Ruminal Fermentation Profiles

Due to common low intakes associated with limit feeding, one would expect that limit feeding simply increases diet digestibility, due to the fact that in most cases digestibility and intake are inversely related. This is supported by Loerch (1990) where DM digestibility during the growing phase increased with increasing levels of restriction as calculated using acid insoluble ash as an internal marker with diets containing moderate levels of roughage. Owens et al. (1986) offered a possible explanation for this; as feed intake increases, rate of passage is accelerated which causes decreased time for digestion, and therefore digestibility of slowly fermented materials, particularly fiber components, is decreased. Owens et al. (1986) presented simple correlations of starch digestibility to intake on a percent of BW basis. While correlations do not always offer an accurate assessment, the correlations for total tract, ruminal, and small intestinal starch digestion were all negative, which supports his hypothesis.

With this in mind, one might suggest that limit feeding simply decreases passage rate. Passage rate (calculated by chromium concentration) and digestibility (determined from acid insoluble ash) as measured by Hicks et al. (1990) were not different between cattle with restricted vs ad libitum access to feed. However, variability in digestibility estimates were quite large, partially due to low levels of acid insoluble ash in the diet. Similarly, Old and Garret (1987) reported that neither intake level (ad libitum, 85% of ad libitum, or 70% of ad libitum) nor protein level (8.9, 11.0, or 12.9%) affected digestibility of a high-concentrate diet. In contrast to this, Murphy et al. (1994b) fed growing lambs a high-concentrate (87 to 74% ground corn and 8% ground corn cobs) diet ad libitum or at 90, 80, or 70% of ad libitum and observed a linear increase in DM, OM, ADF, and starch digestibility with increasing levels of restriction. Nitrogen retention in this experiment was quadratic, and retention was greatest when intake was restricted to 80% of ad libitum. The authors concluded that use of restricted feeding in production systems needs to account for improvements in nutrient digestibility and animal metabolism to match nutrient intake with animal requirements to achieve maximum efficiency and the desired performance. In accordance, Sip et al. (1987) fed 192 steer calves an 80% concentrate diet restricted to provide enough energy for 1.0 kg of gain per day for an 84-d growing period with differing levels of crude protein. The treatments were: 1) crude protein at 90% of NRC; 2) crude protein at 100% of NRC; 3) crude protein at 110% of NRC; or 4) crude protein at 120% of NRC requirements. They observed a linear improvement in daily gain and efficiency with increasing levels of crude protein in the diet. The authors speculated that decreased microbial growth rate and increased ruminal proteolysis of limit-fed cattle may result in increased crude protein requirements; however the actual mechanism is still unclear. Zinn and Owens (1983) fed cannulated Angus steers at a rate of 1.2, 1.5, 1.8 and 2.1% of body weight a diet consisting of 63% dry rolled corn, 6% dehydrated alfalfa meal, and 14% cottonseed hulls. As intake on a percent of BW increased, starch digestion in the rumen increased linearly, but ruminal digestion of organic matter and acid detergent fiber declined in a linear fashion. When intake was at 2.1% of BW, ruminal digestion of acid detergent fiber was zero. The authors offered decreased retention time and low pH as possible explanations for the decreases in ruminal digestibility associated with increasing intake.

If digestibility is indeed altered by limit feeding, then the impact of limited intake should be greater when diets contain less extensively processed grains or a larger amount of slowly fermented roughage. Murphy et al. (1994a) fed ruminally fistulated steers an 80% corn (whole or rolled) diet at ad libitum or 70% of ad libitum intake. The diets of the restricted steers were fortified with additional N, vitamins and minerals so that intake of these nutrients was equal between treatments. A corn processing x intake level interaction was detected for digestibility parameters. Processing in their experiment caused increases in digestibility of DM, OM, N and starch, with higher digestibilities for the rolled-corn diet as opposed to whole shelled when diets were fed at 1.3 compared with 2.0 x maintenance. Conversely, when steers were fed ad libitum, rolling the corn caused a decrease in digestibility for parameters with the exception of starch, which is likely the cause for the interaction. Galyean et al. (1979b) observed DM digestibilities of 85.7, 84.1, 78.9 and 77.6% at 1.0, 1.33, 1.67 and 2.0 x maintenance, respectively, when 84% cracked corn diets were fed; these diets also contained cottonseed hulls and dehydrated alfalfa meal. As intake increased in the experiment of Galyean et al. (1979b) digestibilities tended to decrease, however only the 1.0 and 1.33 x maintenance levels were different from the 1.67 and the 2.0 levels, no linear effect was observed. In contrast to these results as well as the results of Murphy et al. (1994a), Galyean et al. (1979a) fed ruminally canulated steers an equal amount of a 72% concentrate diet which contained either whole-shelled corn or differing diameters of ground corn in order to quantify processing effects on site and extent of digestion. There were no differences in total tract DM digestibility for all treatments; however, all processed corn diets did have greater ruminal DM digestibilities when compared with the whole-corn diet.

Merchen et al. (1986) used Suffolk wethers as the experimental model in a 4 x 4 Latin square to evaluate the effects of two different roughage levels (75% alfalfa vs 25%

alfalfa) at two different intake levels (1,100 g DM/d [LI] vs 1,700 g DM/d [HI]) on ruminal environment, microbial protein synthesis, and site and extent of nutrient digestion. Ground corn was used as the primary concentrate in both experimental diets. Intake level had no effect on ruminal pH and fluid and particulate dilution rate; rumen volume and ruminal fluid outflow were increased with the high level of intake. Feeding whethers at the LI level increased ruminal ammonia N levels compared with those of the HI group. Intake level had no effect on total VFA production; however, total tract apparent digestibility of OM, NDF and N was improved in the LI group compared with the HI group. Microbial efficiency in this experiment favored the high level of intake despite forage level in the diet, which could be due to lower levels of available substrate. This experiment would support the hypothesis of increased digestibility with limit-feeding, although restriction in this case may be more severe than in most limit-feeding situations. Moreover, the microbial protein synthesis portion of this experiment is in agreement with the thoughts of Old and Garret (1987), Sip et al. (1987) and Sip and Pritchard (1991) which suggested elevated protein requirements for limit-fed cattle.

While Merchen et al. (1986) observed no differences in total VFA production in whethers fed at high and low levels of intake, it is still important to distinguish the role, if any, VFA play in improving performance of limit-fed cattle. Murphy et al. (1994a) reported that intake level (ad libitum vs 70% ad libitum) had little impact on proportions of acetate and propionate when whole corn was fed, but with rolled corn, ad libitum intake reduced acetate and increased molar proportions of propionate. Murphy et al. (1994) also reported that steers receiving the low intake had greater concentrations of ruminal VFA at three and four hours after feeding compared with steers fed ad libitum, which was attributed to decreased ruminal volume of the low intake steers. Findings of this study are in disagreement with those of Rumsey et al. (1970), who found that increased intake led to increased total VFA concentrations. Ruminal fluid pH was related inversely to total VFA concentrations (Murphy et al., 1994a) as one hour after feeding steers receiving HI of all concentrate diets had lower ruminal pH (5.95) than steers receiving LI (6.26); these intake effects on ruminal pH were also evident at two hours after feeding. The authors explanation for this is that steers receiving LI consumed a greater percentage of daily feed allotment with in the first two hours after feeding and had increased salivary flow associated with consumption and, therefore, had greater ruminal buffering capacity shortly after feeding.

As mentioned previously, passage as well as ruminal dilution rates may be related to improved digestibility. For example, Merchen et al. (1986) reported that limit feeding had no effect on particulate or fluid dilution rates, which is in disagreement with the findings of Murphy et al. (1994a) who observed decreased dilution rates when steers were fed an all-concentrate diet at 70% of ad libitum intake. These two authors did however have similar findings for ruminal volume; limit feeding decreased ruminal volume. This decrease in ruminal volume is contradicted by Galyean et al. (1979b) in which feeding an 84% cracked corn diet at 1.0, 1.33, 1.67 and 2.0 x maintenance had no effect on ruminal volume. Wise et al. (1968) stated that feeding mixed grain-forage diets results in greater saliva flow than feeding diets high in readily available starch, and the greater the time spent eating the greater the amount of saliva produced. This may account for differences in the ruminal volume findings between Murphy et al. (1994a) where steers were fed all-concentrate diets once daily, and Galyean et al. (1979b) where steers were fed an 84% concentrate diet eight times daily at 3 h intervals.

Intake Variation

Additional potential reasons for improved efficiency are reduced variation in feed intake, both from animal-to-animal and from day-to-day with limit feeding (Zinn, 1987). Zinn (1987) proposed that animals with ad libitum access to feed exhibit wide day-to-day fluctuations in feed intake; these could cause digestive disturbances and decrease feed utilization. In addressing this issue Soto-Navarro et al. (2000) fed a 90% concentrate diet once or twice per day at either a constant level or with a 10% fluctuation in day-to-day intake. He reported that for pH below 6.2, total decrease in ruminal pH over a 24-h sampling period was greatest in steers fed once daily with a 10% fluctuation in day-to-day feed intake or steers fed a constant amount of feed twice daily, intermediate for steers fed a constant amount of feed once daily, and lowest for steers fed twice daily with a 10% fluctuation in day-to-day feed intake. This corresponded to a greater accumulation of total ruminal VFA over the 24-h sampling period in steers fed once daily with a 10% fluctuation in day-to-day feed intake or fed a constant amount of feed twice daily compared with steers fed a constant amount of feed once daily or fed twice daily with a 10% fluctuation in day-to-day feed intake. This data supports the statement that intake fluctuation may result in digestive upset. However, OM digestibility tended to be improved when steers were fed once daily with a 10% fluctuation in day-to-day feed intake compared with steers fed once daily at a constant rate, which contradicts the statement that feed intake fluctuation may decrease feed utilization.

Stock et al. (1995) summarized variation in intake from several trials where intake variation was measured both within and across days. They reported that across all trials, day-to-day variation in feed intake was correlated negatively (r = -0.28) with gain : feed. The authors noted that the correlation did include sources of variation due to trial. Considering only the data from cattle fed all-concentrate diets the correlation was larger (r = -0.49), but using only data with cattle fed a 92.5% concentrate diet, the correlation neared zero (r = 0.03).

Summary

Limit-feeding as evidenced by the literature can be applied to a wide variety of situations. The use of programmed feeding as defined by Galyean (1999) is predominantly used in growing programs for cattle, and the data is conclusive as to the benefits of this type of management. Restricted feeding, however, is much more abstract and can be applied to various situations for varying lengths of time (Galyean, 1999). The results of restricted feeding research show a trend towards improved feed efficiency along with a slight reduction in daily gain. However, the primary mechanism or mechanisms causing this effect are still unclear. There is evidence that total tract digestibility is improved with limit feeding, although many of the findings in the literature are contradicting as to why digestibility is increased. The role of fermentation profiles, visceral mass and the possibility of increased nutrient requirements of limit-fed cattle are still unclear. The bulk of the restricted feeding research associated with feedlot cattle has focused on percentage restrictions for varying lengths of time with moderate success in improving feed efficiency. More data are needed in the area of restricted-feeding high-concentrate diets as a means of adapting cattle to a finishing program. The current literature shows minimal reductions in performance with short-term, moderate restrictions in feed intake, which are common in this type of restricted-feeding program (Weichenthal et al., 1999).

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CHAPTER III

EFFECTS OF RESTRICTED VS CONVENTIONAL DIETARY ADAPTATION ON PERFORMANCE, CARCASS TRAITS AND DIGESTA KINETICS BY FEEDLOT CATTLE

W. T. Choat, C. R. Krehbiel, D. R. Gill, G. C. Duff, and M. S. Brown

Abstract

Three experiments were conducted to determine the effects of restricted feeding of the final diet as a means of dietary adaptation compared with diets increasing in grain over a period of 20 to 25 d on cattle performance, carcass characteristics, digestibility, digesta kinetics and ruminal metabolism. The three experiments consisted of two feedlot experiments and one metabolism experiment. In Exp. 1, 84 Angus x Hereford yearling steers (initial BW=418 ± 29.0 kg) were fed for 70 d. Restricted feeding during adaptation had no affect on overall daily gain and gain:feed ($P > 0.05$), but reduced DMI ($P < 0.05$) compared with ad libitum feeding of step-up diets. In Exp 2, 150 mixed crossbred steer calves (initial BW=289 ± 22.9 kg) were fed for an average of 173 d. Restricted feeding decreased overall daily gain (1.51 vs 1.65 kg/d; $P < 0.01$) and DMI (8.68 vs 9.15 kg/d; $P < 0.05$) compared with ad libitum fed steers; however, gain:feed was not affected ($P < 0.05$) by step-up method. Experiment 3 used eight ruminally and duodenally cannulated steers (initial BW=336 ± 20 kg) in a completely random design. Steers were dosed with Co-EDTA and Yb-labeled dry rolled corn and sampled every 3 h for a 24-h period on the seventh day of each adaptation period. Steers were also evacuated at the end of each period 4 h after feeding to determine liquid and DM fill. Restricted feeding reduced daily DMI variation ($P < 0.10$) throughout the entire experiment compared with ad libitum feeding of three adaptation diets. Restricted steers had reduced intakes and fecal excretions of ADF and had greater OM digestibilities on days 4 through 7, 11 through 14, and 18 through 21 (adaptation method x period interaction, $P < 0.05$). Restricted feeding decreased variation in dry matter intake in yearling cattle, reduced daily gain and final weights in calves and improved OM digestibility. Adaptation using the final diet was successful in all experiments; however, it appears to have less negative effects when used in yearling cattle than calves.

Key Words: Restricted Feeding, Adaptation, Performance, Carcass Traits, Digestibility, Beef Cattle

Introduction

Traditionally, adapting cattle to high-grain diets has been accomplished by using diets with increasing grain levels so that ruminal microorganisms can gradually adjust to a ruminal environment that is lower in pH, in an attempt to minimize subacute acidosis and intake variation that can occur with overeating of grain. Restricting feed intake of high-concentrate diets has shown improvements in feed efficiency (Zinn, 1986; Loerch, 1990; Hicks et al., 1990; Knoblich et al., 1997; Plegge, 1987) and potential reductions in subacute acidosis by reducing fluctuations in feed intake (Soto-Navarro et al., 2000), but little information is available on the use of restricted feeding of the finishing diet as a means of dietary adaptation to a finishing program. Therefore our objective was to compare feedlot performance, carcass characteristics, intake variation, digestibility, digesta kinetics, and ruminal metabolism of steers fed restricted amounts of the final diet during the adaptation period to ad libitum feeding of traditional step-up diets.

Materials and Methods

Experiment 1. Medium framed Angus x Hereford yearling steers (n = 84; initial BW= 418 ± 29.0 kg) were used to determine the effects of restricted feeding of the final diet as a means of dietary adaptation compared with diets increasing in grain over 20 d on cattle performance and carcass characteristics. Steers grazed winter wheat pasture for 185 d prior to placement in a feedlot at the Clayton Livestock Research Center, Clayton, NM on May 11, 1999. Upon arrival, steers were implanted with Synovex S® (Fort Dodge Animal Health, Fort Dodge, IA), administered a Clostridial Ultrabac® 7 vaccine (Pfizer Animal Health, Exton, PA), weighed and allotted to eight pens with 10 or 11 steers per pen. Animals were handled and cared for according to a protocol reviewed and approved by the New Mexico State University Institutional Animal Care and Use Committee. Pens (12.2 x 35.0 m) were uncovered, constructed of pipe and cable, and contained 11 m of bunk space and automatic fence line waters (one per pen). Four pens each were assigned to one of two start-up treatments: 1) ad libitum feeding of four step-up diets over 20 d with steam-flaked corn levels increasing from 46 to 66 percent of the diet (DM basis), or 2) restricted-feeding of the final diet with programmed increases for approximately 25 d until steers reached ad libitum intake. Diets are shown in Table 1; increasing the energy of the step-up diets was accomplished by increasing the percentage of steam-flaked corn and decreasing the percentage of roughage in each sequential diet. Feed samples were analyzed every 28 d for DM according to standard procedures (AOAC, 1996). Steers restricted in intake of the final diet were initially fed 1.25% of BW (DM basis) or approximately 5.0 kg of DM/hd which was increased by 0.23 kg/hd/d until ad libitum intake was reached on approximately d 25. Steers were fed once daily at 0800 h.

Steers were weighed individually at 0700 h before feeding, twice on succeeding days initially and every 28 d throughout the trial. Final live weights were calculated by dividing hot carcass weight by a common dressing percentage (62). All weights were analyzed as initially recorded (un-shrunk) with weights taken on individual animals being averaged among their respective pens. Feed intake was measured by pen and feed efficiency (kg gain/100 kg DMI) was calculated every 28 d. Variation in DMI during the grain adaptation period was calculated separately for each treatment by two methods in accordance with Stock et al. (1995). In the first method, residual intake (for each pen) was calculated as estimated daily DMI minus the average DMI (feed remaining in the bunk unaccounted for) for all days within the concentrate period for that pen. In the second method, residual intake was calculated as estimated daily DMI (for each pen) minus the average DMI for all pens within treatment for each day. Intake variation was calculated on intake residuals within a pen across all days in the grain adaptation period (pen DMI variation), or on intake residuals within the day among all pens within the treatment (daily DMI variation). Steers were harvested when 70% appeared to grade choice based upon subjective evaluation of body composition. Steers were harvested at a commercial facility after 70 d. Hot carcass weight (HCW) was determined following harvest, and carcasses were evaluated by trained personnel after a 24-h chill for the following measurements: subcutaneous fat depth at the 12th rib; longissimus muscle area; percentage kidney, pelvic, and heart fat; yield grade; marbling score; and quality grade (USDA, 1997).

Data were analyzed as a completely randomized design using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC). The model statement for overall feedlot performance and carcass characteristics included treatment along with a random statement "experimental unit(treatment)" to account for inter-experimental-unit variation (Littell et al., 1998). Interim feedlot performance was analyzed using repeated measures over time and included treatment, time, and the treatment x time interaction in the model. The default covariance structure (Variance Component, VC) was chosen based on fit statistics "AIC, AICC, and BIC". Pen served as the experimental unit for feedlot performance and animal was used for variables measured on individual carcasses. Results are discussed as significant if ($P < 0.05$) and as tendencies if ($P > 0.05$ and $<$ 0.10).

Experiment 2. One-hundred-fifty mixed crossbred steer calves (initial BW = 289 ± 22.9 kg) were used to determine the effects of restricted feeding of the final diet as a means of dietary adaptation compared with diets stepped up in grain over 22 d on cattle performance and carcass characteristics. All steers were removed from wheat pasture and transported to the Willard Sparks Beef Cattle Research Center, Stillwater, OK on March 28, 2000. Upon arrival, steers were individually weighed on three consecutive days (d –1, 0, and 1); on d –1 steers were individually ear-tagged for identification. On d 1 steers were processed, blocked by the average individual weight taken on d –1 and 0, and allotted to one of 30 pens (10 pens/block; 5 hd/pen) where Blocks 1 and 2 were fed for 165 d, and Block 3 was fed for 180 d. At processing all steers were vaccinated with Covexin® 8 (Schering Animal Health, Kenilworth, NJ), and Frontier® 4 plus (Intervet Animal Health, Millsboro, DE) and treated for internal and external parasites using

Ivomec® injectable (Merial Animal Health, Duluth, GA). Animals were handled and cared for according to a protocol reviewed and approved by the Oklahoma State University Institutional Animal Care and Use Committee. Pens (12.8 X 4.6 m) were partially covered, constructed of pipe and cable, and contained 4.6 m of bunk space with fence line automatic waters shared between two pens. Fifteen pens each were assigned to one of two step-up treatments: 1) ad libitum feeding of three step-up diets over 22 d, with levels of dry rolled corn (DRC) increasing from 52 to 80% (DM basis), or 2) restricted-feeding of the final diet with programmed increases for approximately 45 d until steers reached ad libitum intake. Diets for Exp. 2 are shown in Table 2. Methods for feed sampling, DM determination and intake variation were the same as those used in Exp. 1. Steers restricted in intake of the final diet were initially fed 1.5% of BW (DM basis) or approximately 4.3 kg of DM/hd, which was increased by 0.23 kg/hd/d until ad libitum intake was reached on approximately d 45. Steers were fed once daily at 0800 h.

Steers were weighed individually prior to feeding on three consecutive days at arrival, every 2 weeks for the first 28 d, and every subsequent 28 d for the duration of the experiment. Feed intake was measured and feed efficiency (kg gain/100 kg DMI) was calculated every 28 d. Final live weights were calculated by dividing each animal's hot carcass weight by the average dressing percentage for steers harvested on the same day. Average dressing percentages were 64 for Blocks 1 and 2 (Harvest 1), and 62 for Block 3 (Harvest 2). Steers from weight Blocks 1 and 2 (heavy and medium) were harvested after 165 d on feed and Block 3 (light) was harvested after after 180 d on feed. All steers were harvested at a commercial facility. Hot carcass weight was determined following harvest, and carcasses were evaluated by trained personnel after a 24-h chill for the following measurements: subcutaneous fat depth at the 12th rib; longissimus muscle area; percentage kidney, pelvic, and heart fat; yield grade; skeletal and lean maturity; marbling score; quality grade (USDA, 1997); and presence of liver abscesses (Brink et al., 1990). Data were analyzed as a randomized complete block design with two treatments in three blocks using the MIXED procedure of SAS. The model for overall feedlot performance and carcass characteristics included statements for treatment and block along with a random statement "experimental unit(treatment)" to account for inter-experimental-unit variation (Littell et al., 1998). Interim feedlot performance was analyzed using repeated measures over time and included treatment, time, block, treatment x block, time x block, and the treatment x time x block interaction in the model. The default covariance structure (Variance Component, VC) was chosen based on fit statistics "AIC, AICC, and BIC" (SAS, 1999). Pen served as the experimental unit for feedlot performance and animal was used for variables measured on individual carcasses. Results are discussed as significant if ($P < 0.05$) and as tendencies if ($P > 0.05$ and < 0.1).

Experiment 3. (Metabolism Exp.) Eight ruminally and duodenally cannulated crossbred steers (initial BW=336 ± 20 kg) were selected to be used in a completely random design to determine the effects of restricted-feeding of the final diet as a means of dietary adaptation compared with diets stepped-up in grain over 21 d on total and compartmental digestion, digesta kinetics, and ruminal metabolism. Four steers were randomly assigned to each of two step-up treatments: 1) ad libitum feeding of three step-up diets over 21 d, with levels of DRC increasing from 52 to 80% (DM basis), or 2) restricted-feeding of the final diet with predetermined increases in intake until ad libitum intake was achieved. Diets and dietary analysis are presented in Table 3. Initial intake of ad libitum steers was set at 2.0% of BW (DM basis) and intake was increased 0.45 kg/hd/d when the previous days feed was completely consumed. Initial intake of restricted steers was calculated using the Level 1 model of the 1996 Beef Cattle NRC. The intake scaler of the Level 1 model was manipulated so that steers consuming the final diet would gain similar weight to ad libitum steers consuming 2.0% of BW (DM basis) of the 65% concentrate diet (Table 3); therefore, initial intake of restricted steers was set at approximately 1.65% of BW (DM basis). Intake of restricted steers was increased 0.23 kg/hd/d when the previous days feed was completely consumed. Steers were housed in individual pens (5 x 4 m) in a barn with slatted concrete floors under continuous lighting and had free access to fresh water. All surgical procedures, post-surgical care, and experimental protocol had been reviewed and approved by the Oklahoma State University Institutional Animal Care and Use Committee.

The dietary adaptation began on June 22, 2000 (d 1) and consisted of four 7-d adaptation periods and a later fifth period, which consisted of both treatments consuming the final diet to appetite. Dry matter intake was recorded on a daily basis; all refusals were weighed, DM content was determined (AOAC, 1996) and subtracted from the total intake of that steer for that respective adaptation period. Chromic oxide (Cr_2O_3; 15 g/d) was dosed intraruminally via gelatin capsules (2/steer) as an indigestible marker of digesta flow throughout the entire experiment.

Sampling. Feed was sub-sampled daily throughout the experiment, and at the end of each step-up period samples were composited by diet concentrate level and dried at 50°C for 36 h. Fecal grab samples were taken on d 4 through 7 of each 7-d adaptation period, following each period, fecal samples were composited by animal. A portion of the composite for each animal was dried in a forced air oven (50°C, 96 h) and ground through a 2-mm screen in a Wiley mill for later determination of DM, OM, Cr, starch, and acid-detergent fiber. A second portion of the fecal composite was frozen and later lyophilized at the conclusion of the experiment. The lyophilized fecal sample was used for N determination. On d 7 of each adaptation period at approximately 0730 h, Co-EDTA (200 ml) and DRC (1 kg) labeled with ytterbium acetate were pulse-dosed intraruminally; 1 kg of Yb-labeled DRC replaced 1 kg of the diet. Ytterbium and Co-EDTA have been shown to be reliable external markers for corn and liquids, respectively, when used in high-concentrate diets (Sindt et al., 1993). Labeling procedures for corn were the same as those outlined by Teeter et al. (1984) whereas procedures for preparing Co-EDTA were the same as those described by Prigge and Varga (1980). Ruminal fluid and particulate matter were collected at 0, 3, 6, 9, 12, 15, 18, 21, and 24 h after dosing. Immediately after collection, 200 mL of rumen fluid was strained through four layers of cheesecloth and pH was measured using a combination electrode. A 10 ml aliquot was acidified with 0.5 mL of 6 N HCl and frozen (-20°C) for later ammonia N analysis. A second 8 mL aliquot was acidified with 2 mL of 25% (wt/vol) metaphosphoric acid and frozen (-20°C) for later VFA analysis. A third and final 10 mL aliquot was frozen (-20°C) for later Co analysis. Samples of ruminal particulate matter were dried at 50°C for 36 h, and ground to pass through a 2-mm screen for later analysis of Yb concentration.

Whole duodenal contents (250 mL) were collected simultaneous to ruminal sampling. Whole duodenal contents were frozen and later lyophilized, ground using a coffee grinder, and composited within animal and period on an equal weight of DM basis.

Four hours after feeding at the end of each adaptation period, steers were weighed and total ruminal contents were removed, weighed, mixed thoroughly, sub-sampled and DM analysis were done for determination of total ruminal DM and liquid contents.

Laboratory analysis. Ground samples of feed, feces, duodenal contents, and ruminal particulate matter were analyzed for DM and OM based on standard procedures (AOAC, 1996). Nitrogen content of feed, lyophilized feces and duodenal contents was determined by the combustion method (Leco NS2000, St. Joseph, MI: AOAC, 1996). Acid detergent fiber concentrations of feed, feces, and duodenal contents were determined by the methods of Van Soest et al. (1991). Feed, feces, and duodenal contents were analyzed for starch in accordance with procedures outlined by MacRae and Armstrong (1968). Chromium concentrations of fecal and duodenal composites were quantified using an Inductively Coupled Plasma Spectrophotometer (ICP Spectro Analytical Instruments, Fitchburg, MA). Preparation of samples for chromium analysis was done by ashing 1 g of sample followed by digestion in phosphoric acid. Ruminal fluid samples were thawed and prepared for analysis by centrifugation at 10,000 X g for 10 min. Concentrations of Co in ruminal fluid and concentrations of Yb in ruminal particulate samples were also determined by ICP analysis. Ytterbium was extracted from ruminal particulate samples using an EDTA solution. The wavelengths used to measure optical emission of Cr, Co, and Yb were 267.7, 228.6, and 265.4 respectively. Ruminal ammonia N was determined using procedures outlined by Broderick and Kang (1980). Volatile fatty acid analysis of ruminal fluid was done using gas chromatography as outlined by Goetsch and Galyean (1983).

Calculations and Statistics. Dilution rates of Co and Cr and passage rate of Yb were calculated by regressing the natural log of marker concentration on time after dosing. Ruminal fluid volume was calculated by dividing dose by ruminal concentration extrapolated to 0 h, and fluid retention time was calculated as 1/ dilution rate.

Digestibility, digesta flow, and ruminal DM and liquid fill data were analyzed as a completely randomized design with the Mixed model using the Mixed procedure of SAS. Random and Repeated statements were used to model the covariate structure in a repeated measures analysis by period. The model included treatment, period, and the treatment x period interaction. Fit statistics AIC, AICC, and BIC were used to determine the proper covariate structure (smaller is better) for each variable. The type option in the repeated statement was used to specify the covariate structure, types VC, CS, AR(1), and UN were tested. Specific metabolites were also analyzed as repeated measures using time as the repeated variable as opposed to period. The model for all metabolites included treatment, period, treatment x period, time, treatment x time, period x time, and treatment x period x time. LSMEANS were used to separate the data at the highest level interaction which was significant ($P < 0.10$). Results are discussed as significant if ($P < 0.05$) and as tendencies if ($P > 0.05$ and < 0.10).

Results

Experiment 1. Overall live weight gains were not affected ($P = 0.43$) by treatment (2.10 vs 2.02 kg/d for ad libitum vs restricted steers, respectively; Table 4). However, interim daily gains revealed differences due to treatment, when separated into 28-d intervals (adaptation x period interaction, $P = 0.003$). Daily gains of restricted steers were reduced by 37.1% during the first 28-d of the feeding period compared with steers fed ad libitum. Adaptation method had no effect (P = 0.33) on daily gain from d 29 through 56, however restricted-feeding improved (P = 0.03) daily gains during the final 14-d on feed. As expected, overall DMI was greater (P < 0.01) for ad libitum vs restricted steers (10.67 vs 9.73 kg/d), which resulted from differences observed during the first 28-d of the feeding period (adaptation x period interaction, P < 0.01) when restricted steers were consuming 77.6% of ad libitum. Daily DMI over time is presented in Figure 1. Overall gain:feed (kg of gain per 100 kg of DMI) was similar (P = 0.14) for restricted compared with ad libitum steers (19.6 vs 20.8 kg/100 kg DMI). Intermittent gain:feed was similar among treatments through d 56, however restricted steers were more efficient during the last 14 d of the feeding period compared with ad libitum fed steers (P = 0.03). Intake variation on a daily basis (Table 5) was greater (P < 0.01) for ad libitum fed steers on d 11 through 15, 16 through 20, and 21 through 25 compared with restricted steers. Similarly, pen intake variation (Table 5) was greater (P < 0.10) for ad libitum fed steers during the entire step-up phase (d 1 through 25) compared with restricted steers. Adaptation method had no affect on carcass characteristics (Table 6).

Experiment 2. Results of feedlot performance for Exp. 2 are presented in Table 7. Overall daily gain was greater (P < 0.01) for steers fed ad libitum compared with restricted steers (1.65 vs 1.51 kg/d). Intermittent daily gains (Table 7; adaptation x period interaction, P < 0.01) for restricted steers were reduced by 37.1% (P < 0.01) during the first 28-d of the feeding period compared with steers fed ad libitum, which was identical to the reduction observed in Exp. 1. Restricted steers also tended to have reduced daily gains from d 113 through 140 (P = 0.08) compared with ad libitum-fed steers. Overall DMI was greater ($P < 0.01$) for ad libitum compared with restricted steers (9.15 vs 8.68 kg/d). Intermittent DMI (adaptation x period interaction, $P < 0.01$) are also presented in Table 7. Dry matter intakes of restricted steers were 69.7% of ad libitum during the initial 28 d of the feeding period ($P < 0.01$), which accounts for a large portion of the differences seen in overall DMI. Restricted steers reached ad libitum intake between d 29 and 56 (see Figure 2) and had greater intakes compared with ad libitum fed steers from d 85 through 112 ($P < 0.01$). Ad libitum fed steers had greater DMI from d 113 through 140 ($P = 0.02$) compared with restricted steers. Overall and intermittent gain to feed (kg of gain / 100 kg of DMI) was similar among the two treatments; however, restricted steers tended ($P = 0.06$) to be more efficient from d 29 through 56 compared with steers fed ad libitum. Daily DMI variation (Table 8), in contrast to the previous study, was greater ($P < 0.01$) for restricted steers from d 9 through 17 compared with steers fed ad libitum. Pen DMI variation (Table 8) was reduced ($P < 0.01$) with restricted-feeding on d 1 through 8, 9 through 17, and 18 through 22 compared with ad libitum feeding, which was similar to results of Trial 1. Final weights as well as hot carcass weights were reduced ($P < 0.01$) with restricted-feeding compared with ad libitum (566 vs 543 kg and 359 vs 344 kg, respectively; Table 9). No differences were observed ($P > 0.05$) in carcass characteristics.

Metabolism Experiment. Because of problems associated with initial adaptation, one steer was removed from the experiment following sampling in period 2, and samples were collected from only 6 of the remaining 7 animals in the fifth period due to health problems not associated with experimental treatments. Daily DMI variation (Table 10) was greater for ad libitum fed steers ($P < 0.10$) from d 1 through 7, 8 through 14, and 22 through 28 compared with steers restricted in intake of the final diet. Animal DMI variation (Table 10) was not affected (P > 0.10) by adaptation method. Total tract, ruminal, and post ruminal digestibilities are presented in Table 11. Adaptation method had no affect on intake and duodenal flow of OM, starch, and N, or fecal excretion of starch, and N (P > 0.05). Fecal excretion of OM tended (P = 0.09) to be reduced in restricted steers (adaptation method x period interaction) compared with steers fed ad libitum. An adaptation method x period interaction (P < 0.05) was observed for intake, duodenal flow and fecal excretion of ADF. Ad libitum fed steers had greater ADF intake and fecal excretion (P < 0.05) on days 4 through 7, 11 through 14, and 18 through 21 compared with restricted steers. Duodenal flow of ADF was greater for ad libitum-fed steers on days 4 through 7 and 11 through 14 compared with restricted steers (P < 0.05). Fecal OM excretion was greater for ad libitum steers on days 4 through 7, 11 through 14, and 18 through 21 (P < 0.05) compared with restricted steers. An adaptation method x period interaction (P < 0.05) was observed for total tract OM digestibility. Restricted steers had greater digestibility of OM (P < 0.05) on days 4 through 7 (80.1 vs 66.4%), 11 through 14 (81.1 vs 66.3%) and 18 through 21 (81.9 vs 72.2%) compared with ad libitum-fed steers. Adaptation method had no affect (P > 0.05) on total tract digestibility of ADF, starch, or N, or ruminal and post ruminal digestibilities of OM, ADF, starch, and N. Digesta kinetics are presented in Table 12. Adaptation method had no affect (P > 0.05) on full BW, DM and fluid fill, passage rate of particulate matter, as well as fluid dilution rates, retention time and ruminal volume. Similarly, adaptation method did not influence (P > 0.05) ruminal pH or ammonia N levels (Table 13). Adaptation method had no affect on total VFA or molar proportions of acetate, propionate, butyrate, valerate, isobutyrate, or isovalerate.

Discussion

The results of the initial performance experiment concur with results of Weichenthal et al. (1999), where restricted-feeding during adaptation caused no difference in daily gain while reducing DMI, resulting in a significant improvement in feed efficiency for restricted steers compared with steers fed step-up diets at ad libitum intake. While no improvement in feed efficiency was observed in either experiment, restricted-feeding of the final diet as a method of adaptation appears practical and contains several other benefits, such as reduced day-to-day and pen-to-pen variation in feed intake, simplified bunk management, reduced feed waste (Lake, 1987), as well as the potential for decreased manure and nutrient output when used in yearling cattle. In our metabolism study we observed that restricted-feeding of the final diet reduced fecal excretion of OM and N by 50 and 35%, respectively, through d 21. This supports the theory of reduced manure and nutrient output with restricted feeding, which might become an important tool to control manure output in the future.

Feed intake variation in the current experiments was reduced with restricted feeding, which may reduce subacute acidosis as observed by Soto-Navarro et al. (2000) where constant daily feed intake reduced pH area below 6.2 compared with a 10% fluctuation in daily feed intake. While pen-to-pen variation in feed intake was reduced with restricted feeding in Exp. 1 and 2, it should be noted that the variation among animals within a pen can still be significant. This is evidenced by results of our metabolism study, where animal-to-animal variation was not affected with restricted feeding of the final diet during adaptation.

The basis for the large reduction in performance by restricted steers during the initial 28 d of the feeding period in Exp. 1 and 2 is most likely due to differences in ruminal fill; however, no difference in fill was observed during the first 21 days of our metabolism study. Hicks et al. (1990) observed similar results when control feeding (85% of ad libitum) an 81% rolled-wheat diet. In their study, daily gain of restricted steers was reduced by 12.9% during the first half of the feeding period (d 0 through 56) and only 4.5% during the last half. The reduction in daily gain by restricted steers observed in Exp. 2 of the current study with lighter-weight steer calves is likely a result of the magnitude and duration of the restriction. The difference in difficulty of adapting calves vs yearlings with restricted feeding of the final diet is best described from Figures 1 and 2. Daily intake of restricted steers during adaptation in Exp. 1 (Figure 1) increased gradually with little to no variation, and this pattern continued until approximately d 46. In contrast, daily intakes of restricted steer calves in Exp. 2 (Figure 2) showed greater variation, and were extremely volatile during the first few days of adaptation. However, similar variation was observed with ad libitum feeding of step-up diets in Exp. 2, which suggests that the difficulty observed in adaptation was not entirely due to restricted-feeding of the final diet, but probably more so to differences in calves vs yearlings. Rapid increases in intake of ad libitum-fed steers in Exp. 1 and 2 in an attempt to reach ad libitum intake as quickly as possible resulted in a sharp decrease in intake towards the end of the adaptation period. While few comparisons are available, this overestimation of ad libitum intake observed with the traditional method of adaptation is likely a common occurrence, and appears to be alleviated with restricted-feeding of the final diet.

It appears that the key to improving feed efficiency with restricted-feeding is to reduce DMI without a reduction in performance. Obviously, an overall reduction in gain can have a negative impact on final live weight and carcass weight. As observed in Exp. 2, reduced gain may cause restricted cattle to require more days on feed and has also been shown to reduce intramuscular fat deposition (Hicks et al., 1990). Hicks et al. (1990) reported that when intake was restricted so that cattle gained only 1.35 kg/d for the entire feeding period, final live and carcass weights as well as marbling and percent choice were reduced compared with ad libitum fed controls. Similar results were reported by Galyean et al. (1999) from unpublished data where steers were restricted 0.45, 0.91 and 1.36 kg of DM from ad libitum intake of pair fed controls which resulted in a linear reduction in daily gain and percentage choice carcasses.

Formulation of diets in our experiments did not account for equal intakes of CP, calcium, phosphorous and monensin between restricted steers and steers stepped-up in concentrate. Tables 14 and 15 show comparisons of nutrient and feed additive intakes between ad libitum and restricted steers in the first two experiments. In programmed feeding of growing cattle it is common practice to increase the concentration of feed additives and nutrients (Loerch, 1990; Loerch and Fluharty, 1998). This is supported by the work of Sip et al. (1991) where increasing the CP level (90, 100, 110, and 120% of requirement) in an 80% concentrate diet fed to steers programmed to gain 1.0 kg/d for 85 d resulted in a linear improvement in daily gain and feed efficiency. Murphy et al. (1994b) fed crossbred wether lambs either 100, 90, 80, or 70% of ad libitum a 92%

concentrate diet with equal intakes of N, vitamins and minerals across all intake levels. Murphy et al. (1994b) observed a linear increase in digestibility of DM, OM, ADF, NDF, and starch along with a linear reduction in metabolic fecal N with increasing levels of restriction. This improvement in digestibility supports the results of Sip et al. (1991). Murphy et al. (1994b) suggested that uses of restricted feeding in production systems needs to account for improvements in nutrient digestibility and animal metabolism in order to achieve maximum efficiency and desired animal performance. However, such practice is uncommon in feedlot research and production. For example, Hicks et al. (1990) studied the effects of percentage restrictions and programmed gain strategies for restricting intake of feedlot cattle and made no adjustments to the nutrient concentrations of the restricted diets. Similarly Zinn (1986) restricted steers based on a programmed level of gain and used a similar diet for both restricted and ad libitum groups. It appears that increasing nutrient concentrations in restricted diets is necessary when restrictions are severe or for extended periods of time. Due to the relatively short adaptation period, nutrient concentrations were not altered in the current experiments so that one diet could be fed throughout adaptation and finishing. The length and degree of restriction in Exp. 1 and 2 of the current study were minimal for yearlings and moderate for calves in comparison to other restricted-feeding experiments. Restricted steers reached ad libitum intake in Exp. 1 and 2 by 25 and 45 days, respectively, and intakes of restricted steers were no less than 69.7% of ad libitum in both experiments. The data presented in Tables 14 and 15 show protein to be the first limiting nutrient based on the Level 1 Model (NRC, 1996) for the first 5-d in Exp. 1 and throughout the adaptation in Exp. 2, which might suggest that increasing the nutrient concentrations in restricted diets is more important with calves than yearlings.

Several mechanisms have been proposed as possible explanations for improved feed efficiency in restricted cattle. However, due to the wide range in restricted feeding applications no single mechanism may be active in every scenario. Due to common low intakes associated with restricted feeding, one would expect that restricted feeding simply increases diet digestibility due to the fact that in most cases digestibility and intake are inversely related. This is consistent with the current metabolism study where total tract digestibility of OM was improved with restricted feeding at times when restriction was greatest. Our observations are consistent with those of Loerch (1990), Murphy et al. (1994b), and Zinn and Owens (1983). Loerch (1990) observed improved DM digestibility with increased restriction when steers in an 85-d growing trial were fed either a corn-silage based diet ad libitum, a 50/50 corn-silage/high-moisture corn diet at 80% of ad libitum or an 80% high-moisture corn diet at 70% of ad libitum. Murphy et al. (1994b) observed similar results in growing lambs fed a high-concentrate (74 to 87% ground corn and 8% ground corn cobs) diet at ad libitum or at 90, 80, or 70% of ad libitum. In contrast, Old and Garrett (1987) reported that intake level (ad libitum, 85% of ad libitum, or 70% of ad libitum) did not affect digestibility of a high-concentrate diet. The greater OM digestibility by restricted steers in the current metabolism study (Exp. 3) is largely attributable to lower percentages of roughage found in the finishing diet compared with the initial adaptation diets, which is comparable to findings of Loerch (1990). Moreover, the length of time in which digestibility was improved in the current metabolism study is consistent with the length of restriction. Therefore, it is important to note that the length of restriction in the current experiments was relatively short compared with the existing literature on restricted feeding, which might reduce the opportunities for improved feed efficiency. In experiment 3 (metabolism Exp.) no difference ($P > 0.05$) in OM intake was observed; however, restriction was evident based on total grams of daily intake. The intakes by restricted steers as a percentage of steers fed ad libitum were 65, 79, 79, 92, and 93% for days 1 through 7, 8 through 14, 15 through 21, 22 through 28, and 68 through 74, respectively. As a possible explanation for improved digestibility, Owens et al. (1986) stated that as feed intake increases, rate of passage is accelerated which causes decreased time for digestion and therefore digestibility of slowly fermented materials, particularly fiber components, to decrease. Thus one hypothesis might be that restricted feeding simply decreases passage rate. Similarly, across the adaptation period, restricted steers had an approximately 17% greater retention time and a 12% reduction in liquid dilution rate compared with steers fed ad libitum in the current experiment. However, results varied considerably from period to period and no statistical differences were observed. These results concur with Murphy et al. (1994a) who observed decreased dilution rates when steers were fed an all-concentrate diet at 70% of ad libitum. In contrast, Hicks et al. (1990) observed no difference in passage rate (calculated by chromium concentration) of steers consuming an 80% cracked-corn diet at either ad libitum, 80% of ad libitum for the first 56 d followed by ad libitum access, programmed intake to gain 1.50 kg/d, or programmed intake to gain 1.35 kg/d.

If passage rate is actually reduced with restricted feeding then differences in ruminal fill should be more difficult to detect than would be expected in cattle at different levels of intake. This theory is consistent with the results of our metabolism study and the results of Galyean et al. (1979) in which feeding an 84% cracked-corn diet at 1.0°, 1.33, 1.67, and 2.0° x maintenance had no effect on ruminal volume. However, these results are inconsistent with those of Merchen et al. (1986) and Murphy et al. (1994b) who observed greater ruminal volumes when sheep were fed at a high-level of intake (2.6% of BW) or at ad libitum, respectively, compared with sheep restricted in intake (1.6% of BW or 70% of ad libitum).

Rumsey et al. (1970) reported that total VFA concentrations increased as intake increased. This is inconsistent with our metabolism study where VFA production was not affected by restricting intake. However, our results do concur with the findings of Merchen et al. (1986) who observed no differences in total VFA production in wethers fed at high and low-levels of intake. Similarly, Murphy et al. (1994a) reported that intake level (ad libitum vs 70% of ad libitum) had little impact on proportions of acetate and propionate when corn was fed whole, but with rolled corn, ad libitum intake reduced acetate and increased molar proportions of propionate. Further, Murphy et al. (1994a) reported that steers consuming 70% of ad libitum had greater concentrations of ruminal VFA at 3 and 4 h after feeding compared with steers fed ad libitum, which was attributed to decreased ruminal volume in steers fed 70% of ad libitum. The lack of differences in intake, ruminal fill, and VFA production likely all contributed to the similar pH values, and ruminal ammonia N levels which were observed in the current metabolism study. The effects of restricting intake on ruminal pH are conflicting, Murphy et al. (1994a) reported that ruminal pH was related inversely to total VFA concentrations as 1 and 2 h after feeding steers receiving ad libitum intake of an all-concentrate diet had lower ruminal pH than steers fed at 70% of ad libitum. While Merchen et al. (1986) observed no difference in ruminal pH due to intake level. Murphy et al. (1994a) reported that ruminal ammonia concentrations were greater in steers fed at 70% of ad libitum compared with steers fed ad libitum at all times sampled which contradicts our findings.

The current metabolism study was conducted in order to quantify differences in performance observed in Exp. 1 and 2. The improvement in digestibility of restricted steers might be offset due to differences in ruminal fill, but data remain unclear. The ease in which restricted-feeding was used to adapt yearling steers to the finishing program is supported by the lack of differences observed in ruminal pH along with the reduced day-to-day intake variation observed in the current metabolism study. The minimal differences in performance observed in yearling steers might be explained by a lack of restricted feeding effects on VFA production, ruminal ammonia concentrations, and the short duration in which steers were restricted in intake.

Implications

Restricted-feeding of the final diet as a means of dietary adaptation can be used in yearling cattle with few problems from acidosis or related intake variation. Care is needed to ensure that the length and degree of restriction is limited so that daily gains are not depressed to a point were increased days on feed are required. This method of adaptation is also efficacious in calves. However, care should be taken in order to avoid disruptions in intake during the adaptation period which might result in restriction for an extended period of time and ultimately increased days on feed and possibly reduced choice carcasses. The effects of restricted feeding during the initial 28 days of the feeding period on site and extent of digestion, digesta kinetics, and ruminal metabolism appear to be minimal, supporting few differences in performance across the finishing period.

Table 1. Composition (DM basis) of adaptation diets performance Exp. 1

	% Concentrate				
Item	70	75	80	85	90
Ingredient, % (DM basis)					
Sorghum hay	9.89	9.93	19.67	7.45	9.8
Alfalfa hay	19.7	14.79	--	7.38	--
Whole shelled corn	9.69	9.7	9.61	9.68	9.58
Steam flaked corn	46.2	53.53	55.73	61.16	65.46
Cane molasses	5.28	5.25	5.2	5.24	5.18
Yellow grease	1.88	2.83	2.81	2.82	2.79
Soybean meal	3.85	0	3.34	2.39	3.57
Limestone	.72	.72	.72	.72	.71
Dicalcium phosphate	.48	.48	.48	.48	.47
Salt	.29	.34	.28	.34	.28
Urea	.81	.97	.96	.87	.95
Ammonium sulfate	.24	.48	.24	.48	.24
Premix[a]	.96	.97	.95	.96	.95
Calculated composition					
Crude protein, %	16.27	14.71	13.87	14.35	13.79
Calcium, %	0.79	0.71	0.55	0.60	0.50
Phosphorus, %	0.40	0.38	0.39	0.39	0.39
NE_m, Mcal/kg	1.98	2.05	2.05	2.14	2.16
NE_g, Mcal/kg	1.32	1.39	1.39	1.45	1.48

[a]Contained (DM basis) wheat midds (90.69%), vitamin A (0.665%), vitamin E (0.27%), Rumensin 80 (1.687%), Tylan 40 (1.125%), $CoCO_3$ (0.02%), $CuSO_4$ (0.183%), CaI_2 (0.015%), $FeSO_4$ (1.09%), $MnSO_4$ (0.791%), $ZnSO_4$ (1.58%), MgO (1.67%), Mineral oil (0.221%)

Table 2. Composition (DM basis) of adaptation diets for performance Exp. 2

Item	% Concentrate			
	65	75	85	92.5
Ingredients, % (DM basis)				
Cottonseed hulls	17.5	12.5	7.5	7.5
Alfalfa, dehy	17.5	12.5	7.5	--
Rolled corn	52.5	62.5	72.5	80
Yellow grease	3.0	3.0	3.0	3.0
Premix[a]	9.5	9.5	9.5	9.5
Calculated composition				
Crude protein, %	13.92	13.79	13.66	13.07
Calcium, %	0.77	0.69	0.62	0.51
Phosphorus, %	0.37	0.39	0.40	0.40
NE_m, Mcal/kg	1.87	1.98	2.09	2.17
NE_g, Mcal/kg	1.11	1.22	1.32	1.39

[a]Contained (% DM basis) soybean meal 47.7 (42.10), Wheat midds (18.42), vitamin A 30,000 IU/g (0.116), potassium chloride (2.11), Rumensin 80 (0.2), Tylan 40 (0.14), dicalcium phosphate (5.26), Limestone 38% (9.47), cottonseed meal (10.53), Salt (2.63), Urea (8.95), Manganous oxide (0 03), Zinc sulfate (0.03)

Table 3. Composition (DM basis) of adaptation diets for Exp. 3 (metabolism)

	%, Concentrate			
Item	65	75	85	92.5
Ingredients, % (DM basis)				
Cottonseed hulls	17.5	12.5	7.5	7.5
Afalfa, dehy	17.5	12.5	7.5	--
Rolled corn	52.5	62.5	72.5	80
Yellow grease	3.0	3.0	3.0	3.0
Premix[a]	9.5	9.5	9.5	9.5
Nutrient composition, (DM basis)[b]				
Crude protein, %	15.37	15.44	15.00	14.31
Calcium, %	0.77	0.69	0.62	0.51
Phosphorus, %	0.37	0.39	0.40	0.40
NE_m, Mcal/kg	1.87	1.98	2.09	2.17
NE_g, Mcal/kg	1.11	1.22	1.32	1.39

[a]Contained (% DM basis) soybean meal 47.7 (42.10), Wheat midds (18.42), vitamin A 30,000 IU/g (0.116), potassium chloride (2.11), Rumensin 80 (0.2), Tylan 40 (0.14), dicalcium phosphate (5.26), Limestone 38% (9.47), cottonseed meal (10.53), Salt (2.63), Urea (8.95), Manganous oxide (0.03), Zinc sulfate (0.03)
[b]Crude protein based on actual laboratory analysis, all other values based on NRC (1996)

Table 4. Effect of restricted feeding of the final diet vs ad libitum dietary adaptation on feedlot performance by cattle (Exp. 1)

Item	Treatment[a] Ad libitum	Limit-fed	SEM[b]	P Value
Steers	43	41	--	--
Pens	4	4	--	--
Days on feed	70	70	--	--
Initial wt, kg	418	418	2.6	0.95
Final wt, kg	564	559	2.9	0.27
Daily gain, kg/d[d]				
d 0 - 28	2.29	1.67	0.14	<0.01
d 29 - 56	2.18	2.37	0.14	0.33
d 57 - 70	1.56	2.01	0.14	0.03
d 0 - 70	2.10	2.02	0.06	0.43
ME allowable[c]	1.90	1.69	--	--
MP allowable[c]	3.10	2.60	--	--
DM intake, kg/d[d]				
d 0 - 28	9.26	7.19	0.17	<0.01
d 29 - 56	11.64	11.35	0.17	0.25
d 57 - 70	11.56	11.56	0.17	0.99
d 0 - 70	10.67	9.73	0.12	<0.01
Gain/100 kg DMI				
d 0 - 28	24.7	23.2	1.19	0.39
d 29 - 56	18.7	20.9	1.19	0.20
d 57 - 70	13.5	17.4	1.19	0.03
d 0 - 70	19.6	20.8	0.47	0.14

[a]Ad libitum=steers adapted to the finishing diet with ad libitum intake of four step-up diets increasing in percent concentrate from 70 to 90; Limit-fed=steers adapted to the finishing diet with limit feeding of the finishing diet during the first 25 d on feed.
[b]SEM = Standard error of the least squares means
[c]NRC (1996) Level-1 model, based on mean feeding weight and DMI.
[d]TRT x weigh period interaction ($P < 0.05$) for intermittent periods only.

Table 5. Dry matter intake variation (kg^2) during adaptation to a high-concentrate diet in cattle (Exp. 1)

Item[b]	Treatment[a] Ad libitum	Limit-fed	SEM[c]	P Value
Daily DMI variation[d]				
d 1 - 5	57.2	37.0	20.7	0.49
d 6 – 10	92.9	29.6	20.7	0.04
d 11 – 15	224.8	55.4	20.7	< 0.01
d 16 – 20	283.5	112.5	20.7	< 0.01
d 21 - 25	257.2	88.0	20.7	< 0.01
Pen DMI variation[d]				
d 1 - 5	209.3	47.3	15.5	< 0.01
d 6 – 10	217.2	57.9	15.5	< 0.01
d 11 – 15	132.2	53.2	15.5	< 0.01
d 16 – 20	89.0	46.9	15.5	0.06
d 21 - 25	107.6	51.3	15.5	0.02

[a]Ad libitum=steers adapted to the finishing diet with ad libitum intake of four step-up diets increasing in percent concentrate from 70 to 90; Limit-fed=steers adapted to the finishing diet with limit feeding of the finishing diet during the first 25 d on feed.

[b]Daily DMI variation=(by days in an adaptation period across all pens in a treatment) Residual intake calculated as estimated DMI minus the average DMI for all pens within a treatment for each day analyzed by diet concentrate level for ad libitum steers and the corresponding days for limit-fed steers; Pen DMI variation=(by pen across all days in an adaptation period) Residual intake calculated as estimated daily DMI minus the average DMI for all days within the concentrate period for that pen. Sample variances were calculated on intake residuals in both methods

[c]SEM = Standard error of the least squares means

[d]TRT x concentrate period interaction ($P < 0.05$).

Table 6. Effect of restricted feeding of the final diet vs ad libitum dietary adaptation on carcass characteristics in cattle (Exp. 1)

Item	Treatment[a]		SEM[b]	P-value
	Ad libitum	Limit-fed		
Carcasses	43	40	--	--
Hot carcass wt, kg	344	335	3.94	0.13
12th rib backfat, cm	1.31	1.22	0.06	0.26
Rib-eye area, cm^2	78.0	76.5	0.90	0.23
REA/cwt, cm^2[c]	22.8	22.9	0.30	0.72
KPH, %	2.26	2.13	0.06	0.10
Marbling score[d]	479	474	11.8	0.75
Quality grade[e]	388	390	5.6	0.83
Yield grade	3.25	3.13	0.53	0.35
% Choice	88.00	87.50	--	--

[a]Ad libitum=steers adapted to the finishing diet with ad libitum intake of four step-up diets increasing in percent concentrate from 70 to 90; Limit-fed=steers adapted to the finishing diet with limit feeding of the finishing diet during the first 25 d on feed.
[b]SEM = Standard error of the least squares means.
[c]Calculation = Rib-eye area, cm^2 / 100 kg of hot carcass weight.
[d]Small degree of marbling = 400, Slight degree of marbling = 300.
[e]Choice quality grade = 400, Select quality grade = 300.

Table 7. Effect of restricted feeding of the final diet vs ad libitum dietary adaptation on feedlot performance by cattle (Exp. 2)

Item	Treatment[a] Ad libitum	Limit-fed	SEM[b]	P-value
Steers	75	73	--	
Pens	15	15	--	
Initial wt, kg	287	288	0.77	0.34
Final wt, kg	567	544	5.85	0.01
Daily gain, kg/d[d]				
0-28	2.33	1.70	0.08	<0.01
29-56	1.80	1.95	0.08	0.19
57-84	1.65	1.50	0.08	0.21
85-112	1.58	1.62	0.08	0.72
113-140	1.46	1.25	0.08	0.08
141-end	1.39	1.50	0.08	0.33
Overall	1.65	1.51	0.03	<0.01
ME allowable[c]	1.70	1.62	--	--
MP allowable[c]	2.42	2.19	--	--
DM intake, kg/d[d]				
0-28	8.18	5.70	0.19	<0.01
29-56	9.52	9.27	0.19	0.35
57-84	9.46	9.03	0.19	0.10
85-112	9.39	10.58	0.19	<0.01
113-140	10.65	10.01	0.19	0.02
141-end	10.38	9.97	0.19	0.12
Overall	9.15	8.68	0.10	<0.01
Gain/100 kg DMI[d]				
0-28	28.35	29.47	0.83	0.34
29-56	18.89	21.11	0.83	0.06
57-84	17.35	16.69	0.83	0.58
85-112	16.85	15.33	0.83	0.20
113-140	13.68	12.40	0.83	0.28
141-end	13.28	15.18	0.83	0.11
Overall	17.12	16.51	0.32	0.19

[a]Ad libitum=steers adapted to the finishing diet with ad libitum intake of three step-up diets increasing in percent concentrate from 65 to 92; Limit-fed=steers adapted to the finishing diet with limit feeding of the finishing diet during the first 45 d on feed.
[b]SEM = Standard error of the least squares means.
[c]NRC (1996) Level-1 model, based on mean feeding weight and DMI.
[d]TRT x weigh period interaction ($P < 0.05$) for intermittent periods only.

Table 8. Dry matter intake variation (kg^2) during adaptation to a high-concentrate diet in cattle (Exp. 2)

	Treatment[a]			
Item[b]	Ad libitum	Limit-fed	SEM[c]	P-value
Daily DMI variation[d]				
d 1 – 8	5.46	7.25	2.11	0.45
d 9 – 17	3.73	11.45	2.11	< 0.01
d 18 – 22	21.40	22.92	2.11	0.61
d 23 - 29	21.07	20.42	2.11	0.79
Pen DMI variation[e]				
d 1 – 8	19.12	8.13	1.54	< 0.01
d 9 – 17	10.24	4.20	1.54	< 0.01
d 18 – 22	16.29	2.25	1.54	< 0.01
d 23 - 29	0.86	0.64	1.54	0.92

[a]Ad libitum=steers adapted to the finishing diet with ad libitum intake of three step-up diets increasing in percent concentrate from 65 to 92; Limit-fed=steers adapted to the finishing diet with limit feeding of the finishing diet during the first 45 d on feed.
[b]Daily DMI variation=(by days in an adaptation period across all pens in a treatment) Residual intake calculated as estimated DMI minus the average DMI for all pens within a treatment for each day analyzed by diet concentrate level for ad libitum steers and the corresponding days for limit-fed steers; Pen DMI variation=(by pen across all days in an adaptation period) Residual intake calculated as estimated daily DMI minus the average DMI for all days within the concentrate period for that pen. Sample variances were calculated on intake residuals in both methods.
[c]SEM = Standard error of the least squares means.
[d]TRT x concentrate period interaction ($P = 0.08$).
[e]TRT x concentrate period interaction ($P < 0.01$).

Table 9. Effect of restricted feeding of the final diet vs ad libitum dietary adaptation on carcass characteristics in cattle (Exp. 2)

	Treatment[a]			
Item	Ad libitum	Limit-fed	SEM[b]	P-value
Carcasses	74	73	--	--
Final wt, kg	566	543	4.50	<0.01
Hot carcass wt, kg	359	344	2.86	<0.01
12th rib backfat, cm	1.38	1.34	0.06	0.70
Rib-eye area, cm^2	88.5	85.9	1.4	0.19
REA/cwt, cm^2[c]	24.7	25.0	0.38	0.66
KPH, %	2.57	2.58	0.07	0.97
Lean maturity[d]	152	151	1.6	0.85
Skeletal maturity[d]	150	152	1.7	0.55
Marbling score[e]	387	390	8.4	0.82
Quality grade[f]	333	341	6.5	0.37
Yield grade	3.07	3.10	0.11	0.82
% Choice	41.9	40.6	--	--
Liver score[g]	0.39	0.25	0.09	0.30

[a]Ad libitum=steers adapted to the finishing diet with ad libitum intake of three step-up diets increasing in percent concentrate from 65 to 92; Limit-fed=steers adapted to the finishing diet with limit feeding of the finishing diet during the first 45 d on feed.

[b]SEM = Standard error of the least squares means.

[c]Calculation = Rib-eye area, cm^2 / 100 kg of hot carcass weight.

[d]Maturity score: "A" = 100, between 9 and 30 mo of age.

[e]Small degree of marbling = 400, Slight degree of marbling = 300.

[f]Choice quality grade = 400, Select quality grade = 300.

[g]Liver score: 0 = a normal liver, 1 = "A" (Elanco System for Grading Abscessed Beef Cattle Livers).

Table 10. Dry matter intake variation (kg^2) during adaptation to a high-concentrate diet in cattle (Exp. 3)

Item[b]	Treatment[a]		SEM[c]	P-value
	Ad libitum	Limit-fed		
Daily DMI variation				
d 1 – 7	2.67	0.35	0.78	0.04
d 8 – 14	3.79	1.81	0.78	0.07
d 15 – 21	4.06	3.32	0.78	0.50
d 22 – 28	6.46	2.74	0.78	< 0.01
d 68 - 74	1.76	1.53	0.78	0.84
Pen DMI variation				
d 1 – 7	2.05	2.88	0.97	0.56
d 8 – 14	0.77	1.59	0.97	0.55
d 15 – 21	0.84	1.75	0.97	0.51
d 22 – 28	3.03	1.31	0.97	0.22
d 68 - 74	1.28	3.13	0.97	0.19

[a]Ad libitum=steers adapted to the finishing diet with ad libitum intake of three step-up diets increasing in percent concentrate from 65 to 92; Limit-fed=steers adapted to the finishing diet with limit feeding of the final diet.

[b]Daily DMI variation=(by days in an adaptation period across all pens in a treatment) Residual intake calculated as estimated DMI minus the average DMI for all pens within a treatment for each day analyzed by diet concentrate level for ad libitum steers and the corresponding days for limit-fed steers; Pen DMI variation=(by pen across all days in an adaptation period) Residual intake calculated as estimated daily DMI minus the average DMI for all days within the concentrate period for that pen. Sample variances were calculated on intake residuals in both methods.

[c]SEM = Standard error of the least squares means.

Table 11. Effect of restricted feeding of the final diet vs ad libitum dietary adaptation on ruminal, post ruminal, and total tract digestibilities by cattle

	Ad libitum[a]					Limit-fed[a]					
Item	65	75	85	92.5	92.5	92.5	92.5	92.5	92.5	92.5	SEM[b]
Intake, g/d											
OM	3968	5960	5358	4411	6304	2567	4694	4223	4039	5893	738
ADF[cd]	810	876	781	437	640	225	417	422	409	597	99
Starch	1898	3446	3485	2895	4136	1687	3464	2884	2649	3865	466
N	103	155	134	114	155	58	97	108	104	145	18
Duodenal output, g/d											
OM	2732	4349	3111	2925	3193	1359	2814	2560	2516	3689	558
ADF[c]	817	874	543	425	617	216	357	364	431	846	175
Starch	340	980	689	495	434	175	578	584	490	658	200
N	108	175	146	146	131	67	143	134	123	166	25
Fecal output, g/d											
OM[c]	1352	1932	1434	984	1090	513	865	738	819	1314	220
ADF[cd]	617	783	577	359	449	200	243	248	296	541	79
Starch	61.2	169.2	60.7	15.3	10.4	9.1	33.1	10.8	17.4	4.4	43.0
N	39.0	51.5	40.3	29.6	35.4	19.8	31.0	26.0	25.4	37.3	6.5
Total tract digestibility, %											
OM[c]	66.4	66.3	72.2	76.6	82.6	80.1	81.1	81.9	79.3	77.7	3.3
ADF	23.5	7.6	22.3	15.6	28.2	12.1	40.3	40.1	24.5	9.2	11.1
Starch	97.1	95.0	98.2	99.5	99.7	99.4	99.0	99.6	99.4	99.8	1.1
N	62.9	66.1	69.1	72.0	77.1	65.9	67.3	74.1	74.9	74.4	3.7
Ruminal Digestibility, %											
OM	32.8	24.8	42.9	24.2	49.4	47.5	40.2	41.7	31.0	36.4	9.6
ADF	-1.23	4.10	30.15	-1.85	5.88	4.53	12.63	18.63	-22.93	-45.01	23.72
Starch	84.1	72.2	81.8	78.5	89.9	89.7	83.7	83.2	78.1	82.8	5.5
N	-3.1	-17.8	-8.3	-44.3	15.8	-14.0	-45.8	-27.2	-23.8	-14.6	16.9
Post ruminal digestibility, %											
OM	46.9	54.2	50.9	64.9	63.5	61.7	68.6	67.8	66.4	60.6	8.5
ADF	15.4	-32.6	-13.6	12.2	21.0	8.1	30.8	18.4	18.3	24.0	27.2
Starch	81.8	78.1	89.6	95.2	97.0	94.9	94.4	95.9	93.9	99.4	5.5
N	62.7	70.9	71.5	79.0	66.8	68.1	77.3	79.9	79.3	75.1	5.3

[a]Ad libitum=steers adapted to the finishing diet with ad libitum intake of three step-up diets increasing in percent concentrate from 65 to 92.5. Limit-fed=steers adapted to the finishing diet with limit feeding of the final diet; periods were 1 = d 1 - 7, 2 = d 8 - 14, 3 = d 15 - 21, 4 = d 22 - 28, and 5 = d 68 - 74.

[b]SEM = Standard error of the least squares means

[c]TRT x adaptation period effect ($P < 0.05$)

[d]TRT effect ($P < 0.05$)

Table 12. Digesta kinetics as effected by restricted versus ad libitum adaptation in cattle

	Ad libitum					Limit-fed					
Item	65	75	85	92.5	92.5	92.5	92.5	92.5	92.5	92.5	SEM[b]
Full BW, kg	333	337	333	328	382	320	335	315	337	371	18
Ruminal fill, g/kg BW											
Dry matter	15.4	20.8	19.2	14.6	16.8	16.7	23.7	22.1	19.1	13.9	3.9
Fluid	106	87	74	66	89	98	110	89	94	65	14
Particulate passage rate, %/h	4.76	1.79	2.46	1.94	1.43	4.63	3.22	5.07	2.30	5.62	1.83
Liquid kinetics											
Dilution rate, %/h	7.76	5.26	5.37	3.85	3.10	4.77	6.33	3.35	3.41	4.87	1.29
Retention time, h	14.4	23.8	19.5	36.7	31.0	21.0	16.9	36.9	30.3	35.9	9.0
Rumen volume, L	72.1	63.4	40.1	33.3	68.5	62.1	63.0	42.4	56.5	71.7	9.7

[a]Ad libitum=steers adapted to the finishing diet with ad libitum intake of three step-up diets increasing in percent concentrate from 65 to 92.5; Limit-fed=steers adapted to the finishing diet with limit feeding of the final diet; periods were 1 = d 1 - 7, 2 = d 8 – 14, 3 = d 15 - 21, 4 = d 22 – 28, and 5 = d 68 – 74

[b]SEM = Standard error of the least squares means

Table 13. Ruminal metabolites as effected by restricted versus ad libitum adaptation in cattle

	Ad libitum					Limit-fed					
Item	65	75	85	92.5	92.5	92.5	92.5	92.5	92.5	92.5	SEM[b]
pH	6.00	5.81	5.57	5.47	5.69	6.13	5.45	5.45	5.18	5.88	0.19
Ruminal NH^3 -N, mg/dL	7.83	7.86	4.38	6.50	6.49	6.74	6.07	9.58	10.41	7.86	2.08
Total VFA, mMol/L	68.5	83.7	70.7	89.0	67.1	46.0	82.6	79.3	84.6	69.8	13.0
	mol / 100 mol										
Acetate[c]	44.6	46.2	45.1	45.1	49.1	45.7	38.7	48.0	49.5	45.3	1.7
Propionate[c]	32.8	31.9	38.6	44.0	42.1	30.9	36.2	46.8	42.3	42.3	5.8
Butyrate	16.4	17.1	12.0	7.8	3.5	16.3	18.7	2.8	4.2	7.0	1.5
Valerate	3.82	2.44	2.28	1.57	1.65	2.79	3.93	1.45	2.10	3.46	0.89
Isobutyrate	1.24	1.25	0.94	0.64	1.11	2.05	1.18	0.46	1.44	0.72	0.28
Isovalerate	1.15	1.12	1.21	0.94	2.51	2.33	1.10	0.53	0.48	1.19	0.24
Acetate:Propionate	1.46	1.48	1.27	1.07	1.26	1.54	1.20	1.04	1.11	1.14	0.12

[a]Ad libitum=steers adapted to the finishing diet with ad libitum intake of three step-up diets increasing in percent concentrate from 65 to 92; Limit-fed=steers adapted to the finishing diet with limit feeding of the final diet; periods were 1 = d 1- 7, 2 = 8 – 14, 3 = 15 – 21, 4 = 22 – 28, and 5 = 68 – 74

[b]SEM = Standard error of the least squares means.

[c]Trt x time effect ($P < 0.10$), data not shown.

Table 14. Calculated nutrient intakes with ME and MP allowable ADG based on the 1996 Beef Cattle NRC (Level 1 Model) (Exp. 1)

	Adaptation period[a]									
	d 1-5		d 6-10		d 11-15		d 16-20		d 1-70	
Item[b]	Adlib	Limit	Adlib	Limit	Adlib	Limit	Adlib	Limit	Adlib	Limit
Intake, kg										
DM	7.14	5.66	9.40	6.76	11.50	7.91	12.99	9.08	10.67	9.73
Crude protein	1.16	0.78	1.38	0.93	1.60	1.09	1.86	1.25	1.47	1.34
Calcium	0.06	0.03	0.07	0.03	0.06	0.04	0.08	0.05	0.05	0.05
Phosphorous	0.03	0.02	0.04	0.03	0.05	0.03	0.05	0.04	0.04	0.04
Monensin, mg/hd	92.8	73.6	122.2	87.9	149.5	102.8	168.9	118.0	138.7	126.5
ME allowable ADG, kg	1.02	0.83	1.68	1.15	2.26	1.48	2.75	1.80	1.90	1.69
MP allowable ADG, kg	1.42	0.75	2.24	1.19	3.43	1.67	3.84	2.16	3.10	2.60

[a]Step-up periods designated by days which ad libitum steers where concuming each sequential step-up diet.
[b]Calculated intakes and allowable daily gains are based on actual DMI and diet NRC (1996) Level-1 model values.

Table 15. Calculated nutrient intakes with ME and MP allowable ADG based on the 1996 Beef Cattle NRC (Level 1 Model) (Exp. 2)

	Adaptation period[a]									
	d 1-8		d 9-17		d 18-22		d 23-29		D 1-173	
Item[b]	Adlib	Limit	Adlib	Limit	Adlib	Limit	Adlib	Limit	Adlib	Limit
Intake, kg										
DM	5.59	3.31	8.53	5.11	8.61	6.64	8.18	7.31	9.15	8.68
Crude protein	0.78	0.43	1.18	0.67	1.18	0.87	1.07	0.96	1.20	1.13
Calcium	0.04	0.02	0.06	0.03	0.05	0.03	0.04	0.04	0.05	0.04
Phosphorous	0.02	0.01	0.03	0.02	0.03	0.03	0.03	0.03	0.04	0.03
Monensin, mg/hd	83.9	49.7	128.0	76.7	129.2	99.6	122.7	109.7	137.3	130.2
ME allowable gain, kg	0.76	0.29	1.70	0.91	1.90	1.40	1.88	1.61	1.70	1.62
MP allowable gain, kg	0.82	0.13	1.94	0.76	2.06	1.32	1.91	1.57	2.42	2.19

[a]Step-up periods designated by days which ad libitum steers where concuming ech sequential step-up diet.

[b]Calculated intakes and allowable daily gains are based on actual DMI and diet NRC (1996) Level-1 model values.

Figure 1. Daily DM intake of yearling steers for 70 days when step-up diets were compared to restricted-feeding of the final diet during the first 25 days on feed (Exp. 1)

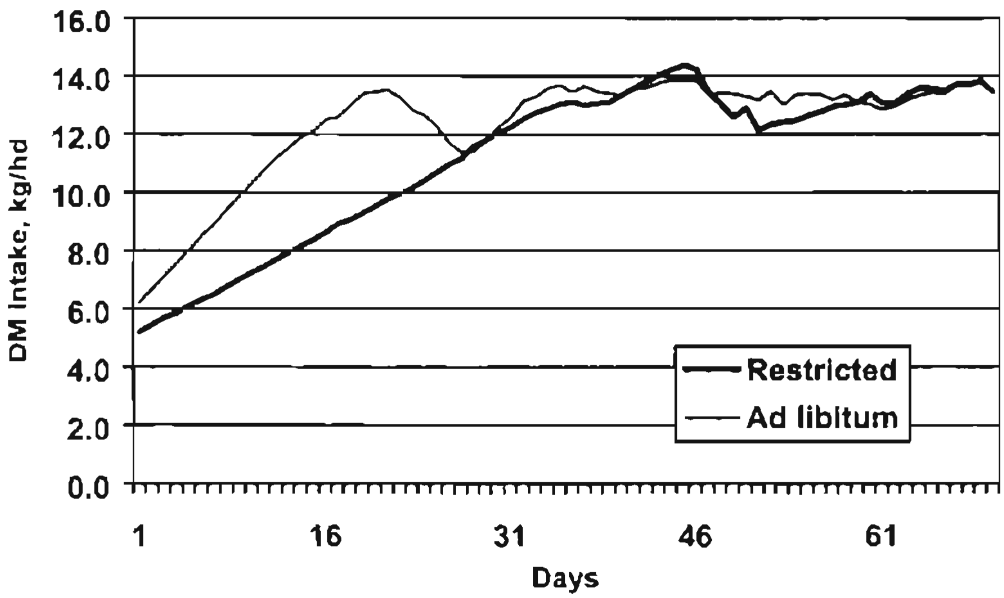
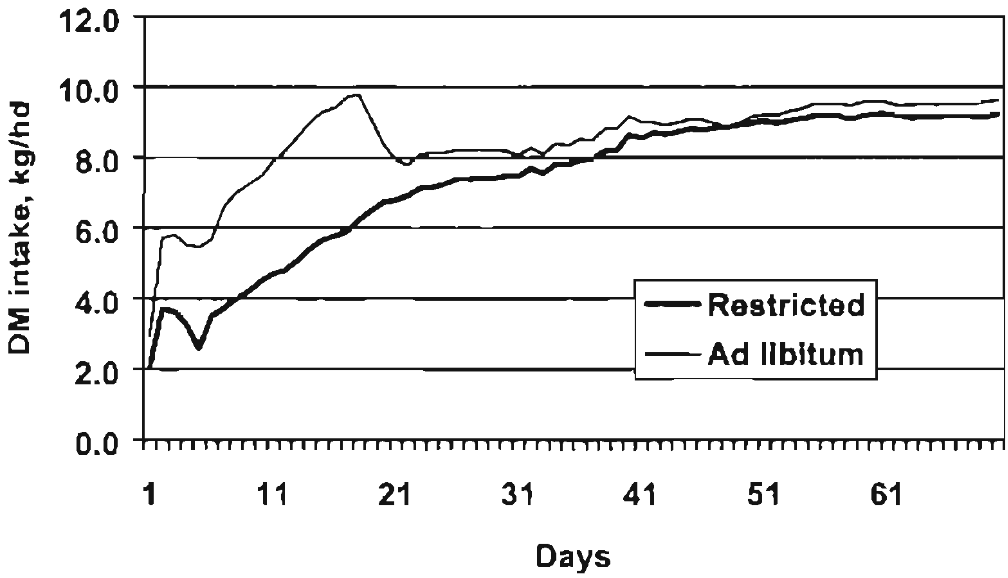


Figure 2. Daily DM intakes of cross-bred steer calves for 70 days when step-up diets were compared to restricted-feeding of the final diet during the first 45 days on feed (Exp. 2)



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APPENDIX

Dietary balance sheets during adaptation And the overall feeding period by feedlot steers in experiments 1 and 2

Table 16. NRC (1996) Level 1. Model Balance Sheet based on actual DM intake of steers fed the 70% concentrate diet ad libitum on days 1 – 5 (Exp. 1)

	NE Diet Mcal / d	NE Reqd Mcal / d	Differ Mcal / d	MP Diet g / d	MP Reqd g / d	Differ g/ d
Totals				729	623	106
Maint	15.5	7.5	8.0	729	351	378
Preg	8.0	0.0	8.0	378	0	378
Lact	8.0	0.0	8.0	378	0	378
Gain	4.8	4.8	0.0	378	272	106
Reserves	0.0			106		

DMI predicted	9.17 kg/d	DIP Required	709
DMI actual	7.14 kg/d	DIP Supplied	740
ME Allowed ADG	1.02 kg/d	DIP Balance	30.9 g/d

eNDF Required	0.57 kg/d	MP from Bacteria	454 g/d
eNDF Supplied	1.28 kg/d	MP from UIP	275 g/d
NDF in Ration	22%DM	Diet CP	15.2%DM
Diet TDN	80%DM	DIP	68.2%CP
Diet ME	2.90 Mcal/kg	Total NSC	55.6%DM
Diet NEm	2.17 Mcal/kg	Cost/d	$0.00/d
Diet NEg	1.29 Mcal/kg		
DMI / Maint DMI	2.08	MP allowed ADG	1.42 kg/d
Est. Ruminal pH	6.18		

Table 17. NRC (1996) Level 1. Model Balance Sheet based on actual DM intake of steers fed the 75% concentrate diet ad libitum on days 6 – 10 (Exp. 1)

	NE Diet Mcal / d	NE Reqd Mcal / d	Differ Mcal / d	MP Diet g / d	MP Reqd g / d	Differ g/ d
Totals				914	773	141
Maint	21.2	7.5	13.7	914	351	563
Preg	13.7	0.0	13.7	563	0	563
Lact	13.7	0.0	13.7	563	0	563
Gain	8.2	8.2	0.0	563	422	141
Reserves	0.0			141		

DMI predicted	8.97 kg/d	DIP Required	916
DMI actual	9.40 kg/d	DIP Supplied	886
ME Allowed ADG	1.68 kg/d	DIP Balance	-30.3 g/d

eNDF Required	0.75 kg/d	MP from Bacteria	586 g/d
eNDF Supplied	1.50 kg/d	MP from UIP	328 g/d
NDF in Ration	20%DM	Diet CP	13.8%DM
Diet TDN	82%DM	DIP	68.4%CP
Diet ME	2.98 Mcal/kg	Total NSC	58.6%DM
Diet NEm	2.25 Mcal/kg	Cost/d	$0.00/d
Diet NEg	1.35 Mcal/kg		
DMI / Maint DMI	2.83	MP allowed ADG	2.24 kg/d
Est. Ruminal pH	6.10		

Table 18. NRC (1996) Level 1. Model Balance Sheet based on actual DM intake of steers fed the 80% concentrate diet ad libitum on days 11 – 15 (Exp. 1)

	NE Diet Mcal / d	NE Reqd Mcal / d	Differ Mcal / d	MP Diet g / d	MP Reqd g / d	Differ g/ d
Totals				1185	901	284
Maint	26.4	7.5	18.9	1185	351	834
Preg	18.9	0.0	18.9	834	0	834
Lact	18.9	0.0	18.9	834	0	834
Gain	11.4	11.4	0.0	834	550	284
Reserves	0.0			284		

DMI predicted	8.85 kg/d	DIP Required	1134
DMI actual	11.50 kg/d	DIP Supplied	1038
ME Allowed ADG	2.26 kg/d	DIP Balance	-95.5 g/d

eNDF Required	0.92 kg/d	MP from Bacteria	726 g/d
eNDF Supplied	1.81 kg/d	MP from UIP	459 g/d
NDF in Ration	19%DM	Diet CP	14.0%DM
Diet TDN	84%DM	DIP	64.4%CP
Diet ME	3.03 Mcal/kg	Total NSC	58.8%DM
Diet NEm	2.30 Mcal/kg	Cost/d	$0.00/d
Diet NEg	1.39 Mcal/kg		
DMI / Maint DMI	3.53	MP allowed ADG	3.43 kg/d
Est. Ruminal pH	6.09		

Table 19. NRC (1996) Level 1. Model Balance Sheet based on actual DM intake of steers fed the 85% concentrate diet ad libitum on days 16 – 20 (Exp. 1)

	NE Diet Mcal / d	NE Reqd Mcal / d	Differ Mcal / d	MP Diet g / d	MP Reqd g / d	Differ g/ d
Totals				1261	1004	257
Maint	30.7	7.5	23.2	1261	351	910
Preg	23.2	0.0	23.2	910	0	910
Lact	23.2	0.0	23.2	910	0	910
Gain	14.2	14.2	0.0	910	652	257
Reserves	0.0			257		

DMI predicted	8.66 kg/d	DIP Required	1171
DMI actual	12.99 kg/d	DIP Supplied	1178
ME Allowed ADG	2.75 kg/d	DIP Balance	6.4 g/d

eNDF Required	1.04 kg/d	MP from Bacteria	750 g/d
eNDF Supplied	1.48 kg/d	MP from UIP	511 g/d
NDF in Ration	15%DM	Diet CP	14.0%DM
Diet TDN	86%DM	DIP	64.8%CP
Diet ME	3.10 Mcal/kg	Total NSC	62.8%DM
Diet NEm	2.37 Mcal/kg	Cost/d	$0.00/d
Diet NEg	1.44 Mcal/kg		
DMI / Maint DMI	4.11	MP allowed ADG	3.84 kg/d
Est. Ruminal pH	5.91		

Table 20. NRC (1996) Level 1. Model Balance Sheet based on actual DM intake of the 70, 75, 80, 85, and 90% concentrate diets on days 1 – 70 (Exp. 1)

	NE Diet Mcal / d	NE Reqd Mcal / d	Differ Mcal / d	MP Diet g / d	MP Reqd g / d	Differ g/ d
Totals				1047	796	251
Maint	25.8	8.4	17.4	1047	396	651
Preg	17.4	0.0	17.4	651	0	651
Lact	17.4	0.0	17.4	651	0	651
Gain	10.7	10.7	0.0	651	400	251
Reserves	0.0			251		

DMI predicted	8.89 kg/d	DIP Required	939
DMI actual	10.67 kg/d	DIP Supplied	930
ME Allowed ADG	1.90 kg/d	DIP Balance	-8.4 g/d

eNDF Required	0.84 kg/d	MP from Bacteria	601 g/d
eNDF Supplied	1.04 kg/d	MP from UIP	447 g/d
NDF in Ration	14%DM	Diet CP	14.0%DM
Diet TDN	87%DM	DIP	62.5%CP
Diet ME	3.16 Mcal/kg	Total NSC	64.7%DM
Diet NEm	2.42 Mcal/kg	Cost/d	$0.00/d
Diet NEg	1.49 Mcal/kg		
DMI / Maint DMI	3.07	MP allowed ADG	3.10 kg/d
Est. Ruminal pH	5.84		

Table 21. NRC (1996) Level 1. Model Balance Sheet based on actual DM intake of restricted steers consuming the 90% concentrate diet on days 1 – 5 (Exp. 1)

	NE Diet Mcal / d	NE Reqd Mcal / d	Differ Mcal / d	MP Diet g / d	MP Reqd g / d	Differ g/ d
Totals				556	577	-21
Maint	13.7	7.5	6.2	556	351	204
Preg	6.2	0.0	6.2	204	0	204
Lact	6.2	0.0	6.2	204	0	204
Gain	3.8	3.8	0.0	204	226	-21
Reserves	0.0			-21		

DMI predicted	8.49 kg/d	DIP Required	498
DMI actual	5.66 kg/d	DIP Supplied	494
ME Allowed ADG	0.83 kg/d	DIP Balance	-4.5 g/d

eNDF Required	0.45 kg/d	MP from Bacteria	498 g/d
eNDF Supplied	0.55 kg/d	MP from UIP	237 g/d
NDF in Ration	14%DM	Diet CP	14.0%DM
Diet TDN	87%DM	DIP	62.5%CP
Diet ME	3.16 Mcal/kg	Total NSC	64.7%DM
Diet NEm	2.42 Mcal/kg	Cost/d	$0.00/d
Diet NEg	1.49 Mcal/kg		
DMI / Maint DMI	1.83	MP allowed ADG	0.75 kg/d
Est. Ruminal pH	5.84		

Table 22. NRC (1996) Level 1. Model Balance Sheet based on actual DM intake of restricted steers consuming the 90% concentrate diet on days 6 – 10 (Exp. 1)

	NE Diet Mcal / d	NE Reqd Mcal / d	Differ Mcal / d	MP Diet g / d	MP Reqd g / d	Differ g/ d
Totals				664	653	10
Maint	16.4	7.5	8.9	664	351	312
Preg	8.9	0.0	8.9	312	0	312
Lact	8.9	0.0	8.9	312	0	312
Gain	5.5	5.5	0.0	312	302	10
Reserves	0.0			10		

DMI predicted	8.49 kg/d	DIP Required	595
DMI actual	6.76 kg/d	DIP Supplied	589
ME Allowed ADG	1.15 kg/d	DIP Balance	-5.3 g/d

eNDF Required	0.54 kg/d	MP from Bacteria	381 g/d
eNDF Supplied	0.66 kg/d	MP from UIP	283 g/d
NDF in Ration	14%DM	Diet CP	14.0%DM
Diet TDN	87%DM	DIP	62.5%CP
Diet ME	3.16 Mcal/kg	Total NSC	64.7%DM
Diet NEm	2.42 Mcal/kg	Cost/d	$0.00/d
Diet NEg	1.49 Mcal/kg		
DMI / Maint DMI	2.19	MP allowed ADG	1.19 kg/d
Est. Ruminal pH	5.84		

Table 23. NRC (1996) Level 1. Model Balance Sheet based on actual DM intake of restricted steers consuming the 90% concentrate diet on days 11 – 15 (Exp. 1)

	NE Diet Mcal / d	NE Reqd Mcal / d	Differ Mcal / d	MP Diet g / d	MP Reqd g / d	Differ g/ d
Totals				776	728	48
Maint	19.2	7.5	11.7	776	351	425
Preg	11.7	0.0	11.7	425	0	425
Lact	11.7	0.0	11.7	425	0	425
Gain	7.2	7.2	0.0	425	377	48
Reserves	0.0			48		

DMI predicted	8.49 kg/d	DIP Required	696
DMI actual	7.91 kg/d	DIP Supplied	690
ME Allowed ADG	1.48 kg/d	DIP Balance	-6.3 g/d

eNDF Required	0.63 kg/d	MP from Bacteria	445 g/d
eNDF Supplied	0.77 kg/d	MP from UIP	331 g/d
NDF in Ration	14%DM	Diet CP	14.0%DM
Diet TDN	87%DM	DIP	62.5%CP
Diet ME	3.16 Mcal/kg	Total NSC	64.7%DM
Diet NEm	2.42 Mcal/kg	Cost/d	$0.00/d
Diet NEg	1.49 Mcal/kg		
DMI / Maint DMI	2.56	MP allowed ADG	1.67 kg/d
Est. Ruminal pH	5.84		

Table 24. NRC (1996) Level 1. Model Balance Sheet based on actual DM intake of restricted steers consuming the 90% concentrate diet on days 16 – 20 (Exp. 1)

	NE Diet Mcal / d	NE Reqd Mcal / d	Differ Mcal / d	MP Diet g / d	MP Reqd g / d	Differ g/ d
Totals				891	801	90
Maint	22.0	7.5	14.5	891	351	540
Preg	14.5	0.0	14.5	540	0	540
Lact	14.5	0.0	14.5	540	0	540
Gain	8.9	8.9	0.0	540	450	90
Reserves	0.0			90		

DMI predicted	8.49 kg/d	DIP Required	799
DMI actual	9.08 kg/d	DIP Supplied	792
ME Allowed ADG	1.80 kg/d	DIP Balance	-7.2 g/d

eNDF Required	0.73 kg/d	MP from Bacteria	511 g/d
eNDF Supplied	0.89 kg/d	MP from UIP	380 g/d
NDF in Ration	14%DM	Diet CP	14.0%DM
Diet TDN	87%DM	DIP	62.5%CP
Diet ME	3.16 Mcal/kg	Total NSC	64.7%DM
Diet NEm	2.42 Mcal/kg	Cost/d	$0.00/d
Diet NEg	1.49 Mcal/kg		
DMI / Maint DMI	2.94	MP allowed ADG	2.16 kg/d
Est. Ruminal pH	5.84		

Table 25. NRC (1996) Level 1. Model Balance Sheet based on actual DM intake of restricted steers consuming the 90% concentrate diet on days 1 – 70 (Exp. 1)

	NE Diet Mcal / d	NE Reqd Mcal / d	Differ Mcal / d	MP Diet g / d	MP Reqd g / d	Differ g/ d
Totals				955	758	197
Maint	23.6	8.4	15.2	955	395	561
Preg	15.2	0.0	15.2	561	0	561
Lact	15.2	0.0	15.2	561	0	561
Gain	9.3	9.3	0.0	561	363	197
Reserves	0.0			197		

DMI predicted	8.85 kg/d	DIP Required	856
DMI actual	9.73 kg/d	DIP Supplied	848
ME Allowed ADG	1.69 kg/d	DIP Balance	-7.7 g/d

eNDF Required	0.78 kg/d	MP from Bacteria	548 g/d
eNDF Supplied	0.95 kg/d	MP from UIP	407 g/d
NDF in Ration	14%DM	Diet CP	14.0%DM
Diet TDN	87%DM	DIP	62.5%CP
Diet ME	3.16 Mcal/kg	Total NSC	64.7%DM
Diet NEm	2.42 Mcal/kg	Cost/d	$0.00/d
Diet NEg	1.49 Mcal/kg		
DMI / Maint DMI	2.81	MP allowed ADG	2.60 kg/d
Est. Ruminal pH	5.84		

Table 26. NRC (1996) Level 1. Model Balance Sheet based on actual DM intake of steers fed the 65% concentrate diet ad libitum on days 1 – 8 (Exp. 2)

	NE Diet Mcal / d	NE Reqd Mcal / d	Differ Mcal / d	MP Diet g / d	MP Reqd g / d	Differ g/ d
Totals				557	536	21
Maint	11.2	6.1	5.1	557	301	256
Preg	5.1	0.0	5.1	256	0	256
Lact	5.1	0.0	5.1	256	0	256
Gain	2.9	2.9	0.0	256	235	21
Reserves	0.0			21		

DMI predicted	8.44 kg/d	DIP Required	359
DMI actual	5.59 kg/d	DIP Supplied	391
ME Allowed ADG	0.76 kg/d	DIP Balance	32.1 g/d

eNDF Required	0.45 kg/d	MP from Bacteria	230 g/d
eNDF Supplied	0.22 kg/d	MP from UIP	327 g/d
NDF in Ration	31%DM	Diet CP	14.3%DM
Diet TDN	76%DM	DIP	48.9%CP
Diet ME	2.76 Mcal/kg	Total NSC	47.2%DM
Diet NEm	2.01 Mcal/kg	Cost/d	$0.00/d
Diet NEg	1.15 Mcal/kg		
DMI / Maint DMI	1.84	MP allowed ADG	0.82 kg/d
Est. Ruminal pH	5.59		

Table 27. NRC (1996) Level 1. Model Balance Sheet based on actual DM intake of steers fed the 75% concentrate diet ad libitum on days 9 – 17 (Exp. 2)

	NE Diet Mcal / d	NE Reqd Mcal / d	Differ Mcal / d	MP Diet g / d	MP Reqd g / d	Differ g/ d
Totals				869	797	72
Maint	18.3	6.1	12.2	869	301	568
Preg	12.2	0.0	12.2	568	0	568
Lact	12.2	0.0	12.2	568	0	568
Gain	7.1	7.1	0.0	568	496	72
Reserves	0.0			72		

DMI predicted	8.16 kg/d	DIP Required	584
DMI actual	8.53 kg/d	DIP Supplied	594
ME Allowed ADG	1.70 kg/d	DIP Balance	9.8 g/d

eNDF Required	0.68 kg/d	MP from Bacteria	374 g/d
eNDF Supplied	0.38 kg/d	MP from UIP	495 g/d
NDF in Ration	25%DM	Diet CP	14.2%DM
Diet TDN	80%DM	DIP	49.0%CP
Diet ME	2.89 Mcal/kg	Total NSC	53.7%DM
Diet NEm	2.15 Mcal/kg	Cost/d	$0.00/d
Diet NEg	1.26 Mcal/kg		
DMI / Maint DMI	3.00	MP allowed ADG	1.94 kg/d
Est. Ruminal pH	5.61		

Table 28. NRC (1996) Level 1. Model Balance Sheet based on actual DM intake of steers fed the 85% concentrate diet ad libitum on days 18 – 22 (Exp. 2)

	NE Diet Mcal / d	NE Reqd Mcal / d	Differ Mcal / d	MP Diet g / d	MP Reqd g / d	Differ g/ d
Totals				897	851	46
Maint	19.6	6.1	13.5	897	301	596
Preg	13.5	0.0	13.5	596	0	596
Lact	13.5	0.0	13.5	596	0	596
Gain	8.1	8.1	0.0	596	550	46
Reserves	0.0			46		

DMI predicted	7.85 kg/d	DIP Required	628
DMI actual	8.61 kg/d	DIP Supplied	597
ME Allowed ADG	1.90 kg/d	DIP Balance	-30.5 g/d

eNDF Required	0.69 kg/d	MP from Bacteria	402 g/d
eNDF Supplied	0.43 kg/d	MP from UIP	495 g/d
NDF in Ration	19%DM	Diet CP	14.1%DM
Diet TDN	84%DM	DIP	49.1%CP
Diet ME	3.03 Mcal/kg	Total NSC	60.2%DM
Diet NEm	2.28 Mcal/kg	Cost/d	$0.00/d
Diet NEg	1.36 Mcal/kg		
DMI / Maint DMI	3.22	MP allowed ADG	2.06 kg/d
Est. Ruminal pH	5.63		

Table 29. NRC (1996) Level 1. Model Balance Sheet based on actual DM intake of steers fed the 92.5% concentrate diet ad libitum on days 23 – 29 (Exp. 2)

	NE Diet Mcal / d	NE Reqd Mcal / d	Differ Mcal / d	MP Diet g / d	MP Reqd g / d	Differ g/ d
Totals				853	845	8
Maint	19.3	6.1	13.2	853	301	552
Preg	13.2	0.0	13.2	552	0	552
Lact	13.2	0.0	13.2	552	0	552
Gain	8.0	8.0	0.0	552	544	
Reserves	0.0			8		

DMI predicted	7.65 kg/d	DIP Required	617
DMI actual	8.18 kg/d	DIP Supplied	537
ME Allowed ADG	1.88 kg/d	DIP Balance	-80.8 g/d

eNDF Required	0.65 kg/d	MP from Bacteria	395 g/d
eNDF Supplied	0.42 kg/d	MP from UIP	458 g/d
NDF in Ration	15%DM	Diet CP	13.6%DM
Diet TDN	86%DM	DIP	48.4%CP
Diet ME	3.11 Mcal/kg	Total NSC	64.4%DM
Diet NEm	2.36 Mcal/kg	Cost/d	$0.00/d
Diet NEg	1.43 Mcal/kg		
DMI / Maint DMI	3.17	MP allowed ADG	1.91 kg/d
Est. Ruminal pH	5.64		

Table 30. NRC (1996) Level 1. Model Balance Sheet based on actual DM intake of steers fed the 65, 75, 85, and 92.5% concentrate diets for an average of 173 days (Exp. 2)

	NE Diet Mcal / d	NE Reqd Mcal / d	Differ Mcal / d	MP Diet g / d	MP Reqd g / d	Differ g/ d
Totals				954	775	180
Maint	21.6	7.6	14.0	954	357	598
Preg	14.0	0.0	14.0	598	0	598
Lact	14.0	0.0	14.0	598	0	598
Gain	8.5	8.5	0.0	598	418	180
Reserves	0.0			180		

DMI predicted	8.81 kg/d	DIP Required	691
DMI actual	9.15 kg/d	DIP Supplied	600
ME Allowed ADG	1.70 kg/d	DIP Balance	-90.4 g/d

eNDF Required	0.73 kg/d	MP from Bacteria	442 g/d
eNDF Supplied	0.47 kg/d	MP from UIP	512 g/d
NDF in Ration	15%DM	Diet CP	13.6%DM
Diet TDN	86%DM	DIP	48.4%CP
Diet ME	3.11 Mcal/kg	Total NSC	64.4%DM
Diet NEm	2.36 Mcal/kg	Cost/d	$0.00/d
Diet NEg	1.43 Mcal/kg		
DMI / Maint DMI	2.85	MP allowed ADG	2.42 kg/d
Est. Ruminal pH	5.64		

Table 31. NRC (1996) Level 1. Model Balance Sheet based on actual DM intake of restricted steers consuming the 92.5% concentrate diet on days 1 – 8 (Exp. 2)

	NE Diet Mcal / d	NE Reqd Mcal / d	Differ Mcal / d	MP Diet g / d	MP Reqd g / d	Differ g/ d
Totals				345	398	-53
Maint	7.8	6.1	1.7	345	301	44
Preg	1.7	0.0	1.7	44	0	44
Lact	1.7	0.0	1.7	44	0	44
Gain	1.0	1.0	0.0	44	97	-53
Reserves	0.0			-53		

DMI predicted	7.65 kg/d	DIP Required	250
DMI actual	3.31 kg/d	DIP Supplied	217
ME Allowed ADG	0.29 kg/d	DIP Balance	-32.7 g/d

eNDF Required	0.26 kg/d	MP from Bacteria	160 g/d
eNDF Supplied	0.17 kg/d	MP from UIP	185 g/d
NDF in Ration	15%DM	Diet CP	13.6%DM
Diet TDN	86%DM	DIP	48.4%CP
Diet ME	3.11 Mcal/kg	Total NSC	64.4%DM
Diet NEm	2.36 Mcal/kg	Cost/d	$0.00/d
Diet NEg	1.43 Mcal/kg		
DMI / Maint DMI	1.28	MP allowed ADG	0.13 kg/d
Est. Ruminal pH	5.64		

Table 32. NRC (1996) Level 1. Model Balance Sheet based on actual DM intake of restricted steers consuming the 92.5% concentrate diet on days 9 – 17 (Exp. 2)

	NE Diet Mcal / d	NE Reqd Mcal / d	Differ Mcal / d	MP Diet g / d	MP Reqd g / d	Differ g/ d
Totals				533	580	-47
Maint	12.1	6.1	6.0	533	301	232
Preg	6.0	0.0	6.0	232	0	232
Lact	6.0	0.0	6.0	232	0	232
Gain	3.6	3.6	0.0	232	279	-47
Reserves	0.0			-47		

DMI predicted	7.65 kg/d	DIP Required	386
DMI actual	5.11 kg/d	DIP Supplied	335
ME Allowed ADG	0.91 kg/d	DIP Balance	-50.5 g/d

eNDF Required	0.41 kg/d	MP from Bacteria	247 g/d
eNDF Supplied	0.26 kg/d	MP from UIP	286 g/d
NDF in Ration	15%DM	Diet CP	13.6%DM
Diet TDN	86%DM	DIP	48.4%CP
Diet ME	3.11 Mcal/kg	Total NSC	64.4%DM
Diet NEm	2.36 Mcal/kg	Cost/d	$0.00/d
Diet NEg	1.43 Mcal/kg		
DMI / Maint DMI	1.98	MP allowed ADG	0.76 kg/d
Est. Ruminal pH	5.64		

Table 33. NRC (1996) Level 1. Model Balance Sheet based on actual DM intake of restricted steers consuming the 92.5% concentrate diet on days 18 – 22 (Exp. 2)

	NE Diet Mcal / d	NE Reqd Mcal / d	Differ Mcal / d	MP Diet g / d	MP Reqd g / d	Differ g/ d
Totals				693	717	-24
Maint	15.7	6.1	9.6	693	301	392
Preg	9.6	0.0	9.6	392	0	392
Lact	9.6	0.0	9.6	392	0	392
Gain	5.8	5.8	0.0	392	416	-24
Reserves	0.0			-24		

DMI predicted	7.65 kg/d	DIP Required	501
DMI actual	6.64 kg/d	DIP Supplied	436
ME Allowed ADG	1.40 kg/d	DIP Balance	-65.6 g/d

eNDF Required	0.53 kg/d	MP from Bacteria	321 g/d
eNDF Supplied	0.34 kg/d	MP from UIP	372 g/d
NDF in Ration	15%DM	Diet CP	13.6%DM
Diet TDN	86%DM	DIP	48.4%CP
Diet ME	3.11 Mcal/kg	Total NSC	64.4%DM
Diet NEm	2.36 Mcal/kg	Cost/d	$0.00/d
Diet NEg	1.43 Mcal/kg		
DMI / Maint DMI	2.57	MP allowed ADG	1.32 kg/d
Est. Ruminal pH	5.64		

Table 34. NRC (1996) Level 1. Model Balance Sheet based on actual DM intake of restricted steers consuming the 92.5% concentrate diet on days 23 – 29 (Exp. 2)

	NE Diet Mcal / d	NE Reqd Mcal / d	Differ Mcal / d	MP Diet g / d	MP Reqd g / d	Differ g/ d
Totals				763	773	-11
Maint	17.3	6.1	11.2	763	301	462
Preg	11.2	0.0	11.2	462	0	462
Lact	11.2	0.0	11.2	462	0	462
Gain	6.7	6.7	0.0	462	472	-11
Reserves	0.0			-11		

DMI predicted	7.65 kg/d	DIP Required	552
DMI actual	7.31 kg/d	DIP Supplied	480
ME Allowed ADG	1.61 kg/d	DIP Balance	-72.2 g/d

eNDF Required	0.58 kg/d	MP from Bacteria	353 g/d
eNDF Supplied	0.38 kg/d	MP from UIP	409 g/d
NDF in Ration	15%DM	Diet CP	13.6%DM
Diet TDN	86%DM	DIP	48.4%CP
Diet ME	3.11 Mcal/kg	Total NSC	64.4%DM
Diet NEm	2.36 Mcal/kg	Cost/d	$0.00/d
Diet NEg	1.43 Mcal/kg		
DMI / Maint DMI	2.83	MP allowed ADG	1.57 kg/d
Est. Ruminal pH	5.64		

Table 35. NRC (1996) Level 1. Model Balance Sheet based on actual DM intake of restricted steers consuming the 92.5% concentrate diet for an average of 173 days (Exp. 2)

	NE Diet Mcal / d	NE Reqd Mcal / d	Differ Mcal / d	MP Diet g / d	MP Reqd g / d	Differ g/ d
Totals				905	760	145
Maint	20.5	7.4	13.1	905	350	555
Preg	13.1	0.0	13.1	555	0	555
Lact	13.1	0.0	13.1	555	0	555
Gain	7.9	7.9	0.0	555	410	145
Reserves	0.0			145		

DMI predicted	8.64 kg/d	DIP Required	655
DMI actual	8.68 kg/d	DIP Supplied	569
ME Allowed ADG	1.62 kg/d	DIP Balance	-85.7 g/d

eNDF Required	0.69 kg/d	MP from Bacteria	419 g/d
eNDF Supplied	0.45 kg/d	MP from UIP	486 g/d
NDF in Ration	15%DM	Diet CP	13.6%DM
Diet TDN	86%DM	DIP	48.4%CP
Diet ME	3.11 Mcal/kg	Total NSC	64.4%DM
Diet NEm	2.36 Mcal/kg	Cost/d	$0.00/d
Diet NEg	1.43 Mcal/kg		
DMI / Maint DMI	2.75	MP allowed ADG	2.19 kg/d
Est. Ruminal pH	5.64		

VITA

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