EFFECT OF DRY MATTER INTAKE RESTRICTION ON ENERGY BALANCE, RUMINAL FERMENTATION, AND NUTRIENT RETENTION BY BEEF STEERS

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The undersigned, appointed by the Dean of the Graduate School, have examined the thesis entitled.

EFFECT OF DRY MATTER INTAKE RESTRICTION ON ENERGY BALANCE, RUMINAL FERMENTATION, AND NUTRIENT RETENTION BY BEEF STEERS

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LIST OF ABBREVIATIONS

ADF	acid detergent fiber
ADG	average daily gain
BRSV	bovine respiratory syncytial virus
BVD	bovine viral diarrhea
BW	body weight
cm	centimeter
cm^2	square centimeter
d	day
DM	dry matter
DMD	dry matter digestibility
DMI	dry matter intake
g	gram
G:F	ratio of body weight gain to feed intake
IBR	infectious bovine rhinotracheitis
i.m.	intramuscular
kg	kilogram
KPH	kidney, pelvic, and heart fat
ME	metabolizable energy
mg	milligram
ml	milliliter
MP	metabolizable protein
N	nitrogen
NE	net energy
NEg	net energy required for growth
NEm	net energy required for maintenance
OMD	organic matter digestibility
P	phosphorus
pH	ruminal pH
PI3	para-influenza$_3$
RDP	proportion of protein degraded in the rumen
s.c.	subcutaneous
SE	standard error
USDA	United States Department of Agriculture
VFA	volatile fatty acids
WSC	whole shelled corn
Yb	ytterbium

ABSTRACT

Two metabolism studies were conducted to determine the effects of DMI restriction on diet digestion, ruminal fermentation, metabolizable energy intake (MEI), and nutrient retention by feedlot steers. In Trial 1, 12 Angus X steers (BW = 450 ± 18 kg) were assigned randomly to one of three diets that were formulated to promote a 1.6 kg ADG at intake levels corresponding approximately to 100% (AL), 90% (IR90), or 80% (IR80) of *ad libitum* DMI. In Trial 2, 12 crossbred steers (BW = 445 ± 56 kg) fitted with ruminal cannulae were randomly assigned to one of two diets that were formulated to promote a 1.6 kg ADG at either AL or IR80. All diets delivered similar total NE, MP, Ca, and P per day. During both trials, fecal DM output was less ($P \leq 0.03$) for IR80 than for AL; IR90 was similar ($P > 0.10$) to AL during trial 1. Total VFA and the molar proportion of acetate of AL were greater ($P \leq 0.03$) than that of IR80 during trial 2; however, IR80 had a greater ($P = 0.03$) molar proportion of propionate. Fluid dilution rate was similar ($P = 0.42$) between treatments during trial 2, whereas metabolizable energy intake (MEI) was similar ($P \geq 0.20$) between treatments during both trials. Retention of N tended to be lower ($P < 0.06$) by IR80 steers compared with IR90 and AL steers during trial 2. Conversely, P retention was similar ($P = 0.46$) between treatments during trial 2. Under the conditions of these studies, restricting DMI while holding energy and protein intake constant decreased manure production, reduced nitrogen retention, and changed ruminal fermentation patterns in finishing steers. Improvements in performance associated with programmed-feeding regimes of the type studied here do not appear to be related to changes in fluid passage rate or MEI.

Crossbred beef steers (N = 189; initial BW = 266 ± 27 kg) at high (HI) or low (LO) risk for respiratory disease were assigned randomly to receive a 5 ml s.c. trace mineral (TM) injection containing 75 mg Cu, 25 mg Se, 50 mg Mn, and 200 mg Zn or a 5 ml s.c. injection of saline (SA) upon arrival at a feedlot. All steers were fed the same receiving diet ad libitum for a period of 28 d and monitored 2 x daily for symptoms of respiratory disease. Risk level for respiratory disease did not affect receiving ADG ($P = 0.78$); however, HI steers had greater ($P < 0.01$) incidence of undifferentiated fever and higher ($P < 0.05$) treatment costs during the receiving period. Incidence of undifferentiated fever and subsequent treatment costs were similar ($P = 0.86$) between TM and SA; however, cattle treated with SA had higher ADG ($P = 0.02$) than cattle treated with TM during the receiving period. Steers were transitioned to a common finishing ration at the conclusion of the receiving period and fed for an average of 196 d prior to harvest. Finishing ADG and DMI were similar ($P > 0.20$) for cattle treated with TM or SA; however, a single treatment with TM at receiving was associated with an increase ($P = 0.04$) in finishing G:F. Steers at low risk for respiratory disease had greater ($P < 0.01$) ADG and DMI during the finishing period than HI steers; conversely, HI steers tended to have greater ($P = 0.09$) finishing G:F than LO steers. Hot carcass weight, KPH, and incidence of lung lesions were similar ($P > 0.23$) between HI and LO steers. Steers at high risk for respiratory disease had higher ($P < 0.01$) incidence of liver abscesses compared to LO steers. Risk level for respiratory disease had pronounced effects on morbidity and treatment costs during receiving and on ADG and DMI during finishing.

CHAPTER ONE

Limit Feeding Literature Review

Traditionally, finishing cattle are fed diets that have been formulated to promote maximum performance when consumed ad libitum. It is usually assumed that finishing cattle performance will be economically most favorable under these circumstances; however, maximum production efficiency may occur at some level of feed intake that is less than ad libitum. Limit-feeding refers to the practice of restricting intake of some dietary component to a level less than ad libitum based on known or predicted animal eating behavior. As limit feeding is practiced with beef cattle, intake of dietary protein, energy, concentrate, roughage, or dry matter may be restricted. Limit-feeding of beef cattle has been studied using cattle of various ages and physiological states. This review will focus on the effects of dry matter intake (DMI) restriction on growing and finishing beef cattle; however, a variety of studies using other experimental models have been included.

Programmed-feeding is a term associated with feeding growing cattle to achieve a predetermined rate of growth. Often the predetermined growth rate is below the maximum potential growth rate predicted by NRC (1996) models for a given class of animal. Programmed-feeding has proven to be a useful technique for managing intake of growing cattle. Feeding growing cattle to gain weight at a rate that is less than maximum may enable cattle managers to optimize market prices for cattle of specific weight classes (Galyean, 1999).

Programmed-feeding is usually accompanied by an improvement in F:G. Galyean et al. (1979) used steers fitted with ruminal cannulae to evaluate the effects of intake level on digestion of high concentrate diets. A common ration was used for all experimental diets, which were fed at varying levels of the maintenance energy requirement. As level of intake increased, digestion of dry matter, organic matter, and starch decreased.

Brown (1966) also observed depressions in digestibility of forages and mixed rations when cattle were fed above a maintenance level. The depression in ME yield of forage-based diets when fed above maintenance was greater than that of concentrate-based rations fed at similar multiples of maintenance. A possible reason for this difference could be the greater amount of methane produced during fermentation of forage-based diets compared with concentrate-based diets.

Lofgreen et al. (1987) fed steers a common growing diet at ad libitum DMI, 90% of ad libitum DMI, or 80% of ad libitum DMI. Steers that were fed 80% of ad libitum DMI had lower ADG compared to cattle fed at the ad libitum level and therefore took longer to reach a targeted end point. Reduced ADG was expected as DMI decreased because successively lower DMI of a single diet would reduce concomitantly intake of energy as well as all other dietary nutrients.

Gunter et al. (1996) evaluated the effects of restricting DMI on performance of cattle fed high-concentrate diets during a 92-d growing period. The three dietary treatments were formulated to promote similar ADG but differed in nutrient density. This was achieved by altering the proportion of concentrate to roughage in the diets such that as DMI decreased the dietary nutrient density increased. Cattle with restricted DMI grew the most efficiently but daily gains were similar between treatments. Subsequently, the cattle in that study were finished on a common finishing ration. Limit feeding during the growing phase had no effect on finishing growth performance; however, limit-fed cattle had increased fat thickness, marbling scores, and yield grades compared to full-fed cattle.

Drager et al. (2004) studied the effect of DMI restriction during a 65d growing period. All treatments received the same diet but at intakes restricted to 85, 90, 95, or 100 percent of ad libitum DMI. Restricting DMI had no effect on F:G but did decrease ADG during the growing period. All cattle were subsequently fed a common finishing ration ad libitum. Restricting DMI during the 65d growing period decreased marbling scores, carcass weights, and yield grades.

Cattle that experience compensatory growth following a period of nutrient restriction usually exhibit high relative G:F during realimentation. Knoblich et al. (1997) performed two studies to determine the effects of ADG restriction during a short-term growing program on subsequent finishing performance. In the first study, steers were assigned to one of five feeding systems for the growing period until a predetermined weight gain was achieved. The feeding systems used three diets that promoted 1.13 kg, 1.36 kg, and maximal ADG. Intakes were adjusted in order to achieve the desired ADG for all diets. Once steers reached a predetermined body weight, they were allowed ad libitum access to feed until reaching a common harvest weight. During the unrestricted feeding period, the limit-fed treatments had higher ADG and G:F than steers fed ad libitum. Carcass characteristics were not affected by treatment. The second study involved two different sequences of restricted feeding during a short-term growing period followed by ad libitum access to feed during finishing. All diets were formulated to deliver the same amounts of protein, minerals, and ionophores; however, energy intake decreased as DMI decreased. Steers subjected to multiple periods of restricted feeding followed by ad libitum access to feed required less feed to achieve market weight while maintaining the same days on feed as cattle fed ad libitum. Moreover, programmed restriction of ADG during a short-term growing period had no effect on carcass characteristics.

Loerch and Fluharty (1998) studied the effects of increasing or decreasing growth rates on performance and carcass characteristics of growing steers. They also attempted to measure the effectiveness of NRC (1984) equations for predicting animal ADG when feed intake was restricted to less than ad libitum. Diets were adjusted to deliver similar levels of protein, ionophores, and macro-minerals. Treatment diets were fed at 71, 79, 88, and 100% of ad libitum intake. Dietary energy concentration was similar among all diets. Intake-restricted steers gained more than predicted; moreover, the difference in actual gain and predicted gain became greater as feed intake decreased. Following the growing phase steers on all treatments were fed a common finishing ration ad libitum. There was no difference in F:G between treatments during the growing phase. Steers that were limit-fed at a constant rate during the growing period and then fed a finishing diet ad libitum were more efficient than steers that were fed growing and finishing diets ad libitum. Conversely, limit-fed cattle required more days to reach a common harvest weight than cattle fed ad libitum.

Loerch (1990) evaluated the effects of restricting intake of high-concentrate diets during an 85d growing phase on cattle performance. Treatments consisted of ad libitum intake, intake restricted to 80% of ad libitum, and intake restricted to 70% of ad libitum. Diets delivered similar amounts of net energy, crude protein, minerals, and ionophores regardless of intake level. Restricting feed intake resulted in greater DMD and G:F during the growing period. Treatment had no effect on subsequent finishing performance or carcass characteristics.

Murphy and Loerch (1994) performed two experiments that evaluated performance and carcass traits of steers fed at 80, 90, or 100% of ad libitum DMI through growing and finishing. The amount of feed offered to steers was based upon the previous 12-d average intake of the ad libitum treatment. Dietary nutrient content was varied to deliver similar amounts of protein and minerals; however, energy density was similar for all three diets. The ad libitum DMI treatment had the greatest ADG and the treatment limited to 80% of ad libitum DMI had the lowest ADG. There were no treatment differences in F:G during the growing period but G:F was greater for the limit-fed steers during the finishing phase. Liver and heart mass were similar between treatments.

As level of intake increases above maintenance requirements, the effective energy content of feed decreases (Moe, et al. 1965). The converse of this phenomenon may occur during programmed intake restriction but does not explain why cattle that are fed the same total amount of energy and protein do not perform equally when only the amount of DMI is varied.

Albin and Durham (1967) measured the effect of restricting intake to 92% of ad libitum on feedlot performance, carcass characteristics, and the incidence of liver condemnation in steers. Intake-restricted steers had lower ADG, reduced F:G, and reduced 12th rib backfat compared with ad libitum-fed steers. Restricting intake did not, however, affect quality grade, dressing percent, rib eye area, or incidence of liver condemnation.

Zinn (1986) reported an increase in G:F when DMI of finishing steers was restricted to 93.8% of ad libitum. Rate of gain and carcass characteristics were similar between treatments.

Wagner (1987) fed a single diet at 83, 85, 93, or 100% of ad libitum DMI to finishing steers. Steers fed less than ad libitum DMI had lower ADG, lower G:F, and requiring more days to reach a common end point than steers fed ad libitum. Carcasses of intake-restricted steers were lighter and had smaller rib eye areas than those of their ad libitum-fed counterparts. There were, however, no differences observed in 12th rib backfat thickness, marbling score, or yield grade between treatments.

Plegge (1987) evaluated the effects of restricting DMI to 92 or 96% of ad libitum on performance of finishing steers. Diets were formulated to deliver similar amounts of protein, vitamins, minerals, and energy. Intake restriction reduced ADG and improved G:F. The author estimated that the metabolizable energy concentration of restricted diets was increased from 1.6 to 4.3 percent compared to diets fed ad libitum.

Hicks et al. (1990) conducted three feeding trials to evaluate the effects of feed restriction on both finishing heifers and steers. Comparisons were made feeding the same diet at 80, 85, 89, or 100% of ad libitum DMI. Intake restriction increased G:F but reduced ADG and carcass quality grade during all three trials.

Murphy et al. (1994) studied the effect of intake restriction on digestion and flow of nitrogenous compounds in ruminally and duodenally fistulated steers. Diets supplied 80, 90, or 100% of ad libitum DMI. All diets were formulated to provide the same total intakes of protein, vitamins, and minerals but had similar energy densities. Thus, as DMI decreased, intake of energy decreased. Restriction of DMI had no effect on ruminal pH or ruminal starch digestion of corn-based diets. Apparent ruminal OM and DM digestion were increased when DMI was less than ad libitum; however, apparent total tract digestibility was not affected. Authors speculated that compensatory hind gut digestion may have accounted for differences in apparent digestion. Ruminal fluid dilution rates decreased with decreasing DMI.

Sainz et al. (1995) studied the effects of restricting DMI of a high-concentrate growing diet to 70% of ad libitum. They compared the intake-restricted treatment to ad libitum intake of high-concentrate and high-forage diets. The authors also examined the residual effects of the growing treatments on finishing performance when finishing diets were fed at 70 or 100% of ad libitum DMI. Growing phase G:F was greatest for steers fed high-concentrate diets ad libitum and lowest for steers fed high-forage diets ad libitum. Steers restricted to 70% of ad libitum intake of a high-concentrate diet were intermediate between the two ad libitum intake treatments. Finishing G:F was greater for steers limit-fed high-concentrate growing rations than steers fed high-concentrate growing rations ad libitum. Finishing DMI of cattle that were intake-restricted during the growing period were higher than that predicted by NRC (1984). Restriction of DM and metabolizable energy (ME) intake during finishing reduced 12th-rib backfat thickness. Abdominal fat and empty body fat also decreased with DM and ME restriction. Quality grade was not different between treatments but DM and ME restriction was associated with a small decrease in marbling score.

Soto-Navarro et al. (2000) studied the effects of intake fluctuation, either 10% higher or lower than constant DMI, by limit-fed finishing steers on ruminal acidosis. There were four treatments: constant intake fed once daily, 10% fluctuation in intake fed once daily, constant intake fed twice daily, and 10% fluctuation in intake fed twice daily. Steers fed at a constant intake were offered 90% of predetermined ad libitum intakes. Steers treated with a 10% fluctuation in DMI were subjected to a 4-d feeding pattern. On d 1, steers were fed 90% of ad libitum (baseline) DMI. On d 2, DMI of the baseline diet was increased by 10%. Intake on d 3 was similar to that on d 1, whereas, DMI was decreased 10% relative to the baseline diet on d 4. There were no differences due to intake fluctuation in digestion of OM, N, or starch by steers that were fed once daily. Among steers fed twice daily, digestion of OM, N, and starch decreased when daily DMI was fluctuated by 10%, relative to when daily DMI was held constant.

Ruminal pH was greater when feed was offered twice per day compared with once per day, regardless of DMI fluctuation. Conversely, OMD decreased among cattle fed twice daily compared with cattle fed once daily.

Rossi et al. (2001) reported lower ADG and DMI by program-fed finishing steers compared with steers fed ad libitum. Feed efficiency was not affected by treatment. Net energy concentration was similar between diets, but crude protein concentrations were higher in the diets of the program-fed cattle. Hot carcass weight (HCW), 12th rib back fat thickness, and the percentage of carcasses graded USDA choice of program-fed steers were less than those of steers fed ad libitum. Conversely, there were no treatment differences in ribeye area (REA) or yield grade.

Schmidt et al. (2005) conducted two studies in order to determine the effects of DMI restriction on feedlot performance and carcass characteristics of finishing beef steers. One study compared DMI at 80, 90, or 100% of ad libitum DMI. A second study compared DMI at 80 or 100% of ad libitum DMI. Diets used in both studies were formulated to deliver similar levels of NEg, NEm, and metabolizable protein on a daily basis. Steers fed 80% of ad libitum DMI had improved F:G, ADG, HCW, and REA compared with 90 or 100% of ad libitum DMI in the first study. There was an increase in 12th rib back fat thickness and USDA yield grade by steers limited to 80% of ad libitum DMI compared with steers fed 90 or 100% of ad libitum DMI. In study two, ADG and F:G were improved in steers fed 80% of ad libitum DMI compared with those fed ad libitum DMI. Schmidt et al. (2005) demonstrated that limit-feeding was possible without restricting growth performance or reducing carcass value. The positive effect that intake restriction can have on F:G is not fully understood. One theory holds that passage rate of ingesta is slower in intake-restricted cattle compared to those fed ad libitum. A decrease in passage rate is usually accompanied by an increase in dietary OM digestion. Colucci et al. (1982) evaluated the effects of feeding high- and low- forage maintenance diets on diet digestibility and passage rate by both lactating and dry dairy cows. Passage rate of the forage fraction of the diet was slower than the concentrate fraction regardless of diet or lactation status. Retention time for both diets decreased as DMI increased. Dry matter digestion was greater for low-forage diets compared with high-forage diets.

Tamminga et al. (1979) studied the effects of feeding different levels of protein with two levels of intake (Low vs. High) on the amount of non-microbial protein entering the small intestine by dairy cows. At the high level of intake, the amount of undegraded protein entering the small intestine was greater than at the low level of intake. Although particulate passage rate was not measured, authors speculated that the increase in undegraded protein passage to the small intestine was due to decreased ruminal protein degradation resulting from increased ruminal passage rate. While this study specifically addressed ruminal protein degradation, the inverse relationship between ruminal passage rate and extent of ruminal digestion may be true for all fermentable substrate.

The weight of visceral organs and their contribution to the maintenance energy requirement of the animal increases as feed intake increases (Ferrell, et al, 1976). Sainz and Bentley (1997) found that liver weights of finishing steers limit-fed a high-concentrate ration were less than those of steers fed the same ration ad libitum. The numbers of liver cells per kg of body weight were the same for limit-fed steers as steers fed ad libitum; however, cell size was smaller in limit-fed cattle. Johnson et al. (1990) correlated liver weight with metabolizable energy intake in lactating cows, lambs, and beef steers. Feeding different forage levels had no effect on fat-free liver weight or gastrointestinal tract tissue weights when metabolizable energy intake was held constant. Weight increases of approximately 14 and 28 $g/BW^{0.75}$ in liver and gastrointestinal tract mass, respectively, was achieved by increasing energy consumption by 1 multiple of maintenance in repeated studies of ruminants. Johnson et al. (1990) concluded that size and maintenance energy requirement of an organ is dependant upon the physiological workload delegated to that organ. In effect, diets containing similar amounts of metabolizable energy and differing only in DMI should not affect visceral organ mass and should therefore have no effect on the maintenance requirements of those organs, according to Johnson et al. (1990).

One concern that cattle feeders have regarding restricting intake of feedlot cattle is the uncertainty of how much bunk space to allow for each animal. Typically 15 cm/hd is adequate when feeding cattle ad libitum (Elam and Grainger, 1977). When limit-feeding a high-concentrate ration to beef cattle, there is concern that variable individual animal intake can result in large variation in animal performance and an increased rate of digestive upset. It is thought that, erratic DMI patterns will result if bunk space recommendations for conventionally fed cattle are employed for limit-fed cattle.

Zinn (1989) evaluated the effect of manger space allotment on the performance of intake-restricted feedlot steers. Zinn concluded that increasing manger space to 30, 45, and 60 cm/hd did not improve performance of intake-restricted steers compared to intake-restricted steers allowed 15 cm/hd of bunk space. Gunter et al. (1996) also evaluated the effect of manger space on the performance of limit-fed growing steers. Manger space treatments were 12.7, 20.3, 27.9, and 35.6 cm per steer. There were no differences in steer performance due to manger space allotment. Moreover, variation in growth performance within pens was not different between treatments. Although the results of these trials indicated that bunk space requirements of intake-restricted cattle might be similar to that of ad libitum-fed cattle, it appears that more research may be needed in this area. Specifically, research is needed to investigate the effects of bunk space allowance on performance and carcass characteristics.

CHAPTER TWO

Effects of Dry Matter Intake Restriction on Diet Digestion, Ruminal Fermentation, Energy Balance, and Nutrient Retention by Beef Steers

Introduction

Limit-feeding refers to the practice of restricting intake of some dietary component to a level less than ad libitum based on known or predicted animal eating behavior (Galyean, 1999). It is generally assumed that performance of feedlot cattle will be economically most favorable at ad libitum DMI; however, maximum production efficiency may occur at some level of DMI that is less than ad libitum. Benefits associated with programmed restriction of DMI include improved diet digestion (Galyean, 1979), improved feed efficiency (Sainz et al., 1995; Rossi et al., 2001; Schmidt et al., 2005) reduced feed costs (Knoblich et, al., 1997; Loerch and Fluharty, 1998), and improved ADG (Schmidt et al., 2005). In most circumstances, programmed DMI restriction has been detrimental to performance of growing and finishing cattle. When DMI and energy intake were restricted concomitantly, ADG decreased (Plegge, 1987; Murphy and Loerch, 1994; Rossi et al, 2001), HCW was reduced (Hicks et al., 1990; Rossi et al., 2001), and carcass quality decreased (Hicks et al., 1990; Sainz et al., 1995; Rossi et al., 2001). This manner of DMI restriction also reduced external carcass fatness (Albin and Durham, 1967; Sainz et al., 1995; Rossi et al., 2001) and decreased USDA yield grade (Sainz et al., 1995). Restricting DMI without restricting protein or energy intake relative to ad libitum feeding improved G:F, increased ADG, and did not affect carcass value (Schmidt et al., 2005). The objective of our research was to evaluate the effects of restricting DMI to 90 or 80% of ad libitum, while holding NE and MP intakes constant relative to cattle fed ad libitum, on diet digestion, nutrient retention, ruminal fermentation, and energy balance.

Materials and Methods

The experiments described in this manuscript were reviewed and approved by the University of Missouri Animal Care and Use Committee (Protocol #3711). Twelve crossbred steers (average BW = 450 ± 18 kg) were used to evaluate the effects of programmed DMI restriction on diet digestion, nutrient excretion, and energy balance in a completely random design (trial 1). Steers were randomly assigned to one of three dietary treatments (Table 2.1): ad libitum (AL), intake restricted to 90% of ad libitum DMI (IR90), or intake restricted to 80% of ad libitum DMI (IR80). In a second experiment (trial 2), twelve crossbred steers (average BW = 445 ± 56 kg) that had previously been fitted with ruminal cannulae were used to evaluate the effects of programmed DMI restriction on ruminal fermentation, fluid dilution rate, and energy balance in a completely random design. Steers were randomly assigned to one of two dietary treatments (Table 2.2): AL or IR80. Diets for trial 1 and trial 2 were all formulated to promote 1.6 kg ADG and to deliver similar amounts of NE, RDP, MP, Ca, and P on a daily basis. Desired intake of DM, NE, RDP, MP, Ca, and P were achieved by varying the ingredient composition of the diets.

Experimental Procedures – Trial 1. Steers were pen-fed their respective treatment diets for 56d; subsequently they were placed in individual metabolism stanchions for a period of 24 d. Treatment diets were individually fed once daily at 0800 during the period of stanchion confinement. Intakes were adjusted such that the AL steers consumed their daily allotment of feed in about 23 h; intakes of IR90 and IR80 steers were based on the rolling 5-d average intake by AL steers.

The 24 d confinement period consisted of a 17 d period of adaptation to environment and diet, followed by a 7 d data collection period. The 7 d data collection period was conducted as follows: individual DMI were recorded on d 1-7; and individual collection of total fecal and urinary output were conducted on d 3-7.

Treatment diets were randomly sub-sampled 1x daily immediately prior to feeding. Diet samples were composited within treatment, across day. Feed composites were dried in a forced-air oven (50°C; 96 h) and subsequently ground to pass a 2 mm screen (No. 4 Wiley mill, Thomas Scientific, Swedesboro, NJ). When present, any orts were weighted daily at 0700 and, if deemed edible, were immediately returned to feed bunks. During the period of intake measurement, consumption of targeted amounts of feed was complete for all treatment groups.

Total fecal output was weighed once daily at 0600. After thorough mixing, fecal material was sub-sampled (approximately 3% of the daily total by weight), weighed, and dried in a forced-air oven (50°C, 96 h). Dried daily fecal samples were ground to pass a 2 mm screen (No. 4 Wiley mill, Thomas Scientific, Swedesboro, NJ) and composited within animal across day. Collected urine was acidified with 6N HCl at 4 h intervals to maintain pH $\leq$ 4.0 (Knowlton et al., 2001). Total urinary output was weighted once daily at 0630, homogenized, and sub-sampled (approximately 3% of the daily total). Daily sub-samples were aggregated into a running composite and frozen (-20°C) immediately after collection.

Experimental Procedures – Trial 2. Steers were adapted to a common, pen-fed finishing diet over 12 d . Subsequently, they were randomly assigned to dietary treatments and placed in individual metabolism stanchions for a period of 22 d. Treatment diets were individually fed once daily at 0800 during the period of stanchion confinement. Intakes were adjusted such that the AL steers consumed their daily allotment of feed in about 23 h; intakes of IR80 steers were based on the rolling 5-d average DMI by AL steers.

The 22 d confinement period consisted of a 14 d period of adaptation to diet and environment, followed by an 8 d data collection period. The 10 d data collection period was conducted as follows: individual DMI were recorded on d 1-7; individual collection of total fecal and urinary output were conducted on d 3-9; and ruminal fermentation and passage rate were characterized on d 10. During the period of intake measurement, consumption of targeted amounts of feed was complete for all treatment groups. Samples of feed, feces, and urine were collected and processed using methods described for trial 1.

Steers were intraruminally infused at 0745 on d 8 with 6.5 g of Co EDTA dissolved in 200 ml water (Uden et al., 1980) and 500 gm Yb-labled whole shelled corn (Teeter et al., 1984; Sindt et al., 1993). Labeled corn, infused as a particulate phase marker, replaced 500 g of the treatment diet. Random grab samples of whole ruminal contents were collected at 0, 4, 8, 12, 16, 20, and 24 h after feeding (0800). Ruminal contents were strained through four layers of cheesecloth into a 250 ml beaker; pH was measured immediately using a combination electrode (Hanna Instruments, Ann Arbor, MI). Two 25 ml sub-samples of rumen fluid were collected. One 25 ml aliquot of ruminal fluid was acidified with 0.5 ml 6N HCl and frozen (-20°C) for subsequent VFA and ammonia analysis. A second 25 ml aliquot was also frozen (-20°C) for Co analysis. Ruminal particulate samples were dried in a forced air oven (50°C, 96 h) and ground to pass a 2mm screen (No. 4 Wiley mill, Thomas Scientific, Swedesboro, NJ).

Laboratory Analysis. Ground composite samples of feed and feces were analyzed for DM P, and N using standard techniques (AOAC, 2003). Gross energy content of feed, feces, and urine was determined by oxygen bomb calorimetry (Parr Instrument Co., Moline, IL). Gaseous energy loss was estimated according to Blaxter and Clapperton (1965). Acidified ruminal fluid samples were thawed and centrifuged at 20,000 x g for 20 min. The supernatant was decanted for VFA and ammonia analysis. Measurement of ruminal VFA was ascertained via gas chromatography (Varian 3400, Varian Corp., Walnut Creek, CA; Grigsby et al., 1992). Ruminal ammonia concentration was measured using a colorimetric procedure (Broderick and Kang, 1980).

Cobalt and Yb content of ruminal fluid and ruminal particulate matter, respectively, were measured using atomic absorption spectrophotometry (Varian SpectrAA 30, Mulgrove, Victoria, Australia; Hart and Polan, 1984). Ruminal particulate and liquid passage rates were calculated by regressing the natural logarithm of Yb and Co concentration, respectively, on time. Slopes of ln Yb vs. time were positive for IR80 cattle. In contrast, slopes of ln Yb vs. time were negative for AL cattle and appeared to be typical of cattle fed high-concentrate diets (2 – 4 %/h). These data were interpreted to indicate that ruminal Yb concentration of IR80 cattle increased over time. Particulate passage data were not analyzed statistically. Authors concluded that the technique used to estimate particulate passage might not have been appropriate for cattle limited to 80% of ad libitum intake.

Statistical Analysis. Intake, digestion, nutrient retention, fluid dilution, and energy partitioning data generated during trial 1 and trial 2 were analyzed using procedures appropriate for a completely random design. A general linear model was used to analyze effects of intake level (SAS Inst. Inc., Cary, NC). Ruminal pH, ruminal ammonia, and ruminal VFA measurements were analyzed as a completely random design split-plot in time (Gill and Hafs, 1971; Littell et al., 1998). A mixed model was used to analyze effects of steer, intake level, and time (SAS Inst. Inc., Cary, NC). Intake level x time was used as the error term to test whole plot effects. When F-tests were significant ($P < 0.05$), means were separated using the method of least significant difference.

Results and Discussion

Actual average DMI were 2.55% of BW by AL, 2.38% of BW by IR90 (93% of AL), and 2.02% of BW by IR80 (79% of AL) during trial 1. During trial 2, actual average DMI were 1.94% of BW by AL and 1.61% of BW by IR80 (83% of AL). Similar intakes of NE_m, NE_g, and MP were maintained throughout both trials for all treatment groups. Cattle assigned to the IR80 treatment consumed their daily allotment of feed within 4 h of delivery during both trials, whereas feed intake by AL cattle was complete 23 h after delivery. In trial 1, IR90 cattle consumed their daily allotment of feed within 12 h of delivery.

Diet digestion and energy balance data from Trials 1 and 2 are reported in Tables 2.3 and 2.4, respectively. During both trials, fecal output (FO) by IR80 steers was lesser ($P \leq 0.02$) than AL steers. Conversely, FO by IR90 steers was similar ($P > 0.10$) to AL steers and greater ($P \leq 0.01$) than IR80 steers during Trial 1. Over both trials, FO by IR80 cattle was reduced 39 ± 4.7% relative to AL cattle ([DMI – FO] / DMI). The sharp reduction in fecal output by IR80 cattle was accompanied by an increase ($P \leq 0.01$) in DMD compared with AL cattle in trials 1 and 2; DMD by IR90 cattle was similar ($P > 0.10$) to that of AL cattle in trail 1. Galyean et al., (1979) reported similar changes in DMD when high-concentrate diets were fed below ad libitum DMI.

Fluid urinary output was similar ($P = 0.16$) between treatments during trial 1; however, IR80 cattle had greater ($P = 0.04$) fluid urinary output than AL cattle during trial 2. Cattle on the IR80 treatment may have compensated for temporally limited access to feed by increasing water consumption. Water intake was not measured during either trial; however, authors noted that IR80 cattle appeared to spend more time drinking than cattle assigned to other treatments.

Fecal, urinary, and gaseous energy loss were similar (*P* > 0.10) between AL and IR90 steers in trial 1, whereas IR80 steers had lesser ($P \leq 0.01$) fecal and gaseous energy loss and tended to have greater (*P* = 0.10) urinary energy loss than that of AL and IR90. In trial 2, fecal energy loss was similar (*P* = 0.16) between treatments. Urinary energy loss was lesser (*P* = 0.04) by AL compared to IR80; moreover, gaseous energy loss tended (*P* = 0.08) to be greater by AL compared to IR80.

The effect of programmed DMI restriction on performance of finishing cattle has been studied extensively. Relative to cattle fed ad libitum, cattle held to less than maximal DMI had improved diet digestion (Galyean, 1979), improved feed efficiency (Sainz et al., 1995; Rossi et al., 2001), reduced feed costs (Knoblich et, al., 1997; Loerch and Fluharty, 1998), and reduced ADG (Plegge, 1987; Hicks et al., 1990; Murphy and Loerch, 1994; Rossi et al, 2001). The aforementioned studies used a single diet to compare ad libitum DMI with DMI restricted to 80-96% of ad libitum DMI. In each case, total energy intake decreased as DMI decreased. Presumably, diet composition was held constant across treatments in these studies to avoid perceived confounding with intake level; however, unequal energy intakes made it difficult to interpret the effects of DMI restriction per se on growth performance.

Schmidt et al. (2005), using an approach similar to that described in our experiments, held NE and MP intakes constant across successively lesser DMI levels by altering diet composition. They reported that G:F and ADG by finishing cattle increased when DMI was restricted to 80% of *ad libitum*. A conceptual drawback to their experimental approach was its reliance on conventions of the California Net Energy System (CNES) to estimate the energetic values of feeds.

Predictive equations used to estimate NE content of feedstuffs within the CNES were based on energy retention at *ad libitum* intake (Lofgreen and Garrett, 1968; Garrett, 1980; NRC, 2000). Schmidt et al. (2005) made the assumption that the energy yield of individual feedstuffs was the same when fed at *ad libitum* DMI, 90% of ad libitum DMI, or 80% of *ad libitum* DMI. We also made that assumption in the present studies despite the fact that level of intake is one of the primary causes of variation in apparent digestibility of a given diet (Brown, 1966). As DMI decreases, digestibility generally increases (Moe et al., 1965; Colucci et al., 1982; Edionwe and Owen, 1989); however, it is unclear if changes in apparent digestibility are accompanied by changes in ME intake or efficiency of ME use by the animal.

Metabolizable energy (ME) density of treatment diets was similar ($P >$ 0.10) between AL and IR90 during trial 1. During trial 1 and 2, ME density of IR80 diets was greater ($P < 0.01$) than that of AL. This was the expected result of intentionally restricting DMI without reducing energy intake relative to ad libitum feeding. Conversely, ME intake was similar ($P \geq 0.20$) between treatments in both trials 1 and 2. This observation led us to conclude that, under the conditions of our studies and those described by Schmidt et al. (2005), the methodology used by the CNES to estimate ME and NE values of feedstuffs is valid at DMI between 80 and 100% of *ad libitum*. Our diets were formulated to supply similar ME intakes at 80, 90, and 100% of ad libitum DMI.

Schmidt et al. (2005) held ME and MP intakes constant while varying DMI between 80 and 100% of *ad libitum*. They reported that cattle restricted to 80% of *ad libitum* DMI had greater ADG, greater G:F, and similar carcass characteristics compared with cattle fed ad libitum. Schmidt et al. (2005) proposed that the primary basis for improved growth performance by the DMI-restricted cattle was increased diet digestibility. Reduced rates of digesta passage rates and longer digesta residence times in the gut are characteristic of both low relative DMI and high relative diet digestibility (Moe et al., 1965, and Colucci et al., 1982; however, fluid dilution rate was similar ($P = 0.42$) between AL and IR80 steers in trial 2 (Table 2.4).

Even though diet digestion by IR80 cattle was improved in our studies compared with AL cattle, ME intake was similar ($P \geq 0.20$) between treatments. We concluded from this information that the basis for improved performance by DMI-restricted cattle, as reported by Schmidt et al. (2005), must lie beyond the point of ME within the classical energy partitioning scheme (Maynard et al., 1979). Our data were interpreted to indicate that, for a given rate of gain, cattle managed for a low relative DMI may have a lesser heat increment (HI) than cattle managed for a high relative DMI.

Energy balance of intake-restricted cattle has not been extensively studied. As DMI increases above maintenance requirements, the effective ME concentration of feeds decreases (Moe, et al. 1965). The converse of this phenomenon may occur during programmed intake restriction (Plegge, 1987) but does not explain why cattle that are fed the same total amount of energy and protein do not perform equally when only the amount of DMI is varied.

The weight of visceral organs and their contribution to the maintenance energy requirement increases as DMI increases (Ferrell, et al, 1976). Sainz and Bentley (1997) reported that steers limited to 70% of *ad libitum* DMI had smaller livers than steers fed ad libitum; moreover, their visceral mass contained less protein and RNA. The numbers of liver cells per kg of BW were the same for limit-fed steers and steers fed *ad libitum*; however, cell size was smaller in limit-fed cattle. Johnson et al. (1990) estimated that portal drained viscera (PDV) accounted for 24% of total energy expenditure by sheep. The liver accounted for 20 to 26% of energy use by the PDV. If visceral organ mass reduction is characteristic of DMI restriction, it is reasonable to expect that maintenance energy requirements may be smaller in limit-fed animals compared with animals fed *ad libitum*. Improved ADG and G:F by cattle limited to 80% of ad libitum DMI, as reported by Schmidt et al. (2005), may have resulted partially from a lesser maintenance requirement.

Nutrient retention by intake-restricted beef cattle has not been widely studied. Effects of DMI restriction on phosphorus retention by feedlot steers in our study are reported in Table 2.5. Intake of P during trial 1 was similar $P \geq 0.47$) between treatments; moreover, retention characteristics were not changed by intake restriction. Fecal P, urinary P, and retained P, expressed as a percent of P intake, were not different ($P \geq 0.15$) when DMI was held to 80, 90, or 100%

of ad libitum DMI. Based on this information, we concluded that strategies used to influence P retention by conventionally-fed beef cattle would likely be effective in limit-fed beef cattle as well.

There were no treatment x time interactions ($P > 0.21$) observed for total ruminal VFA concentration or molar proportions of individual VFA. Therefore, main effect means were reported (Table 2.6). Steers assigned to the AL treatment had greater ($P<0.01$) total ruminal VFA concentration than IR80 steers. The temporal pattern of total ruminal VFA concentration (data not shown) indicated that VFA concentrations were similar ($P > 0.41$) between treatments at 0.25, 4, and 8 h after feeding. Conversely, total ruminal VFA concentration of IR80 steers was lesser ($P < 0.05$) than that of AL steers at 12, 16, 20, and 24 h after feeding. Authors presume that this effect was related to the fact that IR steers consumed their feed within 4 h of delivery, whereas AL steers consumed their daily allotment of feed over a 23 h period. The rate of ruminal fermentation by IR80 steers may have slowed 8 to 12 h post-feeding without continued input of feed.

The average ruminal molar proportion of acetate was greater ($P = 0.03$) in AL cattle than in IR80 cattle (Table 2.6). Conversely, IR80 cattle had a greater ($P = 0.03$) average molar proportion of propionate than did AL cattle. The molar proportions of butyrate and total minor VFA were similar ($P > 0.31$) between treatments. Differences in the proportions of fermentation end products was reflective of dietary ingredient composition; however, this fact had no impact on total ME intake (Table 2.4).

Treatment x time interactions were detected for ruminal pH and for ruminal ammonia concentration (Figures 2.1 and 2.2, respectively). Ruminal pH was similar (*P*> 0.10) between treatments at 0.25, 8, 12, 16, 20, and 24 h post-feeding; however, IR80 cattle had lesser (*P* < 0.01) ruminal pH 4 h post feeding than did AL cattle. Our data were interpreted to indicate that the nadir in ruminal pH of IR80 cattle occurred sooner after feeding compared with AL cattle (4 vs. 8 h) and that the nadir in ruminal pH was lower (*P* < 0.02) for IR80 than for AL cattle.

Murphy et al. (1994) reported that ruminal pH of steers limit-fed high-concentrate diets was not different than that of steers fed high-concentrate diets *ad libitum*. Moreover, Soto-Navarro et al. (2000) indicated that restricting DMI of a high-concentrate diet did not negatively affect ruminal health or digestion of OM, N, or starch. Under the conditions of our studies, limit-fed finishing steers were without feed for 12-20 h without causing clinical digestive upset. Schmidt et al. (2005) reported similar results. Feeding programs that promote rapid consumption of a limit-fed diet may have important ramifications for bunk management. Compared with feeding management systems that are designed to reach and maintain maximum DMI, those that impose a predetermined intake level based on body size and desired performance may be accompanied by more stable intake patterns and a reduced need for bunk management expertise.

Conclusions

Steers limited to 80% of *ad libitum* DMI but not restricted in terms of NE or MP intakes had sharply reduced fecal output and greater diet digestibility compared with steers fed *ad libitum*. Urinary output appeared to be greater by cattle restricted to 80% of ad libitum DMI; however, this condition did not affect retention of dietary phosphorus. In general, fecal energy loss was lesser and urinary energy loss greater by cattle limited to 80% of ad libitum DMI compared with cattle fed ad libitum. There were also temporal changes in ruminal fermentation and in the proportions of end products of ruminal fermentation between treatments. In spite of changes such as these, ME intake was similar among cattle fed 80, 90, or 100% of ad libitum DMI.

We conclude from these data that, at a given ME intake, a 20% reduction in DMI can reduce DM manure output by as much as 39%. Moreover, DMI-restriction was associated with a sustainable ruminal fermentation pattern under the conditions of this study, in spite of the fact that steers limited to 80% of ad libitum DMI were without feed for ≥ 20 h per day. Improvements in ADG and G:F by DMI-restricted finishing cattle do not appear to be related to changes in diet digestion or ME intake. Further research is warranted to determine if the heat increment of limit-fed cattle is lesser than that of cattle fed ad libitum for a given ADG.

CHAPTER THREE

Effects of an Injectable Trace Mineral Supplement Administered at Receiving on Growth Performance, Respiratory Disease, and Carcass Characteristics of Feedlot Steers

Introduction

Bovine respiratory disease (BRD) negatively affects the profitability of cattle feeding in North America. The cost of BRD includes death loss, expenses associated with BRD treatment, and reduced growth performance (Perino, 1992). Respiratory disease also decreased carcass weights, fat deposition, and ribeye area in feedlot cattle (Gardner et al., 1999). Preconditioning steers prior to feedlot placement and supranutritional trace mineral supplementation reduced the incidence and severity of BRD in feedlot steers (Cole, 1985; Pritchard and Mendez, 1990; Galyean, 1999). Cole (1985) described preconditioning as a comprehensive management system designed to immunize calves against some of the major pathogens involved in the bovine respiratory disease complex and to reduce the stressors encountered by feeder calves at marketing. Preconditioned feeder cattle have reduced morbidity, reduced mortality, and increased feedlot performance compared with cattle that have not been preconditioned (Cole, 1985). Mineral deficiencies can decrease the immune response of an animal and therefore increase susceptibility to disease (Suttle and Jones, 1989). Stressed cattle do not have greater trace mineral requirements than unstressed cattle; however, the concentration of trace minerals in receiving rations for stressed cattle are typically increased in order to compensate for reduced feed consumption (Galyean et al., 1999). Supplementing receiving cattle with trace minerals has produced a variety of responses with respect to incidence of BRD and performance. Salyer et al. (2004) reported no differences in performance or morbidity by receiving cattle supplemented with copper and zinc of both organic and inorganic sources. Engle et al. (1995) reported decreased ADG and G:F in feedlot cattle that were fed a zinc deficient diet; however, there was no difference in performance after a 22 d period of feeding a diet adequate in zinc. Galyean et al. (1995) reported that supranutritional copper supplementation tended to decrease morbidity by receiving cattle; however, it was also associated with a decrease in subsequent feedlot performance. The effect of bolus dose trace mineral supplementation on the incidence of BRD, feedlot performance, and carcass traits in both preconditioned and non-preconditioned feedlot cattle has not been widely studied. Our objective was to evaluate the effects of a single bolus dose of Cu, Se, Mn, and Zn on receiving and finishing performance of steers at either high or low risk for respiratory disease.

Materials & Methods

Crossbred beef steers (n = 189; initial BW = 266 ± 27 kg) were used to determine the effect of a single injection of a trace mineral solution (75 mg copper carbonate, 25 mg sodium selenium, 50 mg manganese sulfate, and 200 mg zinc oxide; Multimin™ USA, Inc. Porterville, CA) on average daily gain, incidence of respiratory disease, and respiratory disease treatment costs during a 28 d receiving period and during a subsequent finishing study. The Animal Care and Use Committee of the University of Missouri approved all experimental procedures used in our study (University of Missouri ACUC Protocol #3711). Treatments were applied in a 2 x 2 factorial arrangement of a completely random design. Ninety of the steers were considered to be at low risk (LO) for respiratory disease and 99 of the steers were considered to be at high risk (HI) for respiratory disease. Steers designated LO originated from the University of Missouri beef herd. They were previously vaccinated twice for clostridial diseases (Vision® 7 with SPUR®, Intervet Inc. Millsboro, DE), IBR, BVD (Type 1 and Type 2), PI3, and BRSV (Bovi-Shield® GOLD 5 Pfizer Animal Health Exton, PA). Steers designated LO were treated for internal and external parasites and weaned on their farm of origin for approximately 45 d before the study commenced. Steers designated as HI were procured through local auction markets and had no known history of vaccination, pre-shipment weaning, parasite control, or commingling with other cattle. Both LO and HI steers were castrated, dehorned, and fully healed at the beginning of the study. Approximately half of the cattle from each of the LO and HI groups were randomly assigned to receive a 5 ml injection of trace mineral solution administered s.c. in the neck at arrival, while remaining steers received a 5 ml s.c. injection of saline (0.9% Sodium Chloride Injection USP, Blaxter Healthcare Corporation Deerfield, IL). Steers designated LO or HI were assigned randomly to bolus injection treatment and pen as they were processed upon arrival to the feedlot. All steers in each pen shared a common treatment and risk level.

At arrival, all steers were weighed and given an ear tag for identification. Steers designated HI were vaccinated for IBR, BVD, PI3, BRSV (Bovi-Shield®

GOLD 5 Pfizer Animal Health Exton, PA), and clostridial diseases (Vision® 7 with SPUR®, Intervet Inc. Millsboro, DE); they were also treated for internal and external parasites (AgriMectin® AgriLabs® St. Joseph, MO). All steers were fed a common receiving ration (81.0% DM, 2.44 Mcal NE_m/kg, 1.50 Mcal NE_g/kg; Table 3.1).

Within their assigned pens, steers were observed for clinical symptoms of respiratory disease at 0800 and 1600 daily. Steers that exhibited clinical symptoms of respiratory disease (nasal discharge, ocular discharge, coughing, depression, or anorexia) were removed from pens at approximately 0900 and 1700 daily and walked a maximum of 100 meters to a restraining chute. Suspect steers were weighed and their rectal temperatures were measured. Steers presenting with a rectal temperature ≥ 40℃ (n = 59) were treated with tilmicosin (Micotil^{TM} Elanco® Animal Health Indianapolis, IN; 1.0 ml / 30.3 kg BW s.c.) and subsequently transported to a pen reserved for clinically ill cattle. All treated steers were re-evaluated for body weight and rectal temperature 72 h after initial treatment. Steers whose rectal temperature had returned to < 40℃ were returned to their assigned pens. Steers treated once for an undifferentiated fever that presented a second time with rectal temperatures ≥ 40° C (n = 17) were treated with enrofloxacin (Baytril^{TM} Bayer Health Care LLC, Shawnee Mission, KS; 1.0 ml / 9.1 kg BW s.c.) and returned to the pen reserved for clinically ill cattle. All steers treated twice were evaluated for body weight and rectal temperature 72 h after their second treatment. Steers that had a rectal temperature ≥ 40° C (n = 2) for a third time were retreated using tilmicosin (1.0 ml

/ 30.3 kg BW s.c.). For the purposes of this study, Micotil™ and Baytril™ were valued at $1.77/ml and $1.07/ml, respectively. All steers were weighed at the beginning and end of the 28 d receiving period following a 12 h fast.

Immediately following the 28 d receiving period, steers were adapted to a common finishing ration (84.3% DM, 2.23 Mcal NEm/kg, 1.54 NEg/kg; Table 3.1) that was fed ad libitum at 0800 daily. All steers were implanted on d 1 of the finishing period with Revlor IS® (Intervet, Millsboro, DE); additionally, all HI steers received a second vaccination for IBR, BVD, PI3, BRSV (Bovi-Shield® GOLD 5 Pfizer Animal Health Exton, PA), and clostridial diseases (Vision® 7 with SPUR®, Intervet Inc. Millsboro, DE). All steers were re-implanted using Revlor-S® (Intervet, Millsboro, DE) 56 d after the initial implant. Steers were weighed every 28 d, following a 12 h fast, throughout the finishing period. Because of variation in steer maturity, they were harvested in two groups 28 d apart (average days on feed = 196). Each harvest group had an approximate average pre-harvest BW of 570 kg. The harvest procedure was carried out at a commercial abattoir under USDA supervision, and in compliance with the Humane Slaughter Act of 1978.

Animal identification, hot carcass weight (HCW), liver abscess score, and lung lesion scores were recorded during the harvest process. Livers and lungs were evaluated by trained observers using the methods of Brink et al. (1990) and Bryant et al. (1999), for livers and lungs respectively. Following a 24 h chill (2°C), carcasses were cut between the 12th and 13th ribs and allowed approximately 15 minutes to bloom. Trained evaluators, blinded to treatment, assigned marbling scores and yield grades according to USDA (1997) standards.

Performance data were analyzed as a completely random design, split-plot in time (Gill and Hafs, 1971; Littell et al., 1998). Pen was used as the experimental unit for all performance data. A linear model was used to analyze the effects of bolus injection, respiratory disease risk, and bolus injection x respiratory disease risk. The sub-plot contained effects of weigh period and all appropriate interactions. Pen within bolus injection and respiratory disease risk was used as the error term to test whole plot effects. Carcass characteristics were analyzed as a completely random design, using individual carcass as the experimental unit. A general linear model was used to analyze effects of bolus injection on carcass characteristics. When F-tests were significant ($P < 0.05$), treatment means were separated using the method of least significant difference. Incidence of undifferentiated fever, liver abscesses, and lung lesions by respiratory disease risk and bolus injection were compared using Chi-square analysis (Zar, 1999). Treatment means for cost of drug therapy were separated by respiratory disease risk level and treatment using a simple t-test. A simple t-test was also used to evaluate the effects of treatment frequency for respiratory disease on carcass characteristics of steers that were at high risk for respiratory disease.

Results and Discussion

The bolus injection x respiratory disease risk x weigh period interaction was not significant ($P \geq 0.43$); moreover, bolus injection x respiratory disease risk was also not significant ($P \geq 0.23$). Therefore, main effects of bolus injection type and respiratory disease risk on steer performance during receiving and finishing were reported (Table 3.2). Risk level for respiratory disease had no effect ($P = 0.78$) on growth performance during the 28 d receiving period (Table 3.2). Steers that received a bolus injection of trace minerals at feedlot arrival, regardless of risk level, gained 0.22 kg per day less ($P = 0.02$) than steers that received the placebo injection during the receiving period (Table 3.2). The reason for this performance decrease was unclear; however, there may have been a negative short-term effect on growth performance associated with the supplemental zinc, manganese, selenium, or copper delivered by the bolus injection of trace minerals. Galyean (1995) found that steers supplemented with copper tended to gain less than steers that were not supplemented with copper during a 28 d receiving period. Similarly, Arthington et al. (1995) reported that the calves of cows supplemented with copper oxide boluses had lower weaning weights than calves of non-supplemented cows (Arthington, 1995). These results contrast with those of Berry et al. (2000) who observed that a trace mineral bolus injection similar to the one used in our study had no effect on daily gain during a 28 d receiving period.

Steers at high risk for respiratory disease had greater ($P < 0.01$) incidence of undifferentiated fever than LO steers (Table 3.3). Furthermore, the cost associated with antibiotic treatment for respiratory disease was greater ($P = 0.01$) for HI steers than LO steers (Table 3.4). Cole (1985) reported that preconditioned steers experienced lower morbidity than non-preconditioned steers. Incidence of undifferentiated fever and treatment costs were similar (*P* = 0.86) between cattle treated with a trace mineral bolus injection and those treated with an injection of saline.

Dry matter intake and ADG by LO steers were greater (*P* < 0.01) than that of HI steers during the finishing period. Whereas a bolus injection of trace minerals administered at receiving had no effect (*P* ≥ 0.40) on DMI and ADG during the finishing period. Steers at high risk for respiratory disease tended (*P* = 0.09) to have greater G:F during finishing compared to the LO steers. Moreover, a bolus trace mineral injection administered at receiving was associated with increased G:F (*P* < 0.04) during finishing compared with a saline injection administered at receiving. The reason this association was not clear. Ahola et al. (2005) reported that supplementation of copper, zinc, and manganese available to cows and calves, prior to weaning, produced mixed results on subsequent calf feedlot growth efficiency during a two-year study. In the first year of the study, G:F of cattle that received trace mineral supplementation was lower than unsupplemented cattle; supplemented and unsupplemented cattle had similar G:F during the second year. Spears and Kegley (2002) reported that G:F tended to be greater for cattle that were supplemented with organic zinc than those supplemented with inorganic zinc.

Respiratory disease risk was a function of the origin of the cattle used in this study. All HI cattle were purchased through local auctions markets. They had no known history of vaccination, dry feed consumption, weaning management, or commingling prior to their purchase. Cattle designated as LO originated from the

University of Missouri beef herd. These cattle were selected for superior carcass quality over several generations, whereas HI cattle had no known selection history. Confounding of respiratory disease risk with cattle origin made legitimate comparison of carcass data between HI and LO impossible. For this reason, only bolus injection type main effect means for carcass characteristics were reported (Table 3.5). There was no difference in hot carcass weight ($P = 0.67$), KPH ($P = 0.34$), marbling score ($P = 0.60$), 12th rib fat thickness ($P = 0.99$), longissimus area ($P = 0.81$), or USDA yield grade ($P = 0.69$) between the TM and SA treatments. Ahola et al (2005) reported no differences in carcass characteristics of finishing cattle that were supplemented with copper, zinc, and manganese prior to weaning and those that had not been supplemented prior to weaning. Steers at low risk for respiratory disease had fewer ($P = 0.01$) liver abscesses than HI steers; however, liver scores were similar ($P = 0.23$) between the TM or SA treatments (Table 3.6). There were no differences ($P = 0.23$) in the frequency of lung lesions between steers at HI and LO risk or between TM and SA ($P = 0.96$; Table 7). Similar to reports by Gardner et al. (1999), there appeared to be no relationship in our study between frequency of treatment for undifferentiated fever and frequency of lung lesions. Larson (2005) indicated that the poor relationship between observed clinical illness during finishing and the detection of lung lesions at harvest could have at least two explanations. First, lung lesions could result from respiratory that infection occurred prior to the finishing period. Second, it is possible that respiratory infection may not result in lung lesions.

Steers at high risk for respiratory disease that received a bolus injection of trace minerals at receiving and were also treated for BRD at least once, tended to have a larger longissimus area ($P = 0.13$) and lower USDA yield grade ($P = 0.10$) than HI steers treated with a placebo at receiving (Table 3.8). Gardner et al. (1999) reported that carcasses of cattle treated at least once for respiratory disease had smaller longissimus area and less external and internal body fat deposition than their healthy counterparts.

Conclusions

Results of our study were interpreted to suggest that the incidence of clinical respiratory disease symptoms is more prevalent in non-preconditioned steers than in preconditioned steers. An injectable trace mineral supplement administered at receiving had no effect on the incidence of undifferentiated fever; moreover, it was associated with a decrease in growth performance during the receiving period. The bolus trace mineral injection administered at receiving tended to increase longissimus area and decrease USDA yield grade in steers at high risk for respiratory disease that had been treated at least once for undifferentiated fever. Moreover, an improvement in G:F during finishing was observed in steers injected with a bolus dose of a trace mineral solution at receiving compared to those injected with saline at receiving.

APPENDIX ONE

TABLES OF THE DATA

Table 2.1. Composition (DM Basis) of diets formulated to promote a 1.6 kg ADG by beef steers consuming 100 (AL), 90 (IR90), or 80% (IR80) of ad libitum DMI (Trial 1).

	Treatment		
Item	AL	IR90	IR80
Whole-shelled corn	25.79	32.09	-
Steam-flaked corn	-	-	46.03
Wheat middlings	16.63	20.36	5.12
Dried distiller's grains	-	7.16	18.22
Grass hay	22.75	19.16	9.55
Soybean meal	-	3.89	2.63
Soybean hulls	33.49	11.01	10.19
Choice white grease	-	4.11	5.58
Supplement[a]	1.34	2.22	2.28
NEm (Mcal/kg)[b]	2.05	2.24	2.49
NEg (Mcal/kg)[b]	1.19	1.34	1.52
MP Intake (g/d)[b]	1,160	1,159	1,159
RDP Intake (g/d)[b]	607	604	608

[a] Met or exceeded NRC (2000) recommended levels of salt, trace minerals, and vitamin A. Monensin and Tylosin (Elanco Animal Health, Greenfield, IN) were included at 33 and 11 mg/kg of complete ration, respectively. Proportions of urea and soybean meal were varied to equalize metabolizable protein intakes between treatments.

[b] Calculated (NRC, 2000).

Table 2.2. Composition (DM Basis) of diets formulated to promote a 1.6 kg ADG by beef steers consuming 100 (AL) or 80% (IR80) of ad libitum DMI (Trial 2).

	Treatment	
Item	AL	IR80
Whole Shelled Corn	30.75	-
Flaked Corn	-	33.39
Wheat Middlings	14.00	4.03
Dried Distiller's Grains	-	17.69
Grass Hay	17.73	8.85
Soybean Hulls	34.40	27.11
Choice White Grease	-	4.86
Supplement[a]	3.20	4.07
NEm (Mcal/d)[b]	18.6	17.5
NEg (Mcal/d)[b]	10.7	10.8
MP Intake (g/d)[b]	1128	1133
RDP Intake (g/d)[b]	1015	1015

[a] Met or exceeded NRC (2000) recommended levels of salt, trace minerals, and vitamin A. Monensin and Tylosin (Elanco Animal Health, Greenfield, IN) were included at 33 and 11 mg/kg of complete ration, respectively. Proportions of urea and soybean meal were varied to equalize metabolizable protein intakes between treatments.

[b] Calculated (NRC, 2000).

Table 2.3. Effect of diets formulated to promote a 1.6 kg ADG when consumed at 100 (AL), 90 (IR90), or 80% (IR80) of ad libitum DMI on diet digestion and energy balance of beef steers (Trial 1).

	Treatment				
Effect	AL	IR90	IR80	SE	*P*
DMI (kg/d)	9.95^{a}	8.73^{b}	7.91^{c}	0.21	<0.01
Fecal DM Output (kg/d)	2.80^{a}	2.66^{a}	1.80^{b}	0.15	<0.01
DMD (%)	70.3^{a}	68.8^{a}	78.1^{b}	1.52	<0.01
Fluid Urinary Output (kg/d)	14.96	17.26	36.78	9.025	>0.15
Gross Energy Intake (Mcal/d)	43.1^{a}	40.1^{b}	37.8^{c}	0.99	<0.01
Fecal Energy Loss (Mcal/d)	12.8^{a}	12.6^{a}	8.3^{b}	0.69	<0.01
Urinary Energy Loss (Mcal/d)	4.7^{d}	5.5^{d}	7.8^{e}	1.22	>0.10
Gaseous Energy Loss (Mcal/d)[f]	2.1^{a}	2.1^{a}	1.8^{b}	0.08	<0.02
ME Density (Mcal/kg)	2.48^{a}	2.51^{a}	3.26^{b}	0.057	<0.01
ME Intake (Mcal/d)	23.5	20.0	20.0	1.79	>0.20

[a, b, c] Means within a row that have dissimilar subscripts are different ($P \leq 0.05$).

[e, f] Means within a row that have dissimilar subscripts tend to be different ($P \leq 0.10$).

[e] Gaseous energy loss was calculated (Blaxter & Clapperton, 1965).

Table 2.4. Effect of diets formulated to promote a 1.6 kg ADG when consumed at 100 (AL) or 80% (IR80) of ad libitum DMI on diet digestion, fluid dilution rate, and energy balance of beef steers (Trial 2).

	Treatment			
Effect	AL	IR80	SE	*P*
DMI (kg/d)	9.13[a]	6.91[b]	0.632	0.03
Fecal DM Output (kg/d)	2.81[a]	1.62[b]	0.287	0.02
DMD (%)	69.9[a]	76.8[b]	1.59	0.01
Fluid Urinary Output (kg/d)	15.70[a]	41.10[b]	7.557	0.04
Fluid Dilution Rate (%/h)	7.67	6.84	0.691	0.42
Gross Energy Intake (Mcal/d)	33.4	29.4	2.40	0.26
Fecal Energy Loss (Mcal/d)	10.1	7.6	1.14	0.15
Urinary Energy Loss (Mcal/d)	4.6[a]	10.1[b]	1.66	0.04
Gaseous Energy Loss (Mcal/d)[c]	2.1[d]	1.7[e]	0.12	0.08
ME Density (Mcal/kg)	2.03[a]	2.65[b]	0.081	<0.01
ME Intake (Mcal/d)	18.3	18.3	1.19	0.99

[a, b] Means within a row that have dissimilar subscripts are different ($P \leq 0.05$).

[c] Gaseous energy loss was calculated (Blaxter & Clapperton, 1965).

[d, e] Means within a row that have dissimilar subscripts tend to be different ($P \leq 0.10$)

Table 2.5. Effect of diets formulated to promote a 1.6 kg ADG when consumed at 100 (AL), 90 (IR90), or 80% (IR80) of ad libitum DMI on phosphorus retention by beef steers (Trial 1).

	Treatment				
Item	AL	IR90	IR80	SE	*P*
P Intake (g/d)	58.63	58.87	55.98	2.764	≥ 0.47
Fecal P (% of P Intake)	55.12	52.00	47.38	4.874	≥ 0.29
Urinary P (% of P Intake)	6.31	10.33	10.33	1.804	≥ 0.15
Retained P (g/d)	20.28	17.95	19.28	2.849	≥ 0.57
Retained P (% of P Intake)	34.20	30.23	34.03	3.654	≥ 0.46

$^{a, b}$ Means within a row that have dissimilar subscripts are different ($P \leq 0.05$).

$^{c, d}$ Means within a row that have dissimilar subscripts tend to be different ($P \leq 0.10$).

Table 2.6. Effect of diets formulated to promote a 1.6 kg ADG when consumed at 100 (AL) or 80% (IR80) of ad libitum DMI on ruminal fermentation by beef steers (Trial 2).

	Treatment			
Item	AL	IR80	SE	*P*
Total VFA (mM)	106.92^{a}	85.82^{b}	3.827	< 0.01
Acetate (% of Total)	61.11^{a}	57.75^{b}	1.040	0.03
Propionate (% of Total)	23.93^{a}	27.21^{b}	1.055	0.03
Butyrate (% of Total)	10.33	9.81	0.363	0.31
Minor VFA (% of Total)	4.64	4.85	0.192	0.42

$^{a, b}$ Means within a row that have dissimilar subscripts are different ($P \leq 0.05$).

Table 3.1. Composition (DM%) of receiving and finishing diets.

Ingredient	Receiving	Finishing
Dried Distiller's Grain	27.58	29.30
High Moisture Corn	45.96	25.64
Whole Shelled Corn	0.00	25.64
Pelleted Soybean hulls	4.92	6.41
Chopped Grass Hay	6.57	5.49
Choice White Grease	6.04	4.26
Ground Corn	3.65	2.14
Limestone	0.99	0.92
Sodium Chloride	0.20	0.11
Trace Mineral Premix	0.07	0.04
Vitamin A, D, & E Premix	0.04	0.02
Rumensin (80 mg/kg)[a]	0.03	0.02
Tylan (40 mg/kg)[a]	0.02	0.01
Soybean Meal (44%)	2.95	0.00
Urea	0.99	0.00
DM%	81.0	84.3
NEm (Mcal/kg)[b]	2.44	2.23
NEg (Mcal/kg)[b]	1.50	1.54

[a] Elanco Animal Health, Greenfield, IN

[b] Calculated value (NRC, 2000)

Table 3.2. Effects of respiratory disease risk and a bolus injection of trace minerals or saline at receiving on ADG, DMI, and growth efficiency of beef steers.

	Respiratory Disease Risk[a]		Bolus Injection[b]			*P*	
Item	High	Low	Trace Mineral	Saline	SE	Risk[c]	Injection[d]
n	89	99	89	99	-	-	-
Initial BW (kg)	266	267	266	266	27.2	0.88	0.99
Receiving ADG (kg)	0.58	0.54	0.44[y]	0.66[z]	0.688	0.62	0.02
Finishing ADG (kg)	1.72[w]	1.83[x]	1.79	1.76	0.045	<0.01	0.40
Finishing DMI (%BW)	2.33[w]	2.54[x]	2.45	2.45	0.037	<0.01	0.99
Finishing G:F	0.18	0.17	0.18[y]	0.17[z]	0.002	0.09	0.04

[a] Steers at low risk for respiratory disease were weaned on their farm of origin for 45 d following maternal separation and were vaccinated twice on their farm of origin for clostridial diseases, IBR, BVD, PI3, and BRSV. Steers at high risk for respiratory disease had no known vaccination or weaning history prior the study.

[b] Bolus injection consisted of a 5 ml s.c. injection containing 75 mg copper, 25 mg selenium, 50 mg manganese, and 200 mg zinc or a 5 ml s.c. injection of saline.

[c] P-value for respiratory disease risk comparison (high vs. low).

[d] P-value for bolus injection comparison (trace mineral vs. saline).

[w, x] Means within the same row comparing the effects of respiratory disease level that have dissimilar superscripts differ ($P \leq 0.05$).

[y, z] Means within the same row comparing the effects of bolus injection type that have dissimilar superscripts differ ($P \leq 0.05$).

Table 3.3. Effect of respiratory disease risk and a bolus injection of trace minerals or saline at receiving on incidence of undifferentiated fever among steers during a 28 d receiving period.

Factor	n	Incidence of Undifferentiated Fever	*P*
Respiratory Disease Risk[a]			
High	90	64.4%	< 0.01
Low	99	2.02%	-
Bolus Injection[b]			
Trace Mineral	90	31.1%	0.86
Saline	99	32.3%	-

[a] Steers at low risk for respiratory disease were weaned on their farm of origin for 45 d following maternal separation and were vaccinated twice on their farm of origin for clostridial diseases, IBR, BVD, PI3, and BRSV. Steers at high risk for respiratory disease had no known vaccination or weaning history prior the study.

[b] Bolus injection consisted of a 5 ml s.c. injection containing 75 mg copper, 25 mg selenium, 50 mg manganese, and 200 mg zinc or a 5 ml s.c. injection of saline.

Table 3.4. Effect of respiratory disease risk and a bolus injection of trace minerals or saline at receiving on drug therapy cost among steers during a 28 d receiving period.

Respiratory Disease Risk[a]	Bolus Injection[b]	n	Drug Therapy Cost / Steer
High	Trace Mineral	39	$14.63[y]
High	Saline	50	$16.48[y]
Low	Trace Mineral	50	$0.52[z]
Low	Saline	49	$0.00[z]

[a] Steers at low risk for respiratory disease were weaned on their farm of origin for 45 d following maternal separation and were vaccinated twice on their farm of origin for clostridial diseases, IBR, BVD, PI3, and BRSV. Steers at high risk for respiratory disease had no known vaccination or weaning history prior the study.

[b] Bolus injection consisted of a 5 ml s.c. injection containing 75 mg copper, 25 mg selenium, 50 mg manganese, and 200 mg zinc or a 5 ml s.c. injection of saline.

[y, z] Means within a column that do not share a common superscript are different ($P < 0.05$).

Table 3.5. Effect of a bolus injection[a] of trace minerals or saline at receiving on carcass characteristics of beef steers.

Item	Trace Mineral	Saline	SE	*P*
n	89	98	-	
Hot Carcass Weight (kg)	356	358	3.0	0.67
Marbling Score[b]	47	47	1.1	0.96
12th rib fat Thickness (cm)	1.39	1.42	0.052	0.65
Longissimus Area (cm^2)	78.95	78.36	0.735	0.56
KPH[c] (%)	2.14	2.18	0.035	0.34
USDA Yield Grade	3.35	3.44	0.071	0.39

[a] Bolus injection consisted of a 5 ml s.c. injection containing 75 mg copper, 25 mg selenium, 50 mg manganese, and 200 mg zinc or a 5 ml s.c. injection of saline.

[b] Marbling Scores: 30 = Slight^{00}, 40 = Small^{00}, and 50 = Modest^{00}

[c] KPH = kidney, pelvic, and heart fat

Table 3.6. Effect of respiratory disease risk and a bolus injection of trace minerals or saline at receiving on incidence of liver abscesses among beef steers.

		Liver Score[a]				
Factor	n	0	A-	A	A+	*P*
Respiratory Disease Risk[b]						
High	89	60.7%	32.6%	6.7%	0.0%	<0.01
Low	98	73.5%	15.3%	6.1%	5.1%	-
Bolus Injection[c]						
Trace Mineral	89	62.9%	23.6%	8.9%	4.5%	0.23
Saline	98	71.4%	23.5%	4.1%	1.0%	-

[a] Liver scores were assessed on the following scale: 0 = no visible lesions; A- = 1 small encapsulated abscess (< 2.54 cm. in diameter); A = 2-4 small encapsulated abscesses (< 2.54 cm. in diameter); and A+ = large enflamed abscesses (> 2.54 cm. in diameter) .

[b] Steers at low risk for respiratory disease were weaned on their farm of origin for 45 d following maternal separation and were vaccinated twice on their farm of origin for clostridial diseases, IBR, BVD, PI3, and BRSV. Steers at high risk for respiratory disease had no known vaccination or weaning history prior the study.

[c] Bolus injection consisted of a 5 ml s.c. injection containing 75 mg copper, 25 mg selenium, 50 mg manganese, and 200 mg zinc or a 5 ml s.c. injection of saline.

Table 3.7. Effects of respiratory disease risk and a bolus injection of trace minerals or saline at receiving on incidence of lung abnormalities among beef steers.

Factor	n	Incidence of Normal Lungs	Incidence of Abnormal Lungs	*P*
Respiratory Disease Risk[a]				
High	87	73.6%	26.4%	0.23
Low	95	81.1%	18.9%	-
Bolus Injection[b]				
Trace Mineral	85	77.6%	22.4%	0.96
Saline	97	77.3%	22.7%	-

[a] Steers at low risk for respiratory disease were weaned on their farm of origin for 45 d following maternal separation and were vaccinated twice on their farm of origin for clostridial diseases, IBR, BVD, PI3, and BRSV. Steers at high risk for respiratory disease had no known vaccination or weaning history prior the study.

[b] Bolus injection consisted of a 5 ml s.c. injection containing 75 mg copper, 25 mg selenium, 50 mg manganese, and 200 mg zinc or a 5 ml s.c. injection of saline.

Table 3.8. Effect of a bolus injection[a] of trace minerals or saline at receiving on carcass traits of beef steers at high risk for respiratory disease and treated at least once for undifferentiated fever.

Item	Trace Mineral	Saline	SE	*P*
Hot Carcass Weight (kg)	354.0	358.5	21.62	0.42
Marbling Score[b]	41.2	41.1	8.14	0.99
12th Rib Backfat Thickness (cm)	1.17	1.24	0.774	0.43
Longissimus Area (cm^2)	81.3	78.7	7.22	0.13
KPH[c] (%)	2.1	2.1	0.30	0.78
USDA Yield Grade	3.00	3.26	0.67	0.10

[a] Bolus injection consisted of a 5 ml s.c. injection containing 75 mg copper, 25 mg selenium, 50 mg manganese, and 200 mg zinc or a 5 ml s.c. injection of saline.

[b] Marbling Scores: 30 = Slight^{00}, 40 = Small^{00}, and 50 = Modest^{00}

[c] KPH = kidney, pelvic, and heart fat

APPENDIX TWO

FIGURES OF THE DATA

Figure 2.1. Effect of diets formulated to promote a 1.6 kg ADG when consumed at 100 (AL) or 80% (IR80) of ad libitum DMI on ruminal pH of beef steers (treatment x time – $P < 0.01$; Trial 2).

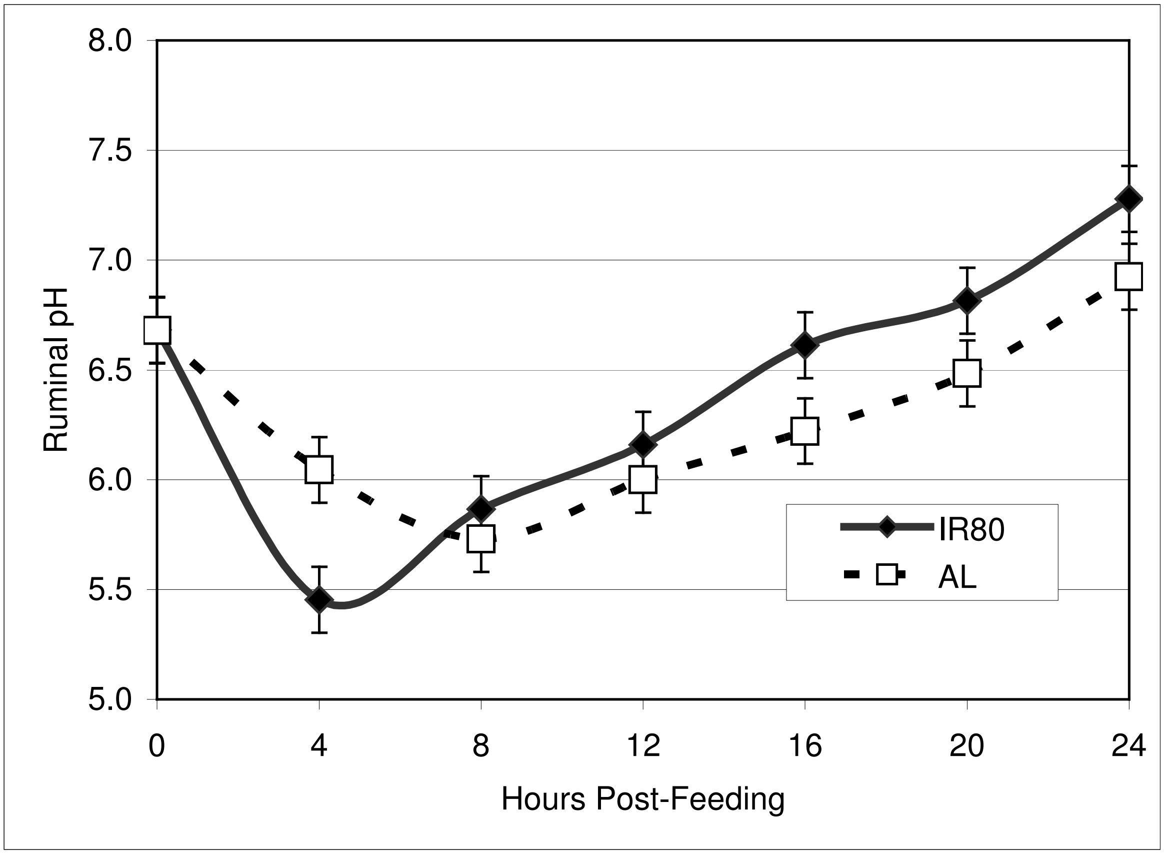
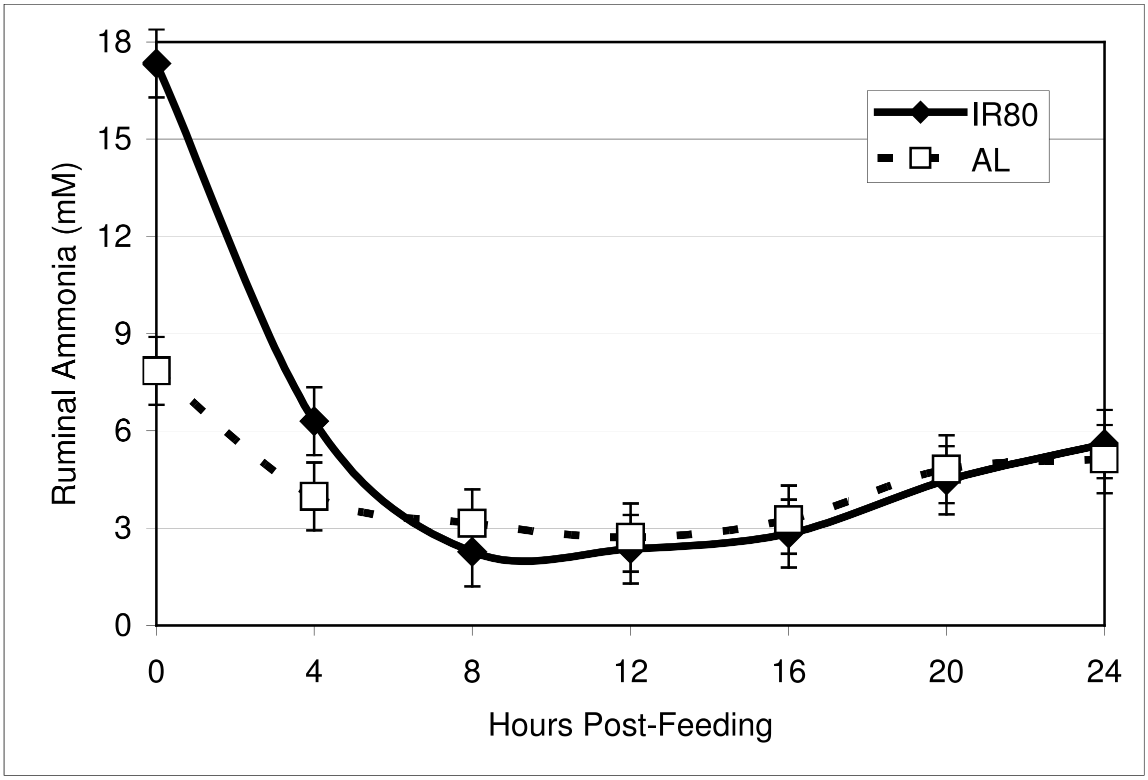


Figure 2.2. Effect of diets formulated to promote a 1.6 kg ADG when consumed at 100 (AL) or 80% (IR80) of ad libitum DMI on ruminal ammonia concentration of beef steers (treatment x time – P < 0.01;Trial 2).



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