THESIS

THE EFFECT OF CRUDE PROTEIN WITHDRAWAL AND THE USE OF OSCIALLTED CRUDE PROTEIN CONCENTRATION ON FEEDLOT PERFORMANCE, CARCASS MERIT, AND AMMONIA EMISSIONS FROM THE PEN SURFACE OF FEEDLOT STEERS

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In partial fulfillment of the requirements

For the Degree of Master of Science

Colorado State University

Fort Collins, Colorado

Spring 2011

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ABSTRACT

THE EFFECT OF CRUDE PROTEIN WITHDRAWAL AND THE USE OF OSCIALLTED CRUDE PROTEIN CONCENTRATION ON FEEDLOT PERFORMANCE, DIGESTIBILITY, CARCASS MERIT, AND AMMONIA EMISSIONS FROM THE PEN SURFACE OF YEARLING STEERS

Six hundred crossbred steers (BW, 329.7 ± 7.58 kg) were used to investigate the effect of CP withdrawal and the use of oscillating CP concentrations on feedlot performance, digestibility, carcass merit, and ammonia emissions from the pen surface of yearling steers. Steers were randomly assigned to one of the following treatments: HCP [Control, 13.5% CP, 3.5% CP equivalents (CPE)]); OCP (11.62% CP, 1.5% CPE fed Wednesday, Thursday, and Sunday and the HCP diet fed Monday, Tuesday, Friday, and Saturday); EICP (12.56% CP from d28 to slaughter, 2.53% CPE); ELCP (11.62% CP from d28 to slaughter, 1.55% CPE); LICP (HCP throughout with the ICP diet fed the last 27d); and LLCP (HCP throughout with the LCP diet fed the last 27d). Urea was used to modify dietary CP concentrations. Steers were housed in 9-steer pens (n=48) or 7-steer mass balance pens (n=24). Steers were weighed and ultrasound images and fecal grab samples were taken 3 or 4 times (depending upon replicate) throughout the trial. Feed samples, fecal grab samples, and mass balance pen surface samples were analyzed for DM, AIA, N, and P. Soil samples were obtained from the mass balance pens for treatments HCP, OCP, and ELCP and tested for total ammonia volatilization. Steers were harvested on d 149 or d

175 and camera carcass data was collected. Although initial BW differences between treatments were not significant ($P > 0.18$), initial BW was a significant ($P < 0.10$) source of variation describing interim and final BW and was therefore included in the data analysis as a covariate. There were no treatment differences for BW ($P > 0.23$) throughout the study. Average daily gain for each time period or for the entire study was not affected by treatment ($P > 0.26$). There was a difference ($P < 0.05$) in DMI between treatments from d 106 to slaughter (HCP > ELCP, LLCP, and LICP), and overall DMI tended ($P < 0.11$) to be affected by treatment (HCP > ELCP and LLCP). Treatment differences for G: F and net energy recovery were not significant ($P > 0.30$). There were no significant ($P > 0.21$) effects of dietary treatment on carcass merit. Treatment differences for DM digestibility calculated from DMI and fecal output as estimated by AIA, were not significant ($P > 0.37$) and averaged 85.7, 83.6, 84.2, and 83.0% for the HCP, OCP, EICP, and ELCP diets respectively. Treatment differences for CP digestibility, calculated from N intake and fecal N, were significant ($P < 0.001$) and averaged 83.3, 76.6, 78.8, and 74.3% for the HCP, OCP, EICP, and ELCP diets respectively (HCP > OCP, EICP, and ELCP). Nitrogen intake was significantly ($P < 0.0001$) affected by treatment and averaged 183, 172, 167, and 155 g per head daily for the HCP, OCP, EICP, and ELCP treatments respectively. Differences between treatments for amount of fecal N ($P > 0.18$) and calculated amount of retained N ($P > 0.42$) were not significant. Urinary N, calculated as N intake minus fecal and retained N, excretion was reduced ($P < 0.0001$) as N intake decreased with treatment averaging 128, 111, 108, and 94 g per steer daily for the HCP, OCP, EICP, and ELCP treatments, respectively. Retained N as a percentage of N intake increased ($P < 0.0001$) and calculated urinary N excretion decreased ($P < 0.001$) with decreasing N intake associated with treatment averaged 12.6, 13.6, 14.1, and 15.0% and 69.8, 64.6, 64.6, and 60.7% of N intake for the HCP, OCP,

EICP, and ELCP treatments respectively. Cattle on the ELCP diet had significantly lower N loss than the HCP treatment ($P < 0.02$) and the OCP treatment ($P < 0.10$) for sampling from d 45 and d 92. Similar results were observed from samples taken on d 148; however there were no significant differences. Ammonia flux reduction of ELCP diet compared to HCP diet decrease from 40% to 21% with increasing days on feed. The average ammonia flux over the feed period for all treatments was 147.3 $g/m^2/d$. There were no treatment differences ($P > 0.36$) for N, P, or N: P ratio found in samples from manure cleaned from the pen surface at the end of the study. Nitrogen to P ratios ranged from 2.13 to 2.23 and was lower than the fecal grab sample N: P ratio. These results indicate that ADG and carcass merit were similar for steers fed OCP and CP withdrawal diets as compared with the HCP control. Although DMI declined during the later stages of the finishing period, feed efficiency was not impacted by OCP or CP withdrawal diets. Reduced CP intake whether it was through the OCP or CP withdrawal diets was associated with less urinary N excretion and lower ammonia emissions from the pen surface.

ACKNOWLEDGEMENTS

I want to thank my mentors, Dr. Gretchen Hill and Mr. Alan Culham, at Michigan State University for encouraging me to pursue my Masters at Colorado State University. Their encouragement and honesty guided me through my undergraduate career. I am also grateful for my advisors, Drs. John Wagner and Terry Engle, for all their support and supervision. Dr. Wagner, I appreciate you putting up with me bomb-barding you with emails on occasion and although it was a clever idea, I think I will pass on your nicknames for me, "Nitrogen Nancy" and "NRC Girl," and stick with "Bob". Dr. Engle your behind the scene help does not go unappreciated. I am grateful for all you have done to help me. Your encouraging words are embedding in my head, "it only gets worse" and "it is all about the love." Thank you fellow graduate students for your advice and comic relief. You have all taught me countless life lessons: texting is dangerous; no matter how excited you are to collect data, it is cheaper to go the speed limit; and cattle *can* wear diapers.

I am grateful for the additional help from the crew at SECRC and the faculty members that played a part in this research project; Drs. Jay Ham, Shawn Archibeque, and Kraig Peel, Dusty Wallace, Jenifer Sexson, Scott Smith and Tim May. Your help did not go unnoticed!

Last, but not least, I want to thank my family and my friends. Thank you for your support and check-in from time to time and keeping me sane during this process.

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CHAPTER I

INTRODUCTION

Cattle are fed in Confined Animal Feeding Operations (CAFO) as an opportunity to control dietary inputs, monitor animal health and performance, and maximize production efficiency. However, there can be significant challenges in managing nutritional requirements due to the variation in animal body weight, frame size, gender, and genetic make-up among individuals in each pen of cattle. Historically, feedyard nutritionists have managed this situation by formulating diets above the National Research Council's (NRC, 2000) recommendation for the average animal in a pen to ensure that no animal is deficient in any nutrient. This strategy provides most cattle with ample nutrients needed for maintenance and gain. Consequently, production efficiency is reduced when cattle are consuming a surplus of nutrients. These nutrients are not utilized by the host animal, but instead excreted into the environment and are resulting unnecessary increases in cost of gain as well harmful environmental effects to the surrounding areas.

Dietary crude protein (CP), more specifically nitrogen (N), requires extensive attention in feedlot, due to its role in growth and proper rumen function. However, feeding in excess of animal's requirement has proven to be indirectly detrimental to the environment. Cattle retain only 12% of all fed N (Kissinger et al., 2007). One-third of the excreted N is harvested in manure and can be utilized for crop production (Kissinger et al., 2007). The remaining two-thirds is

likely volatilized as ammonia or pooled in runoff collection areas and can be concerning to the surrounding areas (Kissinger et al., 2007b).

Colorado is unique in that it supports a heavy populated cattle industry and some of the most pristine mountainous regions. The emerging environmental concerns in Colorado's Rocky Mountain National Park (RMNP) due to increased atmospheric N deposition may be associated with N metabolism in ruminant animals, specifically feedlot cattle. Nitrogen deposition is resulting in changes in aquatic ecosystems and the historic natural state of the Park. It is important to note that there are a variety of N sources that aid in N deposition in RMNP and the proportion and amount of damages from each source has not been determined. Recent studies have shown that, although livestock production possibly is contributing to N deposition, it makes up a small proportion of the overall N sources and furthermore the N deposited in RMNP may be coming from sources outside of the state. However, more closely meeting CP requirements, maximizing nutrient digestibility, and more accurately predicting harvesting of feedlot cattle can aid in managing production efficiency and in improving the manure profile in order to decrease the loss of nitrogenous compounds from feedlot operations.

The variety of protein sources available to ruminant animals provide nutritionists with numerous opportunities for developing rations that work for specific operations. However, with fuel costs driving the cost of protein, producers have been challenged to look at alternative dietary CP regimens. Nutritionists commonly formulate feedlot rations at 13.5% CP (Vasconcelos and Gaylean, 2007); however, nitrogenous losses from beef cattle feedlots were reduced by 60 to 200% by feeding a reduced (11.5%) CP diet compared to a 13% CP diet (Cole et al., 2005). Additionally, Erickson and Klopfenstein (2001) reported a 15 to 33% reductions in N losses when phase-feeding CP. Phase-fed diets resulted in a 10% decrease in N inputs for

calves and a 20% decreases in N inputs for yearlings with no adverse affects on animal performance. Furthermore, oscillating dietary CP regimens may be another vehicle to enhance N recycling (Archibeque et al., 2007b,c). The goals of these alternative protein regimens are to achieve feeding programs that is financially feasible, by reducing the cost of gain, and providing benefit to the cattle and producer, and minimizing the detrimental effects on the environment.

Body weight continues to increase, but growth rate begins to decline as feedlot cattle are nearing the end of the finishing period. Cattle typically have a lower average daily gain (ADG) during this final period relative to the rest of the feeding period. There tends to be more deposition of fat rather than muscle, possibly decreasing protein requirements. Therefore, it is plausible to reduce dietary CP concentrations for beef cattle during the last 28 days before slaughter. This also corresponds to the time when β – agonists are fed. Another logical time to decrease protein concentrations is when cattle are allotted their finishing diet. In a review of opportunities to enhance performance and efficiency through phase-feeding, Cole and Todd (2008) suggested that in dry-rolled corn-based diets CP concentration could be decreased late in the feeding period with no adverse effects on performance. The responses observed in steam-flaked corn based diets were less consistent as a result of the change in the ration of degradable and undegradable intake protein due to grain processing.

Oscillating dietary CP is an additional method to meet, but not exceed, the protein requirement of feedlot cattle. Alternating the dietary CP concentration from high to low in 48-hour intervals was shown to improve N retention. Due to improved recycling of N to the rumen, ammonia emissions were reduced because there was a reduction in the nitrogenous compounds in urine (Archibeque et al., 2007). Additionally, lambs fed oscillated CP concentrations between

high and moderately deficient levels had improved N utilization, and the amount of N required for optimum performance was decreased (Cole, 1999).

Digestibility accounts for a large portion of variation in nutrient utilization in feedlot cattle and dietary CP can be utilized to improve both dry matter (DM) and CP digestibility. Published research has shown a significant increase in CP and DM digestibility in roughage diets (Gallup at al., 1948; Raleigh et al., 1963) and mixed rations (Swift, 1947; Veira et al., 1980, Milton et al., 1997a) with increased dietary CP concentrations. Conversely, increased N intake, either through increased DM intake or increased protein inclusion levels, decreases the digestibility of DM in high concentrate rations (Anderson et al., 1959; Coleman et. al., 1974; Cole, 1999).

Real-time ultrasound is an instrument that has been introduced to feedlot operations to predict the days cattle need to remain on feed to reach a desirable beef quality. The use of ultrasound may allow producers to use dietary CP more efficiently by helping to eliminate feeding excess nutrients by predicting when cattle will begin to have diminishing performance, or by helping to avoid underfeeding cattle which prevent them from reaching their genetic potential. The correlation between ultrasonic and carcass measurement has been variable in the literature, but carcass merit can be predicted with accuracy from live animal ultrasound images (Strouffer et al., 1961; Thompson et al., 1977; Brethour, 1992: Crews et al., 2002; Griener et al., 2003; Wall et al., 2004).

If N volatilization can be reduced and N excretion can be shifted from the urine to the feces by manipulating dietary treatments, a more desirable manure nutrient profile for use in crop production as well as a reduction in air pollution from beef cattle production may be achieved. Therefore, the objective of this research is to investigate the effects of degradable intake protein

withdrawal and the use of oscillating CP concentrations on feedlot performance, digestibility, carcass merit, and ammonia emissions from the pen surface of yearling steers fed a steam-flaked corn based diets. More specifically the goal of this study was to answer the following questions:

1. Can acid-insoluble ash be used as an indigestible indicator substance in diets to accurately determine nutrient digestibility for feedlot cattle?
2. Does the use of urea as a non-protein nitrogen source in various crude protein regimens affect dry matter and crude protein digestibility in feedlot cattle?
3. Can crude protein concentration be reduced in feedlot rations with no adverse effects on animal performance and carcass merit?
4. How does crude protein effect nitrogen utilization and retention?
5. Will decreasing dietary crude protein by feeding reduce crude protein or oscillated crude protein diets reduce ammonia emission from beef cattle feedlots?

CHAPTER II

REVIEW OF LITERATURE

Section I: Ruminant Animal's Gastro-Intestinal Tract

The compartmentalized stomach of ruminant animals is the most developed of all mammals. Ruminant animals tend to consume large amounts of feed in a short period time allowing them to spend the majority of their time ruminating (re-gurgitating and chewing digesta). This eating behavior is possible due to the large capacity of the rumen and the anatomy of the esophageal tract. The anatomy of the esophagus in ruminant animals allows feed to flow in both directions, making it possible to regurgitate and re-chew their feed, breaking it down further to prepare it for microbial activity.

Ruminant animals have a four compartmentalized stomach. The reticulum, rumen, and omasum are classified as the non-glandular fore-stomach. These compartments are the site of anaerobic microbial fermentation and function to store and regulate the passage of digesta. The abomasum is the forth compartment of the stomach and is the only glandular compartment. The esophagus empties into the reticulum and rumen. The recticulum is classified as a blind sac and is noted for its "honeycomb" like mucosal surface. It is muscular and often is considered part of the rumen (reticulo-rumen). The rumen is the largest compartment of the stomach. It is characterized for its finger like projections called papillae. These papillae increase surface area

for nutrient absorption. The length and size of the papillae largely depend on the type of diet being consumed which affects the type of volatile fatty acids (VFA) produced. When a feedstuff is in the rumen, smooth musulcar contractions allow it to continuously churn until the feed particles are small enough to enter the opening into the omasum. The omasum is composed of muscula leaflets with papillae, and water is absorbed in this compartment. Once feed particles are small enough they continue on through the digestive tract to the abomasum. If digesta comes out of the rumen small enough it may bypass the omasum and directly enter the abomasum. The abomasum is considered to be the "true" stomach in ruminant animals. The mucosal lining of the abomasum is arranged in folds. The abomasal environment is very acidic due to the secretion of hydrochloric acid and other digestive enzymes.

The abomasum connects to the small intestine at the pyloric sphincter. The duodenum, the first of the three sections of the small intestine, is where bile and pancreatic secretion enter the gastro-intestinal tract. The doudenum is relatively short in length and connects with the jejunum; the longest section of the small intestine. In the jejunum the largest quantity of nutrient absorption takes place. From the jejunum the small intestine transitions into the ileum. Like the duodenum, the ileum is relatively short. The thicker muscular tunica of the entire small intestine contains finger like projections called villi which facilitate absorption and are similar to the papillae of the rumen. The villi decrease in size and length cranially to caudally in the small intestine.

Succeeding the small intestine in ruminant animals is the hindgut which is functionally similar to other mammals. It is comprised of the large intestine, the cecum, and the colon. Unlike the small intestine, the hindgut does not have villi. The hindgut is the final storage point for digesta before defecation from the rectum. Absorption of inorganic ions and water takes

place in the hindgut; consequently, feces are drier as they move through the large intestine. The large intestine and the cecum are also major sites for microbial fermentation.

Microbial Fermentation

Roughly 66 to 80% of energy provided to the host animal is supplied via microbial fermentation and the rumen provides an ideal environment for the microbial populations (bacteria, protozoa, and fungi) to flourish. The rumen is primarily an anaerobic environment, having little or no oxygen present. The rumen environment is also 38 to 42 degrees Celsius, has a pH between 5.7 and 7.3 (as the amount of concentrate in the diet increases the rumen is more acidic), and is 14 to 18% dry matter (DM). These characteristic as well as the large capacity of the rumen, allows feed particles to remain long enough for microbial fermentation to take place.

Microbial fermentation is the process of microorganisms breaking down substrates from the diet into useful components for both themselves and the host animal. Microbial fermentation yields methane (CH_4), microbial crude protein, VFA, carbon dioxide (CO_2), nitrogen (NH_4^+, NO_3), and hydrogen sulfide (H_2S). Moreover, the microorganisms reside in three locations within the rumen. Microbes can be adhered to the rumen wall, associated with feed particles, or float freely in the rumen fluid.

Carbohydrates enter the rumen and are broken down into branched-chain fatty acids and short-chain fatty acids, also known as VFA. Branched-chain fatty acids are a result of the deamination of branched-chained amino acids. Branched-chain fatty acids help support the growth of rumen bacteria and are essential for the synthesis of essential amino acids (AA). The primary short chain fatty acids are acetate, butyrate, and propionate. Acetate (2 carbons) and butyrate (4 carbons) can be synthesized into fatty acids, or the carbons can be used for oxidation

in the mitochondria for the production of adenosine triphosphate (ATP). Propionate (3 carbons) is transported to the liver were it can be converted into glucose. The quantity and proportion of VFA varies with carbohydrate source. For example, in grain based diets, acetate production is lower and propionate production is higher than it is in hay diets. The result of this VFA shift is due to the change in the composition of bacterial population.

Nitrogen Metabolism

Nitrogen (N) metabolism in ruminant animals is an extensive and critical process. Ruminant animals are unique because the rumen microflora can break down fed protein and synthesizes essential amino acids (AA) and useable N. Microorganisms can manufacture high quality protein the host animal can utilize, from lower quality feedstuffs when there is enough N and carbons present in the rumen. The source of N for microorganisms to use for protein synthesis can be provided either from dietary crude protein (CP) or non-protein nitrogen (NPN). Nitrogen from dietary CP or NPN is broken down and released into the rumen then added to carbon chains by the microorganisms to form essential AA. Therefore, it is critical to have enough carbon available from carbohydrates in the diet in order to capture and utilize dietary N.

Additionally, the microorganisms that break down feedstuff eventually die and are also used as a protein source for the host animal and are absorbed from the small intestine. The bacteria and protozoa within the rumen contain roughly 20 to 60% CP, while rumen bacteria alone average 50% CP with less variation (Owens and Zinn, 1988). Microbial crude protein (MCP) is an important nutritional source of protein in addition to dietary CP. The percentage of protein derived from MCP is directly linked to dietary CP. As dietary CP intake decreases or there is an increase in protein supplied from degradable protein sources, there is an increasing

amount of protein synthesized by MCP. However, the total about of MCP that is produced is a function of the nutrients or energy available for maximal microbial growth.

Crude protein can also be derived endogenously. Protein reaches the rumen and either escapes degradation (UIP) or is degraded into amino acids or ammonia (DIP). Absorbed amino acids derived from DIP are catabolized or oxidized in the liver. The waste form of amino N is urea which is formed in the liver and excreted as urea ($CO_2(NH_2)_2$; See Figure 2.1) in urine. Ammonia (NH_3) is one of the byproducts of this process and is formed from the hydrolysis of urea. Ammonia can be used by the rumen microorganisms to produce energy or is diffused through the rumen wall into the blood.

Nitrogen is continually recycled into the digestive system through the vascular system. Plasma urea can be returned to the system via saliva or by diffusion through the rumen wall. Owens and Zinn (1988) reported that anywhere from 23 to 92% of the urea contained within the plasma can be recycled back into the gastro-intestinal tract. Dietary N, rumen ammonia concentrations, and plasma urea concentrations are all factors that contribute to the amount of N that is recycled. If dietary N is not fed in excess of the animal's requirements, the host animal is forced to utilize N more efficiently. Furthermore, when ammonia concentrations are high in the rumen or when the plasma urea levels are low, the amount of N recycled is reduced. When urea is diffused into the rumen, it is hydrolyzed to form ammonia and carbon dioxide. The amount of urea that is hydrolyzed is a function of the pH level. The lower the pH, the more acidic the rumen environment is, and the more ammonia is captured as ammonium ion (NH_4^+). Ammonium is less absorbable through the rumen wall and as a result continues through the digestive tract and is excreted as urine. Additionally, if the ammonia concentrations in the plasma get too high, ammonia toxicity can occur. Fed urea is a vehicle that can be utilized in

cattle to increase the pH of the rumen and ultimately increase N recycling via greater absorption through the ruminal wall (Owens and Zinn, 1988). Plasma urea concentration is highly correlated to dietary CP level (Preston et al., 1965) and rumen ammonia concentrations (Cheng and Wallace, 1979)both of which can influence endogenous urea N recycling.

Section II: Dietary Crude Protein Sources

Cattle are placed in feedlot operations to ensure efficient growth and performance. One of the most important nutrients for growth is protein. However, cattle do not have a requirement for protein, but a necessity for the components that comprise protein, amino acids (AA) and nitrogen (N). Protein is an essential nutrient in all diets due to its critical role within the body. All cells produce protein for part or all of their life cycle and life cannot exist without protein. Protein is composed of long complex organic compounds that form when AA are bound together by peptide bonds. Most protein molecules are present in muscles, but are also numerous in skin, hair, and hooves. Additionally, protein has many specialized functions including gene expression, enzyme catalyzed reactions, muscle contraction, metabolic regulation, and immune function.

Dietary crude protein (CP) is defined as the gross N in a feedstuff multiplied by a conversation factor of 6.25 and can be calculated from degradable intake protein (DIP) and undegradable intake protein (UIP; described below). Crude protein sources are typically compared by N digestibility or N retention. It is important to note in feedlot rations, corn provides the greatest amount of protein because it typically comprises the majority of the ration. However, corn typically is only 9 to 10% CP.

Degradable Intake Protein

Rumen degradable intake protein (DIP) is used by microorganisms (bacteria, protozoa, and fungi) to produce high quality microbial crude protein (MCP). If there are low levels of N supplied to the rumen, carbon cannot be combined with N to form essential AA and MCP. Furthermore, a majority of energy is synthesized through carbohydrate fermentation resulting in volatile fatty acids (VFA), so N deficiency, specifically due to low DIP levels in a ration, will ultimately decrease the total energy yield from carbohydrate fermentation (Russell et al., 1992). For feedlot steers fed a traditional High-Plains steam-flaked corn diet, DIP should be fed at about 8.3% of dietary DM or between 7.1 and 9.5% to ensure proper rumen function and nutrient utilization (Cooper et al., 2002; Wagner et al., 2010). Steers fed increased amounts of supplemented DIP had increased dry matter intake (DMI; Krehibiel et al., 1998; Wickersham et al., 2008), enhanced digestion rates (Petit and Veira, 1994; Olson et al., 1999; Heldt et al., 1999), higher ruminal ammonia, higher total VFA production (Heldt et al., 1999), and improved urea recycling and N retention (Wickersham et al., 2008). Similarly, the addition of DIP, specifically soybean meal, enhances digestion and performance in cattle on a low quality roughage diet (Mathis et al., 1999).

Urea is frequently utilized in feedlot rations as an economical DIP source. Urea is the combination of atmospheric N with ammonia and carbon dioxide which contains roughly 46.7% N and is present in numerous plants. Feed grade urea, at 287% crude protein equivalent (CPE) provides the required level of N for proper rumen function and allows the liver to synthesize the AA profile needed for the host animal. Urea can be a protein supplement fed to feedlot cattle during the finishing period. The inclusion rate of urea is dependent on the amount of digestible energy in the ration, but it is suggested that a range of no more than 15 to 25% of total CP be fed

to cattle consuming a high concentrate ration (Stanton and Whittier, 2006). Furthermore, urea has low palatability and needs to be thoroughly mixed into a ration to be accepted by the animal. There is no adaptation required for the utilization of urea, but due to palatability issues, urea should be introduced into rations gradually.

It is important to note that urea toxicity can occur when feeding a high level of urea. Urea itself is not toxic to the host animal, but if the production of ammonia from the metabolism of urea exceeds the ability of ruminal microorganisms to metabolize the ammonia or the ability of the host animal to excrete N in the urine, there can be detrimental effects for the host animal (Emerick, 1988; Pond et al., 1974). Ammonia toxicity occurs when the concentration in rumen fluid is greater than 100 mg/dL, rumen pH is greater than 8, and plasma ammonia concentration is greater than 2 mg/dL (Owens and Zinn, 1988). The physical signs of urea toxicity include increased respiration rate, labored breathing, tremors, slight incoordination, and excessive salivation (Emerick, 1988; Pond et al., 1974).

Undegradable Intake Protein

Undegradable intake protein (UIP) is not degraded by the ruminal microorganisms and is available for digestion and absorption only in the small intestine. The amount of protein that passes through the rumen undegraded varies by feedstuff. Metabolizable protein is referred to as the actual amount of microbial crude protein (MCP) and UIP that enters the small intestine and is absorbed into the body. Feeds frequently used in feedlot rations with relatively higher UIP levels include dried distiller's grains (25% CP), wet brewer's grains (23.2% CP), cottonseed meal (45.2% CP), and corn gluten meal (46.8%).

The addition of UIP to feedlot rations has been shown to increase N and energy digestibility (Petit and Veira, 1994). When UIP was provided by corn gluten meal there was no effect on average daily gain, DM intake, feed conversion, or final body weight (Wagner et al., 2010). Futhermore, increased levels of DIP decreased marbling scores, and Wagner et al. (2010) reported that UIP levels above 5.1% of DM did not improve feedlot performance. Digestibility varies greatly among protein source and with grain processing, but it is assumed that the digestibility of UIP is around 80% (NRC, 2000).

Degradable Intake Protein to Undegradable Intake Protein Ratio

There are several feedstuffs that provide opportunities to meet the protein requirements, and more specifically the N and AA requirements for finishing cattle. Cattle of varying initial weight may have differing requirements for protein and more explicitly DIP and UIP. Providing the proper concentration and ratio of the two types of protein improves animal performance (Stock et al., 1981; Milton et al., 1997b; Cooper et al., 2002; Wagner et al., 2010). The composition of growth changes to more fat accretion and less lean deposition later in the feeding period resulting in a greater requirement for DIP and consequently lower requirement for UIP (Cooper et al., 2000). A greater requirement for DIP is due to increased intake during this time, and UIP requirements decrease because of a larger supply of MCP and change in the composition of growth (Cooper et al., 2000). It is important to note that grain processing and the concentration of protein types that rations contain can lead to varying results in performance and carcass merit (Milton et al., 1997b; Cooper et al., 2002). For example, dry-rolled corn may have 60% UIP, whereas high moisture corn is 40% UIP (Cooper et al., 2000).

Section III: Dietary Crude Protein Regimens

The percentage of crude protein (CP) in the finishing rations of beef cattle has been more defined due to a greater understanding of the utilization and fate of nitrogen (N). Faster growing cattle, in general, require a greater amount of protein than slower growing, smaller framed cattle. Furthermore, as animals mature their protein requirement, as a percentage of the diet, decreases and protein requirements change with gender due to differences in the composition of growth. One of the earliest strategies used to meet nutritional requirements in feedlot cattle was to organize homogenous pens of cattle. This allowed feedyard nutritionists to formulate specific diets for each pen with more precise nutrient concentrations to meet, but not exceed, the nutritional CP requirements of the animals.

Providing supplemental protein is a common management practice in range cattle operations as well as in feedlots. Supplementing protein to low quality forage diets increases animal performance and nutrient digestibility (Church and Santos, 1981) by providing N that can be utilized by the rumen microorganisms to capture carbons. The nitrogenous compounds allow the microorganisms to grow which ultimately improves the energy status of the animal due to the increase in volatile fatty acid (VFA) production (Russell et al., 1992; Köster et al., 1996; Griswold, 2003). Furthermore, providing supplemental CP to low CP diets has also been shown to increase body weight, feed intake, and feed efficiency (Raleigh and Wallace, 1963).

In contrast, reducing the protein inclusion level in feedlot cattle rations can stimulate N recycling in the gastro-intestinal tract (Wickersham, 2008). Cattle fed lower-protein diets can recycle N from the circulatory system into the rumen to supply N to rumnial microorganisms (Reynolds and Kristensen, 2008). In addition to the historical reduction of the concentration of

dietary CP in feedlot rations, two protein regimens have been researched that can increase N retention and decrease N excretion: oscillated dietary CP diets and phase-feeding CP.

Oscillating Dietary Crude Protein

Intermittent CP supplementation was first utilized in grazing cattle operations as a vehicle to decrease labor and protein costs. Ruminant animals can survive on diets that are low in protein for a short period of time if they had access to higher protein diets prior. This is possible due to higher plasma urea levels that are a medium for N recycling back to the digestive tract during the time the protein is deficient in the diet (Owens and Zinn, 1988). It is documented that with low CP diets (5% CP or less), 70% of N intake is recycled back to the rumen via urea (NRC, 1985). This value decreases to 11% when high dietary CP is fed (CP> 20%; NRC, 1985).

The alternating of low protein diets with diets adequate in protein could prove to be beneficial with no adverse effects on performance. The theory is that oscillated CP diets stimulate the recycling of endogenous N back into the rumen (Hunt et al., 1989; Krehbiel et al., 1998; Archibeque et al., 2007c). When low levels of N in the rumen are coupled with surplus N in the large intestine, a greater uptake of N from the large intestine could replenish the N deficiency in the rumen through the circulatory system (Cole, 1999). Correspondingly, N from high N concentrations in the rumen would be absorbed into the blood and diffused into the large intestine. This N would then be transformed into microbial protein which will be excreted in the form of feces rather than urine (Ulyatt et al., 1975; Norton et al., 1982). As a result, this would improve the manure profile and there would be less N available for volatilization.

For oscillated CP diets to be successful, the timing of CP changes and the rate of passage need to be synchronized. There have been numerous studies that have reported that feeding

oscillated CP diets to ruminant animals at 24-, 48-, 72- and 96- hour intervals did not adversely affect performance relative to feeding continuous dietary protein at 13.5% of the dry matter (DM). Collins and Pritchard (1992) document no difference in DM and N digestibility or total volatile fatty acid (VFA) production when feeding undegraded intake protein (UIP) or degradable intake protein (DIP) at 24-or 48-hour intervals. Furthermore, oscillating 10% and 15% CP (DM basis) diets on a 24-hour basis did not affect N retention (Cole, 1999). In another study, six Dorset ewes were fitted with hepatic venous, hepatic portal, abdominal aortic, and mesenteric venous catheters (Krehbiel et al., 1998). They were given a low quality forage (7.5 % CP; DM basis) diet and fed soybean meal every 24- or 72-hours (Krehbiel et al., 1998). Krehbiel et al. (1998) concluded that the absorption patterns may be affected, but the net flux of nutrients was not affected by the frequency of protein supplementation. The removal of urea N by the portal-drained viscera was greater with the protein supplementation which was possibly a product of improved N concentration for the rumen microorganism (Krehbiel et al., 1998). Interestingly, in Krehbiel et al., (1998) dry matter intake (DMI) fluctuated as a result of the inclusions of soybean meal. Ewes that were not fed soybean meal in addition to the low quality forage had lower DMI than ewes that were fed soybean meal. Furthermore, ewes on the oscillated CP diets (72-hour intervals) had the lowest DMI on the day the soybean was fed and the highest DMI three days later. In another oscillated CP study, ewes had higher DMI when fed protein supplement every 48-hours compared to a continuous protein source (Archibeque et al., 2007c).

Cole (1999) conducted a study in which lambs were fed a 10%, 12.5%, or 15% CP (DM basis) diet or 10% and 15% CP (DM basis) diet oscillated on a 48-hour basis, with cottonseed meal used as the primary protein source in trial one and cottonseed meal: urea (50:50) in trial

two. In both trials, feeding supplemental protein every 48-hours was favorable in high concentrate feedlot rations and may be ideal timing for synchronization of passage rate and dietary CP changes (Cole, 1999). However, the rate of passage and retention time in the gut are largely influenced by diet composition and feed intake, explaining some of the variation in results.

When comparing oscillating dietary CP at 48-hour intervals to daily CP supplementation, there was little to no effect on digestibility (Collins and Pricthard, 1992; Ludden et al., 2002a), average daily gain (ADG; Collins and Pritchard, 1992; Ludden et al., 2003; Cole et al., 2003), VFA production (Ludden et al., 2002a), passage rates, (Ludden et al., 2002a; Hunt et al., 1989), or N utilization (Collins and Pritchard, 1992; Cole, 1999; Ludden et al., 2002a). In contrast, Archibeque et al. (2007b, c) concluded that N and DM digestibility and N retention increased with oscillated CP diets (9.1% and 13.9% CP, and 9.9% and 14.2% CP, respectively; DM basis; soybean meal) in 48-hour intervals and DMI was greater in the oscillated CP diets.

Nitrogen recycling is increased when ammonia concentrations within the rumen are reduced and urea concentration in the plasma are elevated (Owens and Zinn, 1988). When feeding oscillated CP, between 13 and 17% (DM basis) to sheep or cattle at 48- hour intervals, there was lower ruminal ammonia N concentration (Ludden at el., 2002a); however, there was also lower serum urea N concentration (Ludden at el., 2002a). Ludden et al. (2002b) observed a decrease in N retention by 42% with oscillated CP diets. However, in this study CP levels were comparatively high (13 and 17%) and both diets likely exceeded requirements which could cause these detrimental effects (Ludden et al., 2002b). Similar serum urea N results were seen when feeding cattle 11 and 15% CP diets oscillated on a 48-hour basis (Ludden et al., 2003). Furthermore, Archibeque et al. (2007a) documented that for the majority of the feeding period

steers fed oscillated CP (9.1% and 14.9%; 48-hour intervals), diet did not have different plasma urea N levels when compared to steers fed a constant (9.1, 11.8 or 14.9% CP) protein diet.

The improved N retention in intermittent protein supplementation (Collins and Pritchard, 1992; Cole, 1999; Cole et al., 2003; Archibeque et al., 2007b,c; Cole and Todd, 2008) could result in decreased urinary N and increased fecal N ultimately improving the quality of the manure by having a more desirable nitrogen: phosphorus (N: P) ratio (Cole, 1999) because of a reduction in N volatilization that occurs from urinary N. When N is high in the rumen, it will be absorbed into the circulatory system and then plasma urea N could diffuse into the large intestine and replenish the lower levels of N there due to the intermittent CP supplementation. The N in the large intestine will be converted to microbial protein and excreted in the feces rather than urine. The shift in the media in which N could be excreted would be beneficial to the environment as well as the host animal. Nitrogen present in feces is less readily volatilized compared to N excreted in the urine. This will ultimately increase the N remaining in the manure making it a more ideal crop fertilizer due to the improved N: P ratio.

Phase-feeding Dietary Crude Protein

Phase-feeding provides another opportunity to decrease N inputs by more efficiently meeting and not exceeding the protein requirements for feedlot cattle during the finishing period. Cooper et al. (2002) stated that the requirement for DIP increases with increasing DMI, while requirements for UIP decrease with days on feed due to the change in the composition of growth that is occurring later in the feeding period. Therefore, the ratio of DIP to UIP may change throughout the feeding period and phase-feeding is one way to address this nutritional change.

Feedlot cattle do not require more than 8 to 9% CP in the later portion of the finishing period (Putnam et al., 1969) and not more than 8.4% DIP (DM basis; Wagner et al., 2010). This agrees with the NRC (2000) which states, as cattle approach slaughter weight they require less dietary CP. Decreasing CP concentration in finishing diets containing dry-rolled corn had no adverse effects on animal performance (Cooper et al., 2000; Cole and Todd, 2008). Putnam et al. (1969) and Young (1978) reported no adverse affects in corn diets when protein was decreased in the later part of the finishing period, either when DMI reached a certain level (4.5, 5.9, or 7.3 kg) or when an animal reached a set weight (318, 386, or 454 kg). Many other studies suggest there are also minimal to no affects on ADG, DMI, feed efficiency (gain to feed ration; G: F), or carcass merit form the withdrawal of dietary CP in the last 84 days (Dartt et al., 1978), 56 days (Cole et al., 2006), or 28 days (Cole et al., 2006).

However, Cole et al. (2006) stated that detrimental effects in feedlot performance (ADG, DMI, G: F) could be seen when protein is decreased to 10% or less in feedlot rations with 56 or 28 days remaining in the finishing period. Although there were no adverse affects on animal performance, Vasconcelos et al. (2006) noted that in addition to higher blood urea N levels, steers that were fed a constant protein level (13% CP; DM basis) had greater marbling scores at harvest and steers fed decreased CP levels (day 63 until slaughter; 11.5 or 10% CP; DM basis) in the later part of the feeding period had greater fat thickness (Vasconcelos et al., 2006). Another study showed that in diets containing corn silage, ground shelled corn, and soybean meal, the removal of soybean meal the last 84 days on trial negatively affected gains and feed efficiency, but the results were less significant when an ionophore (monensin) was included in the diet (Dartt et al., 1978).

Thomas et al. (1976) examined the effects of supplemental protein withdrawal from feedlot rations with different lengths of time remaining during the feeding period and found that the primary effect from the withdrawal was decreased DMI which leads to decreased ADG and feed efficiency. This study also showed that the most detrimental effects were seen when CP was decreased early in the finishing period before 84 days on feed. However, it is important to note that the steers on this trial were not fed any more than 10.82% CP at any point during the finishing period.

The difference in results for phase-feeding diets could be explained by the difference in DIP requirement for the different methods of corn processing, dry-rolled corn versus steam-flaked corn (Cooper et al., 2002; Gleghorn et al., 2004). Cooper et al. (2002) determined that for dry-rolled corn, high moisture corn, and steam-flaked corn the DIP requirements are 6.3%, 10.0% and 8.3% respectively. Similarly, Wagner et al. (2010) stated for maximum performance, heavy feedlot cattle require 7.4% to 8.4% DIP in rations containing 5.1% UIP. Deceasing DIP in steam-flaked corn diets may cause a deficiency in DIP because the amount of DIP required for steam-flaked corn diets is greater than it is for dry-rolled corn diets (Galyean, 1996; NRC, 2000).

Phase-feeding is ultimately a vehicle for decreasing N inputs, the amount of N excreted per head per day, and decreasing N volatilization from feedlot pen surfaces (Cole et al., 2006). It has been reported that phase-feeding improves the N: P ratio of the harvested manure (Vasconcelos et al., 2006).

Section IV: Digestibility

Digestibility is defined as the mechanical and chemical breakdown of food into simpler compounds that can be absorbed in the gastrointestinal tract for utilization by the host animal. This process is completed by microbial fermentation in the rumen and enzymatic breakdown mediated by secretions of gastric juices from the stomach, small intestine, and accessory organs. Digestibility causes a large variation in the utilization of nutrients and as a result is extensively studied in ruminant nutrition to determine the nutrient value of feedstuffs and feed efficiency.

Methods for Measuring Digestibility

Conventional Digestion Trials: Early digestibility trials, known as conventional digestion trials, weretimely and costly, but the results continue to be used as a baseline to compare other methods of measuring digestibility. These trials require an acclimation period of at least two weeks, in which an animal is adjusted to a particular ration or feedstuff of a known composition. This acclimation period is followed by a data collection period of 4 to 10 days in which feed consumption is controlled and feces are collected and analyzed for chemical composition. Total collection of feces and urine can be obtained by housing animals in metabolism crates, or animals can be fitted with collection bags. From the analyzed compositional makeup of feces and feed, apparent digestibility can easily be determined. Apparent digestibility does not differentiate between unabsorbed feedstuffs and components of endogenous origin and can be calculated using the following equation:

$$Eq\ 2.1: Apparent\ Digestibility\ (\%) = \frac{(nutrient\ intake - nutritent\ in\ feces)}{nutrient\ intake} * 100$$

External and Internal Markers: Due to the intense labor associated with conventional digestion trials, they are commonly used only to verify the accuracy of alternative methods of calculating digestibility, such as the use of external and internal markers. A marker is defined as a compound that can be utilized to observe chemical and physical characteristics of digestion and additionally can be used to estimate fecal output. An ideal marker is a substance that is not absorbed, does not disturb, or is not disturbed by the microbial profile in the rumen or digestive tract, and flows with and is very similar to the material it is to mark (Owens and Hanson, 1992). Although, no marker meets all of these characteristics, markers have historically been, and will continue to be, important in advancing the understanding of digestion in ruminant animals. Additionally, fecal crude protein concentrations have also been used with success to determine digestibility by measuring feed refusal and feces output (Boval et al., 2003; Lukas et al., 2005; Franchone et al., 2009).

Historically, external markers have proven to be an accurate predictor of digestibility, but there are also concerns associated with them (Smith and Reid, 1954). External markers are manually added to rations or given orally in a capsule or drench. These markers can easily be separated from the ration, and consequently rations must be thoroughly mixed to ensure a uniform distribution of the marker. There may be large variation in the results when large numbers of range or feedlot cattle are tested with external markers. Additionally, external markers are excreted in a diurnal pattern, sometimes making complete recovery difficult (Merchen, 1988). Commonly used external markers are listed in Table 2.1.

Internal markers are non-digestible compounds that naturally occur in feedstuff, therefore eliminating the additional time and labor involved with mixing external markers in rations.

Internal markers that have been studied and used in research are listed in Table 2.2. Most internal markers are digested partially, but are considered to be an accurate predictor of digestibility (Thonney et al., 1979). Furthermore, because internal markers are naturally occurring in a feedstuff they can be used to not only measure digestibility, but also can successfully measure total consumption and grazing patterns of herbivorous species of range animals (Shrivastava and Talaptra, 1962; Cook et al., 1963; Van Dyne and Lofgreen, 1964).

External and internal markers are measured in both the feed and feces and the equation for generating the digestibility of nutrients is as follows:

$$Eq.\,2.2:\ Apparent\ Digestiblity\ (\%) = 100 - (100\ (\frac{\%I_{fd}}{\%I_{fc}}) * (\frac{\%Nt_{fc}}{\%Nt_{fd}})$$

where I represents the "indicator", fd is "in food," fc is "in feces," and Nt represents the "nutrient". For the most accurate results when using internal markers, fecal grab samples are preferred over fecal samples from pen surfaces. Fecal grab samples eliminate the possibility of contaminating the sample with dust and soil.

Factors Influencing Digestibility

Ruminant animals have the capability to regurgitate, remasticate, and reswallow feedstuff that is unsuitable for human consumption. The four chambered-stomached animals have the unique ability to digest fibrous feedstuff that many other species cannot. Variation in digestibility can be explained by feed processing, dietary crude protein (CP) concentrations and source, feed additives, interactions among feedstuffs, and levels of feed intake. Moreover, digestion can vary greatly between ruminant species. Sheep historically have higher digestibility capabilities than cattle (Cook et al., 1963; Van Dyne and Lofgreen, 1964; Kilmer et al., 1979; Kohn et al., 2005).

Grain Processing: Processing cereal grains, specifically corn, allows nutrients to be more readily available for degradation within the rumen by providing more surface area for microbial attachment. Digestibility is higher for lambs and cattle fed steam-flaked corn (SFC) based diets compared to dry rolled corn (DRC) or high moisture corn (HMC) diets (Galyean et al., 1976; Zinn, 1987; Barajars and Zinn, 1998; Zinn, 1990; Theurer et al., 1999). These can be explained as a result of increasing the starch availability for microbial fermentation and absorption in the lower gastro-intestinal tract. However, in another study that compared SFC, steamed-whole and whole shelled corn, DM or CP digestibility did not differ, but starch digestion was greater for SFC (Ramirez et al., 1985).

Nitrogen level and CP Regimens: In addition to processing methods, diet N concentration affects digestibility. Zinn et al. (2007) found that apparent N digestibility is closely associated (r^2=0.73) with N concentration in the diet. It has been well documented that increased dietary CP concentrations up to a certain level could increase DM digestibility, CP digestibility, or both in roughage-based and grain-based diets (Swift et al., 1947; Gallup and Briggs, 1948; Raleigh and Wallace, 1963; Putnam et al., 1966; Veira et al., 1980; Pritchard and Males, 1985, Petersen et al., 1985; Boggs et al., 1987; Archibeque et al., 2007b). However, contradicting the aforementioned findings Coleman and Barth (1974) and Cole (1999) documented that DM digestibility tended to decrease as protein inclusion increased. Furthermore, Collins and Pritchard (1992) and Cole (1999) reported that oscillated CP treatments did not have a significant effect on digestibility of DM. On the other hand, Archibeque et al. (2007b) reported that DM and N digestibility increased with increased protein, but was the highest for oscillated CP diets. This result likely differs due to different protein levels and sources, and other confounding components of the ration.

Protein source: Literature documents varying digestibility with different protein sources, but possibly as a result of outside variables and the parameters in which each experiment was conducted. The inclusion of protein, either from urea (Swift et al., 1947; Raleigh and Wallace, 1963; Zinn et al., 2003; Griswold et al., 2003), casein, (Swift et al., 1947) or soybean meal (Church and Santos, 1981) increased apparent digestibility of CP and DM. However, with this increase in digestibility there is an increase in the production of volatile fatty acids, ammonia, and nitrogenous compounds (Griswold et al., 2003). Coleman and Barth (1974) and Pritchard and Males (1985) indicated that the percentage of N supplied by urea had no significant affect on DM digestibility in cattle. Furthermore, Milton et al. (1997b) documented an increase in N digestion in finishing steers when protein was supplied by soybean meal rather than urea. When protein was supplied by soybean meal there was a linear increase in DM digestibility in weaned calves (Veira et al., 1980). Similar results were reported in an experiment conducted by Paterson and his colleagues (1983). This experiment reported that N digestibility was higher when protein was supplied by soybean meal (largelt DIP) compared to a combination of dehydrated alfalfa and dried distillers grains (largely UIP; Paterson et al., 1983). The difference between the protein sources was the extent to which protein is degraded to N and carbon chains in the rumen resulting in improved nutrient availability for microbes. There was no difference in DM digestibility in this study (Paterson et al., 1983). Moreover, when cottonseed meal (14% CP; DM basis) was the supplemented protein compared with urea (11% CP; DM basis), N digestibility increased for both SFC and for DRC (Barajar and Zinn, 1998). The variation in these results is most likely due to differences in ration composition and the parameters in which the study was conducted.

Ionophors: Monensin is a polyether antibiotic ionophore extensively used in the beef cattle industry. Monensin is a tool to increase the production of propionic acid and decrease bloat and acidosis. It allows the host animal to obtain more energy from feedstuff, while also improving their feed conversion and health. Even in low protein diets, N digestibility increased with monensin supplementation (Beede et al., 1986). Conversely, Dinius et al. (1976) reported no difference in DM and N digestibility with the inclusion of monensin. As a result of the addition of monensin to ruminal fluid in an *in vitro* study, there was an increase in peptide and non-ammonia non-microbial N which will inhibit the breakdown of protein (Whetstone et al., 1981). Consequently, there was a decrease in degradation of ruminal protein allowing more dietary protein to be available to the lower gastro-intestinal tract (Whetstone et al., 1981).

Energy: The interaction of protein and energy also influence digestibility. Putman et al. (1966) observed that CP digestibility was lower in high energy diets compared to low energy diets. In slight contradiction, increasing the percentage of concentrates in the ration decreased N digestibility by 1.2%, but increased DM digestibility in a study done by Coleman and Barth (1974). Similar results were report by Tyrrell and Moe (1974). Joanning et al. (1981) noted a 15% increase in DM and N digestibility with an all-grain diet compared to an all-silage diet. Raleigh and Wallace (1963) reported that to reach maximum performance with higher protein diets more energy needs to be provided in the diet to supply more carbon chains to capture the N. If high protein diets are low in energy protein will then be used as an inefficient energy source for the animal (Raleigh and Wallace, 1963). Furthermore, ruminal fermentation is more rapid in high concentrate diets, consequently increasing N recycling (Cole, 1999).

Feed Intake: It is generally believed that as dry matter intake (DMI) increases, digestibility decreases and the decrease is more pronounced in high concentrate rations

(Anderson et al., 1959). When mixed forages were fed to lactating dairy cows there was a decrease in the digestion of the feedstuff with increasing intakes higher than that required for maintenance (Wiedmeier et al., 1983). Furthermore, Joanning et al. (1981) documented a decrease in digestibility with increased intakes in feedlot steers fed corn silage-corn grain diets. The decrease in digestibility with increased intake is possibly the result of increased rate of passage. However, it is important to note that particle size and particle density affect rate of passage as well. Similarly, as shown by Andersen et al. (1959), digestibility of mixed rations (concentrate and forages) decreased as feed consumption increased. Other trials showed that intake had no effect on digestibility. Andersen et al. (1959) justified the difference in results as an outcome of varying maturity of forage and compositional makeup of the roughages in the diets. However, it is interesting to note that digestibility was not affected in all forage diets within this study (Andersen et al., 1959). Joanning et al. (1981) also noted that the intake of single-feed diets did not affect DM digestibility. Moreover, when N intake increased as a result of increased DM consumption there was a decrease in DM digestibility (Coleman and Barth, 1974).

Section V: Carcass Evaluation

Historically, postmortem carcass measurements have been used to develop equations to predict retail yield and provide a basis for the evaluation of meat quality. These measurements are independent of the performance of the live animal and do not reflect differences production practices. Therefore, there are two types of evaluation, subjective and objective, that are used as vehicles for predicting carcass merit. Visual appraisal is a subjective evaluation that is continually utilized to assess carcass composition and market readiness of live beef cattle. It

takes training and experience to accurately assess the market quality of live animals (Lewis et al., 1969; May et al., 2000). Objective evaluations such as, photogrammetry, electrometry, and linear measurements are also used (Hendrick, 1983). However, ultrasound imagining or sonography has been the most successful objective live animal carcass evaluation (Davis et al., 1966; Herring et al., 1994a; Hamlin et al., 1995b; Brethour, 2000; Crews et al., 2002; Greiner et al., 2003; Wall et al., 2004; Thériault et al., 2009; Ripoll et al., 2010).

Live Animal Ultrasound Imagining

Ultrasound evaluation uses a sound-emitting probe, called at transducer, which sends, as well as receives, sound waves. Piezoelectric crystals in the transducer convert electrical energy into short pulses of ultrasound. The transducer is pressed snug again the animal and these short pulses of ultrasound are reflected and scattered by tissues and tissue interfaces (Nyborg and Zisken, 1985). A standoff is made of pliable material that often is placed on the transducer to help fit the curvature of the animal better than the transducer alone. Once the transducer receives the returned signals they are then converted to an electrical current transported to a real-time picture on a computer screen. A computer with a frame grabber and proper software are required when analyzing carcass composition in livestock. The most common carcass traits evaluated with ultrasound include fat thickness and longissimus muscle area, rump fat thickness, and intramuscular fat.

The sound wave frequencies that are most commonly used in livestock ultrasounding are 3.5, 5.0, and 7.5 MHz. The depth of the penetration of the sound wave is dictated by the frequency of the sound wave with 3.5 MHz having the greatest penetration, but less detail, and 7.5 MHz resulting in less penetration, but greater detail.

Ultrasound imagining has been used since the mid-1950s and progressively become a valuable tool in the livestock industry since the 1990s. It is accurate in predicting body composition in swine (Stouffer et al., 1961), is becoming increasingly more popular in beef cattle, and is in the beginning stages of being implemented within the sheep industry.

Ultrasound imaging was initially used as a breeding selection instrument. Due to the heritability of carcass traits, ultrasonic imagining is utilized among seedstock producers to improve carcass quality through genetic selection of superior seedstock animals expressing desirable carcass traits. In a review of studies from 1962 to 2004, it was documented that carcass characteristic for ribeye area, backfat thickness, and marbling score were moderately heritable (Utrer and Van Vleck, 2004). However, there was a wide range in results that could be explained by the various research parameters, breed differences, methods of estimating measurements, observation number, sex, and management in these studies (Utrer and Van Vleck, 2004).

In addition to being used in breeding operations, ultrasonic evaluation recently has been utilized in feedlot industry. Several studies have been conducted to develop prediction equations to estimate the desirable end point of finishing cattle. Information obtained from ultrasonic evaluation of feedlot cattle during the feeding phase may yield economic returns (Koontz et al., 2000). The information obtained from ultrasonagraphy assists cattle operations selling cattle on value-added or value-based systems to harvest cattle when the preferred theoretical carcass composition is achieved. Furthermore, based on ultrasonic evaluation, cattle can be sorted into alternative marketing groups of similar compositional makeup early in the feeding period to reduce production inefficiency from over or under-feeding cattle (Koontz et al., 2008). Koontz et al. (2008) determined when grouping cattle, sorting with ultrasound measurements would

yield economic returns around $15 to $25 per animal and production efficiency would be greatly improved.

Increasing accuracy and minimizing errors will continue to be a challenge when utilizing ultrasonic evaluation in feedlot systems to predict carcass readiness, but it can still be a valuable tool when done properly and at the right time. Ultrasonic evaluation of carcass characteristics of calves entering the feedlot is inaccurate in predicting final carcass merit (Brethour, 2000). However, pre-harvest ultrasound imaging has been documented to be repeatable (Brethour, 1990; Brethour, 1992; Herring et al., 1994a) and feasible (Wall et al., 2004). Moreover, carcass traits have been reported to be highly correlated with actual carcass measurements when evaluated at the end of the finishing period (Perkins et al., 1992b; Herring et al., 1994a; Hassen et al., 1999). If careful and precise measurements are not taken, there can be variation in results due to technicians/operators (Stouffer et al., 1961; Davis et al., 1966; McLaren et al., 1991; Robinson et al., 1992; Perkins et al., 1992b; Herring et al., 1994a), equipment/machines (Davis et al., 1966; Herring et al., 1994a), animal species (Stouffer, 1961), age and weight of the animal (Hamlin et al., 1995a), the side of the animal that was scanned (left versus right; Robinson et al., 1992), and image interpreters (Herring et al., 1994a).

Traditionally, the longissimus dorsi muscle area (ribeye area, REA), back fat thickness (BF), and intramuscular fat (IMF) are measured between the 12th and 13th rib. For a review of correlations between ultrasound measurements and actual carcass measuremrnts see Table 2.3.

Ribeye Area: The transverse section of the longissimus dorsi muscle is photographed typically between the 12th and 13th rib, and reported as the ribeye area (REA) or longissimus dorsi muscle area (LMA). However, the correlations between live animal ultrasound evaluation and actual carcass merit have been highly variable. Studies have shown no correlation

(Thompson et al., 1977), a moderate correlation (r=0.55; Thériault et al., 2009), or a high correlation (0.91 and 0.79; Greiner et al., 2003). There are many factors when pinpointing the cause of variation in these studies. In a study utilizing lambs, the correlation between the actual carcass measurements and real-time ultrasound for the depth of the REA (r = 0.59) was stronger than the correlation seen with the width (r = 0.23; Ripoll et al., 2010). Additionally, the diversity in correlations may be a result of the transformation that occurs during slaughter, carcass hanging, and variability in the pressure of the ultrasound transducer on the hide (Stouffer et al., 1961). These factors can lead to a change in the size and shape of the muscle.

Griener et al. (2003) found that steers that had a smaller REA (< 70.3 cm^2) were overestimated with ultrasound and animals with larger REA (> 90.3 cm^2) were underestimated.

Crouse et al. (1975) reported a moderate correlation (r = 0.47) between the REA and the cutability of a carcass. The cross sectional view of the REA has also been reported to be a poor predictor of the total percentage of retail product (Crouse and Dikeman, 1976).

Backfat Depth: Similar to the REA measurement, backfat thickness (BF) is also measured between the 12^{th} and 13^{th} rib. The fat thickness of cooled carcasses is traditionally measured ¾ of the way across the longitudinal length of the longissimus dorsi muscle, but in ultrasound scans it takes the average of serial measurements along the entire muscle. Fat is the greatest predictor of body composition and cutability (Crouse et al., 1975) and is an important component of yield grade (Powell and Huffman, 1973). However, there is a wide variation and uneven distribution of fat depth in cattle both when measured on the live animal and on cooled carcasses. Consequently, the coefficient of variation tends to be high for BF (Crews et al., 2002).

Thompson et al. (1977) documented a high correlation (r = 0.74) for the fat thickness at the 12th rib as measured on a live animal and carcass. Griener et al. (2003) observed that the fat thickness tended to be overestimated in leaner animals (carcass BF <0.51 cm) and was underestimated in fatter animals (carcass BF > 1.02 cm). Inaccuracies and variation in results could be explained with the conclusions of research done by Brethour (2000), who suggested that scans can be used as a prediction of the days to reach target BF thickness with 30 days or less remaining in the feeding period. However, it was noted that a minimum of 3 mm BF thickness is needed in order to get an accurate measurement and make any projections as to the number of days cattle need to remain on feed. Similarly, another study indicates an increase in correlation of ultrasonic BF measurements with actual measures from 0.67 to 0.78 to 0.86 for measurements taken at weaning, yearling, and pre-harvest respectively (Crews et al., 2002).

Intramuscular Fat/Marbling: Marbling is an important component in determining quality grade of beef carcasses (Wall et al., 2004) and is the most genetically evaluated carcass trait due to its high heritability (Utrera and Van Vleck, 2004) and its influence on meat quality. However, it is impossible to measure intramuscular fat (IMF) visually in a live animal, but can easily be measured using ultrasound imaging.

Intramuscular fat (IMF) is measured within the longissimus dorsi muscle. Brethour (1990) noted 80% accuracy for IMF ultrasound measurements to predict carcass marbling score. Furthermore, projections made from the live animal measurements of ether extract accumulation in the longissimus dorsi muscle may be greater than 75% accurate in distinguishing between choice and select quality grades of the final carcass (Brethour, 2000). The accuracy of evaluating marbling in a live animal will be improved as the animal approaches market readiness due to the very slow initial rate of accumulation (Brethour, 2000; Wall et al., 2004). In more

detail, fat accretion is estimated to be at a rate of 0.01 mm per day on feed; taking 100 days to increase one quality grade. The rate increased when cattle reached a quality grade of low choice (Wall et al., 2004).

Section VI: Nitrogen Deposition in Rocky Mountain National Park

Colorado's Front Range and the High Plains Region are the setting for numerous confined animal feeding operations (CAFO). Approximately 80% of the cattle on feed reside in High Plains States; Texas, Kansas, Nebraska, and Colorado (National Agricultural Statistics Service, 2010). The abundance of beef production brings economic benefits to the area. Coupled with it are the pristine mountainous regions of Rocky Mountain National Park (RMNP) which bring tourist from all over the world. However, N emission from cattle operations in addition to numerous other source are potentially causing detrimental environmental impacts the alpine regions, which are concerning for the area parks, natural surroundings, ecosystems as well as human health.

The Rocky Mountain National Park was establish in 1915 and is noted for its high alpine ecosystem, glaciers, lakes and streams, and wildlife. However, the ecosystem and nature of the park on the east side of the Continental Divide has been slowly changing over time as a result of nitrogen (N) deposition. Two-thirds of the park is above tree line and due to high elevations it is highly susceptible to changes from N deposition (NDRP, 2007; Woodford, 2010). Nitrogen deposition in the soil favors some species of plants more than others. There has been a slow shift from flowering plants to more N tolerant grasses. Moreover, the increasing accumulation of N in the soil increases the microbial activity, which stimulates more N production resulting in acidic soil conditions. The soils in the alpine are shallow and have low buffering capacity. Thus, a large

fraction of N deposition is leached from the system and ends up in alpine lakes and streams. There are notable increases in N concentration, in the form of nitrates in surface waters which is causing plant shifts in aquatic plant types. The health of the ecosystem in and around the waters is declining as a result of the N saturation. Furthermore, increasing accumulation of N causes metals to be released that damage plant root systems and contaminate ground water. Nitrogenous compounds also create haze and decrease the visibility throughout the Front Range and mountainous regions. Coupled with the environmental concern, are the human health concerns (NDRP, 2007; Ham, 2010).

Increases in N deposition have been noted since the 1950's (Baron et al., 2000; NDRP, 2007; Aneja et al., 2008; Elser et al., 2009). The current levels of N in RMNP are 4.0 kg/ha/yr, about 20 times higher than the historic natural state of the park at 0.2 kg/ha/yr (NDRP, 2007). The majority of N deposition occurs in the form of wet deposition (rain and snow; 3.1 kg N/ha/yr), but can also occur from dry deposition (particulate matter and gases; 0.9 kg N/ha/yr; NDRP, 2007).

Ammonia, hydrogen sulfide gas, particulate matter, volatile organic compounds, odors, and greenhouse gases are the main focus concerning environmental contamination from livestock operations. Despite the fact that a majority of cattle feeding operations are east of the mountain range and air currents typically move from west to east, livestock still are the largest contributor of the ammonia emissions that aid in the deposition of N in the alpine parks (Woodford, 2010). The high and low pressure systems associated with upslope snow storms can move air from the eastern feedlot regions west into the mountains. Additionally, during the summer nights valley winds draw air from the eastern plain regions to the mountains with the cooler temperatures.

Total N deposition in the park is caused from the amalgamation of oxides of N with ammonia. A portion of ammonia emissions are a product of beef cattle operations. Some studies say roughly 40% of ammonia emissions are from livestock operations while other studies document 45% from livestock (Woodford, 2010). In a 2002 evaluation of statewide ammonia emissions it was estimated that 24,894 ton of N are emitted in a year from beef cattle operations (Woodford, 2010). However, the science behind these estimates may be inaccurate and need further scientific investigation. The ROMANS (2009) study reported that northeast Colorado's cattle operations are only one of many contributors to N deposition, and the impact of this part of the state is mainly limited to the spring and early summer. Once the ammonia from these operations is released into the atmosphere it reacts with N oxides and N nitrates, which are the product of point sources, industrial sources, and mobile vehicles. The reaction of ammonia and oxidized N creates the pollutant of concern. The nitrogenous compounds from this reaction have a very short lifetime of 1 to 5 days, but they have the ability to be carried significant distances (Aneja et al., 2008). This explains why large beef cattle feedyards in central and eastern Colorado, as well as in the surrounding states can have a notable impact on the ecosystem of the RMNP several hundred kilometers to the west.

Baron et al. (2000) noted that even the slightest increase in N emitted can result in a change in the ecosystem of an alpine region. Therefore, it is important to understand feedlot N cycles to be able to reduce N emissions. The reduction of N input in one area may not necessarily result in an overall reduction in N output. Figure 2.2 illustrates the sources of N inputs as well as points of ammonia (NH_3) losses. The best management practices (BMP) for feedlot operations demand an integrated approach to control ammonia emissions.

Ammonia reduction efforts are currently a voluntary approach for livestock producers. However, the concern has been intensified over the last few decades. The Emergency Planning and Community Right-To-Know Act (EPCRA) requires feedlots with over 1,000 cattle to report the expected ammonia and hydrogen sulfide emissions if they are anticipated to be greater than 45.4 kg of N emitted per year (Ham, 2010). Several efforts have been put into place to preserve the beauty and nature of the park; Rocky Mountain National Park Organic Act (1915), NPS Organic Act (1916), Wilderness Act (1964), and the Clean Act Amendments of 1977. More recent plans have been implemented to monitor, control, and decrease N deposition (NDRP, 2007).

There are two dominant sources of ammonia from beef cattle feedyards; ammonium (NH_4^+) hydrolyzed from urea in urinary excretions and mineralization of nitrogenous compounds in feces (Todd et al., 2008). As a result of the cation exchange that transforms ammonium to ammonia, the mobility of ammonium is low leading to the slow mineralization of organic N (Vaillant et al., 2008). The prevailing form of N excreted is in urine in the form of urea which can be quickly hydrolyzed to ammonia. The volatilization of N from urine is a fast process and N excreted in urine equals anywhere from 30 to 80% of total fed N (Todd et al., 2008). It is estimated that 50 to 60% of N can be removed from feedlot pens and 10% is captured in runoff areas; however, the remaining N escapes into the atmosphere (Gilberston et al., 1971).

Several studies have been conducted to look at the effects of climate (Sweeten et al., 1985) temperature/season (Hutchinson et al., 1982; Kissinger, 2005; Todd et al., 2006; Kissinger et al., 2007; Todd et al., 2008; Li et al., 2009), surface amendments to decrease surface pH (Shi et al., 2001), feedlot soil surfaces (Miller and Berry, 2005), and manure handling and management (Rotz, 2004; Adams et al., 2004) to control ammonia emission. However, dietary

regimens may be the most efficient and cost-effective method to reduce emitted atmospheric ammonia (Todd et al., 2006).

Best Management Practices for Feeding Cattle

Feeding dietary crude protein (CP) to meet, but not exceed, the N requirement for finishing beef cattle has continued to be a management challenge due to the cost of protein and the effect of N on the environment. Furthermore, with the growing concern of N emissions from large feedlots it cannot be ignored. Nitrogen excreted is directly related to N input (Rotz, 2004; Erickson and Milton, 2001; Kissinger et al., 2007). It has been documented that cattle retain 12 to 15% of the N they are fed and roughly 85% of fed N is excreted in the form of urine, feces, or gas (Ham, 2010). However, others suggest that anywhere from 10% (Bierman et al., 1999) to 30% (Kissinger et al., 2007) of input N is retained within the host animal. Moreover, Rotz (2004) charted that feeder cattle excrete 11% of their body weight worth of N over the entire finishing period.

Shifting the site of fermentation has been a vehicle used to address this issue. Hindgut fermentation shifts N excretions from primarily urinary to more fecal N. Consequently, if more N is excreted in feces, there is less N volatilization. However, with the microbial activity breaking down nutrients in fecal matter, N is still being released into the environment but it at a slower rate. Bierman et al. (1999) determined that dietary fiber can shift the site of fermentation and affect N excretion, yet believes that total N excretion is more of a concern.

Therefore, reducing dietary CP may be a more feasible means of decreasing excreted N (Erickson and Milton, 2001; Todd et al., 2006). When reducing protein inclusion levels by 1.5% and 2.0%, N excreted was lower by 15 and 20% respectively (Erickson and Milton, 2001).

In addition to reduced protein in diets, phase-feeding is another means to reduce N inputs without having any negative effects on performance (Erickson and Klopfenstein, 2001). Phase-feeding most commonly occurs in the later part of the finishing period when there is a change in the protein requirement due to increase in fat accumulation and less muscle deposition (see Section III: Dietary Crude Protein Regimens). Reducing the amount of protein in feedlot rations based on when cattle reach a predetermined weight, dry matter intake, or days on feed defines phase-feeding. Phase-feeding decreases the amount of N excreted, decreasing the N available for volatilization (Cole et al., 2006), and improving the nitrogen-phosphorus ratio in the manure (Vasconcelos et al., 2006).

Oscillating dietary CP is another dietary treatment to reduce N input without adverse affects (see Section III: Dietary Crude Protein Regimen). Oscillating CP in 48-hour intervals synchronizes digestion and nutrient unitization in the rumen and intestine, allowing the host to be more efficient retaining and ultimately excreting less N.

Table 2.1. External markers used to measure digestibility and digesta passage rates in ruminant animals.[a]

Marker	Characteristic	Advantages	Disadvantages
Stained Feeds	Dyes include: Acid fucsin or magenta, brilliant green or blue, crystal violet and carmine red.	Allows for identifying specific particles during passage through the GI tract. Good measurement of retention, but should be considered relative.	Stained particle must be analyzed by visual inspection and is subject to human error. Currently stained feeds are rarely used in digestibility studies.
Chromic Oxide	A *metal oxide* that is most commonly used.	Simple preparation. Not digested. Fairly accurate in measuring digestibility and postruminal digesta flow.	Not suited for measuring retention time because it travels as a suspension in digesta and flows at a different rate independent of the physical stage it is in.
Chelates	One of many rare earth elements.	Simple preparation. Binds with feed particles and can measure digesta flow.	Partially absorbed/retained. Physicochemical changes can occur as a result of rumen pH.
Chromium Mordanted Fiber	A compound between chromium and plant cell wall.	Stable in rumen fluid and acid media. Indigestible when Cr is greater than 8%. Accurately measures digestion and digesta flow.	Complex preparation process. Influenced by the density of the feedstuff.
Polythelene glycol (PEG)	One of many water soluble markers.	No preparation needed. Completely recovered in feces.	Techniques for analysis are imprecise. May absorb in certain types of dietary ingredients.

[a] (Owen and Hanson, 1992; Merchen, 1988)

Table 2.2. Internal markers used to measure digestibility and digesta passage rates in ruminant animals[a].

Marker	Characteristic	Advantages	Disadvantages
Lignin or chromogen	Naturally occurs in feedstuff.	Indigestible. Accurate predictor of digestibility	Difficult to obtain complete fecal recovery therefore can underestimate digestibility. Degraded or modified in its structure during passage.
Silica	Naturally occurs in feedstuff.	Was assessed to be an indigestibile marker and recommended for use over 100 years ago.	Over recovery in feces can occur possibly as a result of underestimating silica intake. Slightly absorbed.
Acid-Insoluble Ash (AIA)	Naturally occurs in feedstuff.	Accurate indicator of digestibility. Little diurnal variation in feces. Indigestible.	Precision is poorest when feedstuff is low in AIA (grains and alfalfa), and greater chance of error is likely when analyzing feed than feces.

[a](Owen and Hanson, 1992; Merchen, 1988)

Table 2.3. A review of the correlations of ultrasound scans on the live animal to the actual carcass measurements for ribeye area (REA), backfat thickness (BF), and marbling (IMF) in cattle.

Researcher, year	REA[1] [2]	BF[2]	IMF[2]	Comments about the parameters of the study
Stouffer et al. (1961)	0.49	0.35	NM	Large amount of variability in the study can be placed on different locations, equipment, and technicians that were utilized
	0.22	0.32	NM	
	0.85	0.54	NM	
	0.57	0.42	NM	
	0.58	0.04	NM	
Davis et al. (1966)	0.92	0.57	NM	Operation A, Ultrasound Unit A
	0.87	0.71	NM	Operation A, Ultrasound Unit B
	0.85	0.75	NM	Operation B, Ultrasound Unit B
	0.84	0.73	NM	Operation B, Ultrasound Unit B
Thompson et al. (1977)	NS	0.74	NM	
Brethour (1990)	NM	NM	0.67	
Brethour (1992)	NM	0.91	NM	
Robinson et al. (1992)	0.87	0.9	NM	
Perkins et al. (1992a)	0.6	0.75	NM	
Perkins et al. (1992b)	0.76; 0.82	0.87; 0.86	NM	Technician 1;Technician 2
Herring et al. (1994b)	NM	0.72; 0.68	NM	Adjusted fat; Actual fat
Crews et al. (2002)	0.86	0.67	NM	Residual correlation adjusted for year, gender, and age at time of measurement
	0.86	0.78	NM	
	0.87	0.86	NM	
Griener et al. (2003)	0.86	0.89	NM	
Wall et al. (2004)	0.52	0.58	0.63	
	0.66	0.74	0.61	
Brethour (2004)	NM	0.59	0.39	
Thériault et al. (2009)	0.34; 0.55	0.82	NM	REA (depth; area)

[1]NS; Not significant
[2]NM; Not measured

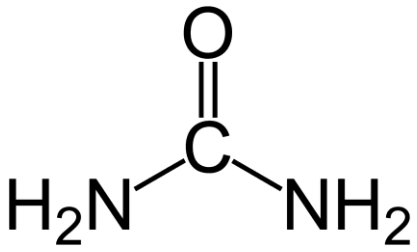
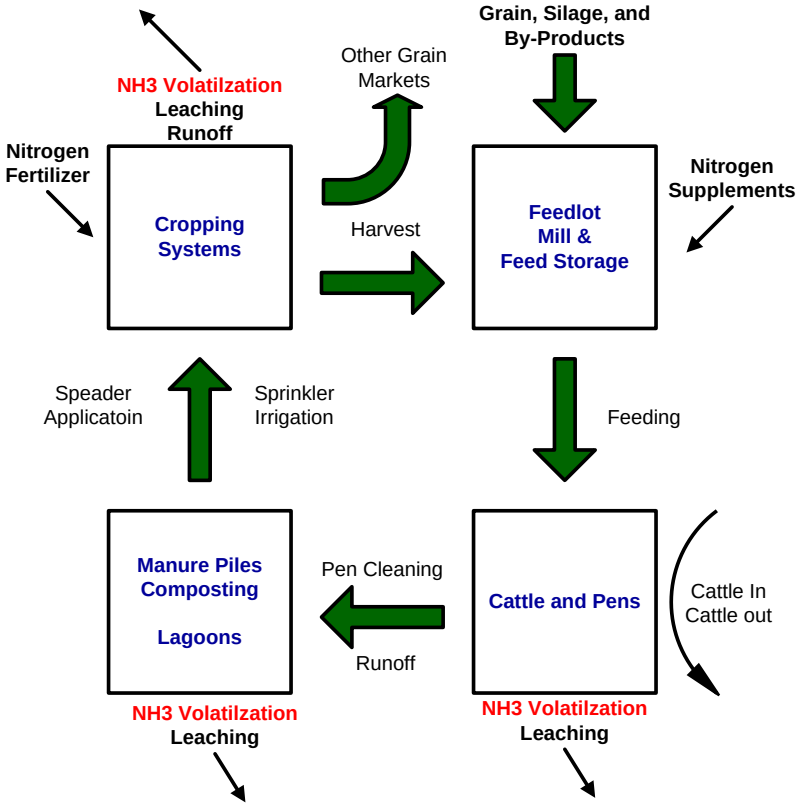


Figure 2.1. Urea compound $CO(NH_2)_2$)

Figure 2.2: Nitrogen Cycle of a Feedlot System (Ham, 2010).



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CHAPTER III

MATERIALS AND METHODS

This study was a collaboration of efforts between JBS Five Rivers Cattle Feeding (Greeley, Colorado), the Department of Animal Sciences, and the Department of Soil and Crop Sciences at Colorado State University (Fort Collins, Colorado). The Colorado State University Animal Care and Use Committee approved the parameters of the study.

Cattle Source, Processing and Randomization

Six-hundred forty-nine crossbreed steers (pay-weight, 345 kg) arrived at Colorado Beef in Lamar, Colorado, on October 27, 2009. Immediately upon arrival, steers were given *ad libitum* access to long-stem grass hay and water. The following morning, steers were trailed to the Southeast Colorado Research Center (SECRC) for processing. During processing steers were identified with lot tags and electronic identification tags, given a breed type score, and weighed. Additionally, all steers received Express 3[1] for Bovine-Rhinotracheitis-Virus Diarrhea, Noromectin[2] and Safe-guard[3] to control internal parasites, Permectrin CDS[4] to control external

[1] Bovine Rhinotracheitis-virus Diarrhea Vaccine, Modified Live Virus, Boehringer Ingelheim, Ingelheim, Germany.
[2] Ivermectin, Norbrook Inc. USA, Lenexa, KS.
[3] Fenbendazole, Intervet/Schering Plough Animal Health, DeSoto, KS.
[4] Permethrin, KMG Chemicals, Inc., Houston, TX.

parasites, and implanted with single dose, delayed release implant, Revalor-XS[5] to improve growth efficiency.

To maintain a homogenous group of cattle for the study, any steer with BW ± 2 standard deviations beyond the average weight obtained during processing was disqualified. Steers exhibiting excessive Brahman, Longhorn, or Dairy breed characteristics were also removed from further consideration for the study. Remaining steers were assigned a random number from 1 to 1000 using Microsoft® Excel 2007 and sufficient steers with the lowest random numbers were removed, leaving 600 qualifying steers for the study.

Steers were ranked by weight within breed type, and within each breed type divided into 12 weight replicates. Within each breed type by replicate group, each successive group of 6 steers were assigned to one of 6 treatments based on their successive random number. By following this procedure, breed type distribution was similar for all pens. On November 3, 2010, all steers were returned through the processing facility and weighed. They were tagged with a five digit identification tag, which specified the study number (5), treatment (1-6), replicate (01-12), and steer within pen (1-7) or (1-9). They were then sorted into their respective treatment pens and the study was started (d 0).

Pen Layout

Steers were sorted into one of two pen styles. Twenty-four seven-steer pens (replicates 3, 5, 8, and 10) were designated to represent a nitrogen mass balance trial and resulted in a pen roughly 6.10 by 13.72 m (Figure 3.1.). A 0.61- to 0.91-m rubber belt was secured between pen boundaries to contain manure within treatment pens. A retention pond lined with plastic was built at the bottom of each pen in an attempt to collect pen run-off. The retention pond measured

[5] Estradiol (40 mg) and trenbolone acetate (200 mg), Intervet/Schering-Plough Animal Health, DeSoto, KS.

approximately 2.44 x 3.05 m by 0.61m deep and could hold approximately 380 L in the event of a run-off. An electrical spring gate was placed 4.57 m from the bottom of the pen to contain steers in the upper portion of the pen away from the retention pond. The remaining 48 pens housed nine steers and were 6.10 by 18.29 m. Every pen contained a 2.44 m concrete apron that extended the length of the pen in front of the feed bunk, and every two pens shared a common water tank. Equal number of treatments and replicates were represented in each pen design.

Treatments

Steers were allotted to one of the six dietary crude protein (CP) regimes that were examined for the study. There were 12 pen replicates for each treatment. Cattle on all treatments were fed a traditional start-up and step-up ration from d 1 through d 21 and the respective treatments started on d 22. Treatments included:

1. *Control/High Crude Protein (HCP):*13.5% CP, 3.50% crude protein equivalent (CPE) from non-protein nitrogen (NPN) through slaughter;
2. *Oscillating Crude Protein (OCP):*alternating an 11.62% CP, 1.55% CPE from NPN diet (low crude protein diet (LCP)) with control diet (HCP);
3. *Early-Intermediate Crude Protein (EICP):*12.56% CP, 2.53% CPE from NPN from d 22 through slaughter;
4. *Early-Low Crude Protein (ELCP):*11.62% CP, 1.55% CPE from NPN from d 22 through slaughter;
5. *Late-Intermediate Crude Protein (LICP):* control diet fed then a 12.56% CP, 2.53% CPE from NPN the diet fed last 26 d before slaughter; and
6. *Late-Low Crude Protein (LLCP):* control diet fed then a 11.62% CP, 1.55% CPE from NPN diet fed the last 26 d before slaughter.

The as-fed inclusion rates for the major ingredients plus supplements were equal for all of the diets fed. Composition of the supplements changed with varying portions of ground corn and urea, resulting in the respective CP and NPN concentrations for the various treatments. Furthermore, to prevent confusion during the manufacturing and delivery of the oscillated CP diets, the high and low CP diets were feed on the same day every week. The low CP diet was fed every Wednesday, Thursday, and Sunday from d 22 through slaughter and control diet was fed Monday, Tuesday, Friday, and Saturday throughout the feeding period.

Nutrition

A starter and 2 step-up diets (Table 3.1.) were fed to acclimate the steers to steam-flaked corn and Rumensin[6]. Diets were formulated to meet or exceed the NRC (2000) requirements for finishing cattle for all vitamins and minerals (Table 3.2.). Diets were manufactured just prior to delivery and were formulated to contain respective treatment protein levels. All finishing diets were designed to contain 68.3% dry matter (DM), 4% Neutral-detergent fiber (NDF) from the forage components of the diet, 0.70% calcium, 0.71% potassium, 0.31% magnesium, 2204.6 IU/kg vitamin A, 33.1 IU/kg vitamin E, 33.1 mg/kg Rumensin, and 11 mg/kg Tylan[7] on a DM basis. With either 26 d (replicates 7 through 12) or 27 d (replicates 1 through 6) remaining on feed respectively, rations for the LICP and LLCP treatments were changed. No ß-agonists were used in this study.

Diets were fed two times daily. Feed bunks were evaluated each evening at roughly 1500 h and in the morning at 0700 h. Steers were fed to have only a few crumbles of feed remaining in each bunk during the morning evaluation. If bunks were devoid of feed for 2 consecutive d,

[6] Monensin, Elanco Animal Health, Greenfield, IN.
[7] Tylosin, Elanco Animal Health, Greenfield, IN.

the amount of feed delivered was increased by 0.18 kg of DM per steer. Conversely, if bunks contained excessive feed, feed delivery was reduced to an amount intended to force the steers to clean their bunks.

Dry Matter Determination

Dry matter consumption for each pen was calculated from the amount of DM delivered each d and dividing the result by the number of steers per pen. Dry matter deliveries were calculated by multiplying the as-fed feed delivered to each pen by the average DM concentration as determined weekly by drying samples for 48h in a 60ºC forced-air oven at SECRC for each diet during each period. From the dry matter intake (DMI) and theoretical CP concentration for each diet, nitrogen (N) intake was calculated by dividing CP intake by a conversation factor of 6.25.

Weighing and Ultrasound Conditions

The initial weights used for the study were the average of 2 individual weights obtained during randomization (d -1 and d 0). Final weights were the average of 2 consecutive individual weights obtained 2 d prior to slaughter; March 29 and 30 (d147 and 148) for a March 31, 2010 slaughter for replicates 7 through 12 and April 26 and 27 (d175 and 176) for a April 27, 2010 slaughter for replicates 1 through 6.

Interim individual weights were obtained on d 30 or 31 (December 2 or 3, 2009), d 73 or 74 (January 14 or 15, 2010), d 106 or 107 (February 16 or 17, 2010), and d 141 (replicates 1 through 6 only, March 23, 2010). The weights from d 106 and d 107 (replicates 7 through 12) or from d 141 (replicates 1 through 6) were collected 8 or 9 d respectively preceding the change of

rations for the LICP and LLCP treatments. A 4% shrink was applied to all weights prior to analysis.

When steers were weighed on interim d, ultrasound scans of ribeye area (REA), back fat thickness (BF), and intramuscular fat (IMF) were taken from the left side of the animal between the 12^{th} and 13^{th} rib. The ultrasound evaluations were done by experienced technicians. An Aloka SSD-500V model with an L2 linear probe and using 3.5 Hz was used, and all imagines were interrupted and edited as needed with Designer Genes Technologies software[8]. The ultrasound data were used to monitor rate of REA growth, BF deposition, and IMF accretion.

Net Energy Recovery

Net energy requirements for maintenance (NE_m) and gain (NE_g) for each pen of steers from d 0 through d 30 or 31, from d 31 or 32 through d 73 or 74, from d 74 or 75 through d 106 or 107, from d 107 or 108 through d 141, the last 26 (replicates 7 through 12) or 27 d (replicates 1 through 6) before slaughter, and from d 0 to slaughter were calculated using equations published by NRC (2000). Net energy for maintenance and NEg derived from the diet for each pen were calculated from pen performance and pen requirements for NEm and NEg using the quadratic equation derivation of the energy equations (Appendix A; further described by Zinn, 1992).

Cattle Observations

Pens were observed daily between feedings to assure all steers were accounted for in each treatment pen and to monitor health status. Steers showing significant signs of illness were removed from the pens and assigned scores of zero or one for each of the following symptoms:

[8] Designer Genes Technologies, Inc., Harrison, Arkansas

eye discharge, nasal discharge, coughing, rapid breathing, and depressed appearance. Rectal body temperatures were recorded for steers removed from a pen. Two additional points were assigned to steers exhibiting body temperatures greater than 39.7ºC. Steers with a total of four or more points were considered morbid and treated according to the appropriate treatment schedule and immediately returned to the pen. If problematic health status persisted in treated animals, they were removed from the pen and disqualified from the study.

Sample and Data Collection

All commodities, supplements, and diets were sampled weekly. Duplicate 100 g sub-samples of all commodities and rations were dried in a 60˚C forced air drying oven at SECRC for 48 h for determining DM content. Weekly as-fed samples were frozen and then composited monthly to be sent to a commercial laboratory[9] for routine nutrient analysis. An additional sub-sample of each diet was saved for later analysis to determine acid-insoluble ash (AIA) and N composition.

Fecal grab samples (approximately 40 g) were collected from each steer on trial on the interim weigh days (d 30 or 31, d 73 or 74, and d 106 or 107). A shoulder length palpation sleeve was used to grab and store individual fecal grab samples to prevent any soil contamination. Samples within treatment pens were then placed together in an 8 mil LDPE plastic bag and frozen until subsequent analysis. For DM analysis, individual grab samples within a treatment pen were composited in aluminum drying tins and placed in a 60˚C forced air drying oven at Colorado State University Agriculture Research Development and Education Center (ARDEC) for 48 to 60 h depending on sample size. Samples were stirred approximately every 8 h to prevent molding and decrease drying time.

[9] SDK Laboratories, Hutchison, Kansas.

Dried fecal samples and monthly composite diet samples were ground through a 1 mm screen (Wiley Mill). Diet and fecal samples were analyzed for AIA using methods outlined by VanKeulen and Young (1977). For this process, a representative 5 g sample from each composite sample (Ws) was placed in an empty, dry crucible (We) and ashed for 12 h. After samples were cooled, they were weighed and then transferred to beakers and mixed with 100 ml of 2N HCl. Samples were covered and placed on a hot plate to boil for five minutes. Samples were then removed from the heat and filtered through an ash free filter paper. The samples were placed back in the ashing oven for 12 more h and then weighed (Wf). The percent AIA was determined by the following equation:

$$\text{Eq.1: } AIA\ (\%) = \frac{Wf - We}{Ws} \times 100$$

Furthermore, fecal grab samples and diet samples were analyzed for N using LECO CN-2000 carbon/nitrogen analyzer[10]. The fecal grab samples were also composited by treatment within sampling d and were analyzed for phosphorus (P) content using a commercial laboratory[11].

Crude protein and DM digestibility were calculated with the following equation using AIA concentrations as the indicator and N and DM content respectively, as the nutrient measuring:

$$\text{Eq.2: } Digestiblity\ (\%) = 100 - \left(100 \times \frac{\%\ indicator\ in\ feed}{\%\ indicator\ in\ feces} \times \frac{\%\ nutrient\ in\ feces}{\%nutritent\ in\ feed}\right)$$

Pen surface samples from the N balance pen were taken at the end of the feeding period (April 01, 2010 for replicates 8 and 10 and April 14, 2010 for replicates 3 and 5). Feedlot surface samples were analyzed for DM, N, AIA, and P using the same procedures and methods

[10] LECO, St. Joseph, Michigan
[11] SDK Laboratories, Hutchinson, Kansas

described earlier. Twelve mass balance pens (two replicates per treatment) were cleaned in replicate order on d 151 and total manure collection was measured. Actual total manure collections were compared to calculated total fecal output (FO) obtained from the use of AIA in the following equation:

$$\text{Eq.3:} \quad Fecal\ Output\ (FO;\ Weight) = \frac{(DMI \times Feed\ AIA\ concentration)}{Fecal\ AIA\ concentration}$$

Diet DM digestibility was also calculated from DMI and FO using the following equation:

$$\text{Eq.4:} \quad DM\ Digestibilty(\%) = \frac{(DMI - FO)}{DMI} \times 100$$

Crude protein digestibility was also calculated from nitrogen intake (NI) and fecal nitrogen (FN) using the subsequent equation:

$$\text{Eq.5:} \quad CP\ Digestibility\ (\%) = \frac{NI - FN}{NI} \times 100$$

Where NI equals DMI * analyzed CP / 6.25 and FN equals FO * N concentration in the feces. Dry matter and N digestibility calculated by the two methods (Eq.2 and Eq.4/Eq.5) were compared.

Nitrogen Balance

The data from mass balance portion of the trial was used to determine the fate of NI based on dietary treatment. Dry matter intake and theoretical dietary CP concentrations were used to determine average N consumption per steer per d. Nitrogen intake was calculated by dividing CP intake by a conversation factor of 6.25. Retained N was calculated from the following set of equations: (NRC, 2000)

Eq. 6: $Shrunk\ Body\ Weight\ (SBW) = Weight * 0.96$

Eq. 7: $Empty\ Body\ Weight\ (EBW) = SBW * 0.891$

Eq. 8: $Empty\ Body\ Gain\ (EBG) = 0.88 * SBW + 14.6 * NE_M - 22.9\ 6$

Eq. 9: $Shrunk\ Weight\ Gain\ (SWG) = Average\ Daily\ Gain * 0.96$

Eq. 10: $Retain\ Engery\ (RE) = 0.0635 * EBW^{0.75} * EBG^{1.097}$

Eq. 11: $Retained\ Nitrogen\ (RN) = [SWG * (268 - (29.4 * (\frac{RE}{SWG})))]/6.25$

Fecal nitrogen (FN) was estimated from calculated FO and N levels. Urinary N was determined from the equation below.

Eq 12: $Fecal\ Nitrogen\ (FN) = FO * \frac{FN\ from\ fecal\ samples}{100}$

Eq 13: $Urinary\ Nitrogen\ (UN) = Nitrogen\ intake - RN - FN$

Soil Samples and Flux-Chamber Systems

Mass balance pen soil surface samples were obtained from each of the following treatments: HCP, OCP, and ELCP. Samples were taken from the center of each pen in three different locations. Sample 1 (replicate 1) was taken roughly 0.35 m from the concrete apron near the feed bunk. Sample 2 (replicate 2) was taken from approximately the middle of the pen. Sample 3 (replicate 3) was taken in the region near the electrical spring gate at the bottom of the pen. Figure 3.1 illustrates the sampling locations. A sample ring 12.7 cm in diameter and 4 cm deep was randomly placed on the pen surface in the respective sampling locations. The core was pounded in the ground and the sample and core were removed from the pen surface. Excess soil was eliminated. Sample and sampling core were double bagged in labeled 8 mil LDPE plastic bags and sealed to prevent any ammonia flux. Each sample from similar treatments were stacked

horizontally and stored in a cardboard box until further analysis. All samples were frozen within eight h of initial collection. Samples were collected on d 45, 92, and 148.

An ammonia flux chamber system at Colorado State University, Fort Collins, Colorado was used to evaluate N loss from all individual soil samples. Ammonia-free air at a controlled humidity and temperature was routed into each chamber. All samples ran in the system for 7 d. See Galles et al. (2011) for further details on methods and material for ammonia flux

Carcass Data Collection

Steers were slaughtered in two groups at the JBS Plant in Cactus, Texas. The first group, weight replicates 7 through 12, was slaughtered on March 31, 2010 (d on feed = 149) and the second group, replicates 1 through 6, was slaughtered on April 27, 2010 (d on feed = 175). Slaughter order and carcass tag data, hot carcass weight (HCW), and liver abscess scores were recorded by Cattlemen's Carcass Data Collection Service[12] on the d of slaughter. Back fat thickness, ribeye area, marbling score, quality grade, and yield grade were determined using a Cold Camera Grading device provided by JBS. On the day of slaughter, steers were fed approximately 30% of their daily feed allowance at 0700 h and later trailed to Colorado Beef for shipment at approximately 1130 h. Steers were transported to JBS and slaughtered upon arrival.

Data Analysis

Data were analyzed as complete randomized block designed with 6 treatments and 12 weight blocks per treatment. Data collected from d 30 or 31 were classified as period 1; d 73 or 74, period 2; and d 106 or 107, period 3. Pen was the experimental unit for all data analysis. Treatment, period, and treatment by period were included in the models as a fixed classification effect. Weight block replicate and weight block by period were included in the models as a

[12] Dr. Ty Lawrence, West Texas A&M University, Canyon, TX.

random classification variable. Subject of repeated measures was period by weight within treatment, and AR(1) covariance structure was used. Results were considered significant when $P < 0.05$ and trended towards significance if $P > 0.05$, but $P < 0.20$.

Feedlot performance, finishing diet nutrient concentration, hot carcass weight (HCW), dressing percentage (DP), and carcass fat depth, ribeye area, marbling score, and yield grade data were analyzed as a randomized block design using PROC MIXED of SAS (2003). Carcass categorical data, including USDA quality grade, USDA yield grade category, and liver abscess data were analyzed using PROC GLIMMIX of SAS to calculate the likelihood that an individual carcass was classified into each quality and yield grade category, and to calculate the likelihood that an individual liver showed signs of abscesses. Dry matter and N intake, DM and CP digestibility, N retention, urinary and fecal N, and fecal output were analyzed in the same manner. Fecal and manure nitrogen-phosphorus ratios were analyzed without period effect. Treatment differences were evaluated using the PDIFF option of the LSMEANS statement in PROC MIXED of SAS (2003).

Ultrasound data was analyzed using standards mentioned previously for experimental unit, repeated measures, fixed effects, and random effects. Ribeye area, intramuscular fat, and backfat thickness were the dependent variables included in the models. Pearson correlation coefficients were determined using the CORR procedure of SAS (2003). The REG procedure of SAS (2003) was used to analyze data for linear, cubic, and quadratic relationships between dependent variables, and days-on-feed with and without the variable weight. The regression analysis was performed to develop prediction equations for REA, BF, and IMF measurements from live animal ultrasound evaluation to predict the number of days cattle need to fed based on treatments.

Finishing diet and supplement nutrient concentration data were analyzed as a complete randomized design. Diet was included in the model as a fixed classification variable, and month was included as a random classification effect.

For analysis of treatment differences on ammonia flux, PROC MIXED of SAS with a Tukey adjustment for multiple comparisons was used. The initial and final pH values were compared with a paired t-test.

Table 3.1. Ingredient and theoretical dry matter nutrient concentration for the starter and step-up diets used for the oscillated crude protein and crude protein withdrawal study.

Item[a]	Starter	Step-up 1	Step-up 2
Ingredient			
Corn silage	25.977	12.269	15.114
Steam-flaked corn	35.431	54.137	63.405
Alfalfa hay	25.000	25.000	10.000
DDG[b]	8.872	2.378	3.188
CCDS[c]	3.000	3.000	3.000
Yellow grease	.	1.000	2.25
Supplement	1.72	2.216	3.043
Nutrient			
Dry matter, % of as-fed	60.373	69.216	63.263
Crude protein	14.000	13.500	13.500
Non-protein nitrogen [d]	1.000	1.750	2.500
RUP % Protein[e]	5.228	6.138	7.335
RDP % Protein[f]	8.771	11.862	12.665
Acid detergent fiber	20.115	15.611	11.171
Neutral detergent fiber	30.114	24.156	19.313
Effective NDF	20.505	16.546	10.890
Crude fiber	15.300	11.559	8.560
Forage NDF[g]	24.000	18.000	12.000
NEm, Mcal/kg DM	1.860	1.990	2.133
NEg, Mcal/ kg DM	1.193	1.315	1.437
Ether extract	4.169	4.570	6.099
Calcium	0.700	0.700	0.700
Phosphorus	0.355	0.330	0.335
Potassium	1.287	1.145	0.848
Magnesium	0.310	0.310	0.310
Sulfur	0.248	0.206	0.187
Vitamin A, IU/kg DM	2204	2204	2204
Vitamin E, IU/kg DM	33.060	33.060	33.060
Rumensin, g/ kg DM	0.017	0.017	0.024
Tylan, g/ kg DM	.	0.011	0.011

[a] Percentage of dry matter unless stated otherwise.
[b] Condensed corn distiller's solubles
[c] Dried distiller's grains.
[d] Crude protein equivalent.
[e].Rumen-undegradable protein.
[f] Rumen-degradable protein.
[g] Neutral detergent fiber from the forage components of the diet.

Table 3.2: Formulated ingredient composition of the finishing diets used for the oscillated crude protein and protein withdrawal study

Item[a]	DM Basis	As-fed Basis
Ingredient		
Corn silage	9.688	19.452
Steam-flaked corn	76.787	68.205
Dried distillers grains plus soluble	2.905	12.178
Corn steep liquor	3.000	4.822
Yellow grease	3.530	2.482
Supplement[b]	4.091	2.862

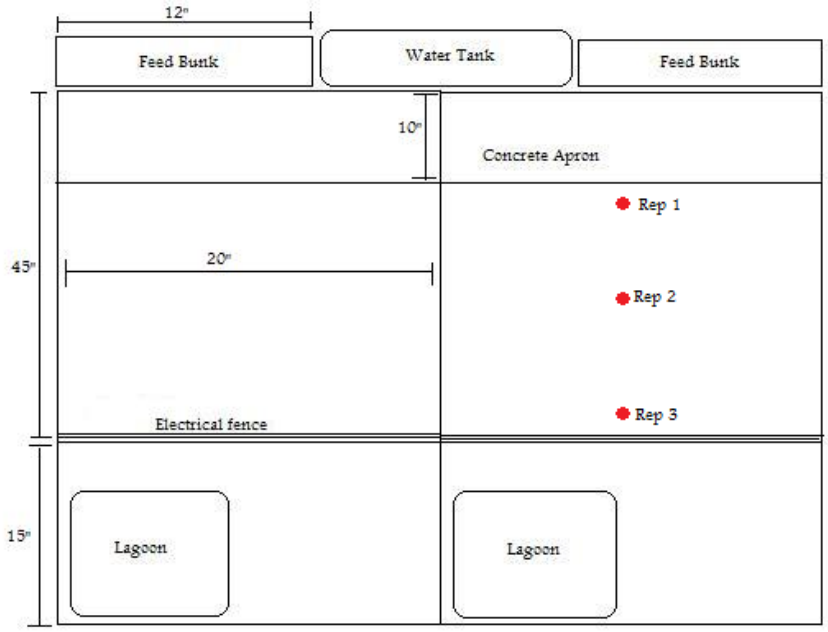
[a] Percentage.
[b] Major ingredient dry matter and as-fed composition was identical for all finishing diets. Supplement composition varied with treatment (see Table 3.3).

Table 3.3. Formulated ingredient composition of supplements used for the oscillated crude protein and crude protein withdrawal study.

Ingredient [a]	Starter	Step-1	Step-2	HCP[b]	ICP[b]	LCP[b]
Urea	17.2690	25.9692	27.3970	28.9484	20.9328	12.9172
Ground Corn	.	.	.	.	8.0157	16.0313
Calcium Carb.	4.5152	2.5574	15.7582	19.3826	19.3826	19.3826
Min-Ad[c]	55.5679	53.2120	42.8428	35.3162	35.3162	35.3162
Salt	14.4169	11.1979	8.1664	6.0922	6.0921	6.0921
KCl[d]	.	.	.	5.2774	5.2774	5.2774
Mineral oil	2.0002	2.0003	2.0003	2.0000	2.0000	2.0000
TM premix[e]	4.6136	3.5831	2.6132	1.9496	1.9496	1.9496
Vit. A premix[f]	0.1156	0.0893	0.0656	0.0487	0.0487	0.0487
Vit. E premix[g]	0.9609	0.7468	0.5442	0.4062	0.4062	0.4062
Rumensin 80[h]	0.5406	0.4100	0.4492	0.4569	0.4569	0.4569
Tylan 100[i]	.	0.2239	0.1631	0.1219	0.1219	0.1218

[a] Percentage of as-fed.
[b] HCP = 13.50% crude protein (CP) finish diet with 3.50% CP equivalent (CPE) from non-protein nitrogen (NPN), ICP = 12.56% CP finish diet with 2.53% CPE from NPN, LCP = 11.62% CP finish diet with 1.55% CPE from NPN.
[c] Min Ad Inc., Amarillo, TX. (21.45% calcium and 11.68% magnesium, DM basis).
[d] Potassium Chloride.
[e] Trace mineral premix: Cobalt, 500 ppm; Copper, 2.5%; Manganese, 6.25%; Zinc, 18.75%; Iodine, 630 ppm; and Selenium, 300 ppm.
[f] 110,200,000,000 IU vitamin A activity per kg.
[g] 198,360 IU vitamin E activity per kg.
[h] Monensin, 176.4 g per kg.
[i] Tylosin, 220.5 g per kg
.

Figure 3.1. Mass balance, 7-steer pen layout and surface soil sample locations for the oscillated crude protein and protein withdrawal study.



*Trial pens maintained roughly a 5-7% slope, with the bottom of the pen being at the lowest point.

Literature Cited

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CHAPTER IV

RESULTS AND DISSCUSSION

Feed Ingredient and Finishing Diet Nutrient Concentration

Analyzed nutrient concentrations for the starter and step-up diets were not determined. Raw means and standard errors describing the nutrient composition for the finishing diets and supplements are presented in Appendix B. The analyzed dry matter (DM) nutrient concentrations for the finishing diets and primary feed ingredients are displayed in Tables 4.1 and 4.2, respectively. Concentrations observed for most nutrients were reasonably close to theoretical values displayed in Table 3.3. Dry matter concentrations were not different between treatments *(P > 0.10)*. However, DM was different for sampling month *(P<0.05)*, likely due to differences in DM concentration of the corn silage. As expected, crude protein (CP) concentration differed by treatment *(P < 0.01)*. Analyzed CP concentrations were 13.01, 12.08 and 11.39% (DM basis) for control (HCP), intermediate CP (ICP), and low CP (LCP) rations respectively, and were slightly lower than theoretical CP levels, possibly due to nitrogen (N) volatilization that likely occurred during the sampling, oven drying, and analysis processes. Non-protein nitrogen (NPN) concentrations for the HCP and ICP diets, 3.18% and 2.43% NPN (DM basis) respectively, were slightly lower than the theoretical values, while the LCP diet had a slightly higher NPN concentration (1.70%) than expected. Neutral-detergent fiber (NDF) and fat concentrations differed by treatment *(P < 0.05)* for unknown reasons since all diets were

formulated to contain equal as-fed composition for the primary ingredients and only the ingredient composition of the supplements varied by treatment.

Cattle Health Summary

Six steers exhibited signs on illness prior to the onset of the study and were not assigned to treatment. During the feeding period not enough health issues were observed to effectively conduct a statistical analysis of the health data. Three steers were treated for foot-rot and recovered. There were 2 deaths due to bloat, 1 death for each nerve damage, pen injury, and respiratory illness. Total death loss during the study was 0.83%.

Fecal and Manure Sample Profiles

Dry matter, acid-insoluble ash (AIA), and N content for fecal grab samples from cattle in the16 mass balance pens fed the HCP, OCP, EICP or ELCP diets are presented in figures 4.1, 4.2 and 4.3 respectively. Treatments LICP and LLCP had not implemented when samples were taken therefore are not included in the analysis. Additionally only the mass balance pens are included in this analysis because manure surface samples were not taken from the remaining pens.

Days on feed *($P < 0.0001$)* had a significant effect on DM content of the fecal grab samples and treatment *($P > 0.06$)* and treatment by days on feed *($P > 0.18$)* interaction tended to be significantly different for DM content (Figure 4.1). Steers on higher CP concentrations had fecal with higher DM content. Similar results were seen in Cole et al. (2003) where it was report that fecal DM was higher for steers fed at 14% CP diet and oscillated CP diets compared to a lower CP (12%) diet. However, the reason for the differences in both studies is not apparent.

Days on feed differences in the fecal grab samples for DM content could possibly be explained by dying techniques. Samples were dried in different oven for sample from d 74 and 106 than they were for d 30. Dry matter content from day 30 were numerically lower than d 74 and 106 for all treatments, but all sampling period were significantly different than one another *(P < 0.05).* The samples from d 30 were also in the drying ovens for approximately seven d, while samples from d 74 and 106 were in the drying oven for 2 or 2 d depending on sample size and the samples were also stirred roughly every eight h to decrease drying time.

Similar to DM content, sampling period had a significant effect on AIA (Figure 4.2; *P < 0.05*) and N (Figure 4.3; *P < 0.05).* This could possibly be explained by the digestibility results for this study. Both DM and N digestibility increased with d on feed. Therefore, the AIA concentration in the fecal samples is likely to be higher and the N content is likely to be lower in the first period compared to the last period and the results from this study support that explanation. AIA content was significantly higher for d 106 than it was for d 30and 74 *(P < 0.05).* Nitrogen content of the fecal grab samples from d 30 were significantly lower than both d 74 and 106 *(P < 0.05)*. Crude protein regimen did not affect either AIA *(P > 0.69)* or N *(P > 0.73)* concentration of the fecal samples. In another study, fecal N and AIA concentration did not vary between high, intermediate and oscillated CP treatments (Cole et al., 2003).

It is important to note that there appeared to be outliers for the analysis of fecal AIA content within each treatment group (see figure 4.2), however the data was analyzed with and without these data point (when AIA% > than 13%) and the results appears to be similar. Consequently, the data point remained in the data set and the results are obtained from the complete set of data.

Phosphorus content was not different for days on feed *(P > 0.40)*, treatment *(P > 0.50)* or treatment by days on feed interaction *(P > 0.50)*. In addition, there was no treatment effect for the nitrogen to phosphorus ratio (N: P; *P > 0.73)*. However, there tended to be a period and treatment by days on feed interaction in the N: P *(P < 0.10)*. The difference in the N: P is likely a result in the difference in N content of the fecal grab samples, which ultimately is a result of N digestibility.

The analyzed pen surface samples that were collected on d 150 or 163 from the mass balance pens on were not different in DM, AIA, N, or P content *(P > 0.23)*. The N: P ratio in the fecal grab samples compared to the final manure surface samples is presented in Figure 4.4. Fecal grab samples were composited by treatment for P analysis. Therefore, statistical analyses could not be performed to test for treatment differences for N: P. Pen surface samples were analyzed as independent replicates and no treatment differences *(P > 0.36)* for N or P concentration or N:P ratio. The N: P ratios ranged from 2.13 to 2.23 and where drastically lower than the fecal grab sample N: P ratio. The reason for the change in N: P is likely due to the loss of N due to volatilization and runoff. Although Nebraska researchers have demonstrated that N lost as run-off from the surface of open feedlot pens is low (Bierman et al., 1999). The N: P ratio for the fecal grab samples tended to be significantly different for days on feed *(P < 0.10)* and treatment by days on feed effect *(P < 0.10)*, but there was no treatment effect *(P > 0.10)*. There was no overall difference in the surface manure samples.

Feedlot performance

Raw means and standard errors describing feedlot performance for the steers are presented in Appendix D. Least squares means describing feedlot performance and net energy

recovery results for the study are presented in Tables 4.3 and 4.4. Steers were on feed for an average of 162 d (149 d for replicates 7 through 12 and 175 d for replicates 1 through 6). Although treatment differences for initial BW (328.7 ± 7.6 kg) were not significant *(P > 0.18)*, covariate analysis demonstrated that initial weight was a significant *(P < 0.10)* source of variation describing most feedlot performance measurements and was thus used as a covariate in the statistical analysis. There were no treatment differences for shrunk BW at d 30 (381.6 ± 1.87 kg, *P > 0.91*), d 74 (446.3 ± 2.47 kg, *P > 0.64*), d 106 (486.0 ± 3.85 kg, *P > 0.24*), d 141 (531.5 ± 4.44 kg, *P > 0.23*), or slaughter (549.0 ± 5.94 kg, *P > 0.27*). Average daily gain (ADG) for d 1 through d 30 (P > 0.90), d 31 through 74 *(P > 0.50)*, d 75 through 106 *(P > 0.26)*, d 107 through 141 *(P > 0.69)*, during the final 28 d on feed (P > 0.88), and d 1 through slaughter *(P > 0.32)* were not affected by CP regimen. As expected, ADG gradually decreased with increasing days on feed for all treatments.

Daily DMI was not significantly affected by treatment from d 1 through d 30 *(P > 0.44)* as steers were being stepped-up on feed, from d 31 through d 74 *(P > 0.45)*, or from d 75 through d 106 *(P > 0.60)*. However, from d 107 through d 141, and d 142 through slaughter DMI was affected by treatment *(P < 0.05)*. Daily DMI from d 107 through d 141 for the HCP treatment (8.83 kg) was similar to DMI for the OCP (8.73 kg, *P > 0.72*), EICP (8.60 kg, *P > 0.41)*, and LICP (8.55 kg, *P > 0.31*) treatments; however, DMI was reduced for the ELCP (8.26 kg, *P < 0.05*) and LLCP (7.99 kg, *P < 0.01*) treatments as compared with HCP. A similar pattern was found for DMI the final period immediately before slaughter with similar (*P > 0.35*) DMI observed for the HCP, OCP, and EICP treatments (8.64, 8.40, and 8.40 kg, respectively) and reduced DMI observed for the ELCP (8.00 kg, *P < 0.02*), LICP (8.14 kg, *P < 0.07*), and LLCP (7.82 kg, *P < 0.01*) treatments as compared with HCP. From d 1 through slaughter, DMI

tended to differ between treatments *(P < 0.11*). Although DMI from d 1 through slaughter was similar for OCP (8.70 kg, *P > 0.70)* and EICP (8.62 kg, *P > 0.37*) steers as compared with HCP (8.76 kg) steers, DMI appeared lower for the ELCP (8.49 kg, *P < 0.09*) and LLCP (8.35 kg, *P < 0.01)* treatments as compared with HCP.

Despite this apparent reduction in DMI and non-significant differences in ADG associated with CP treatment during later stages of the feeding period, treatment differences for efficiency, either feed-to-gain (F:G), gain-to-feed (G:F) ratio, or NE recovery were not statistically significant *(P > 0.30).*

In comparison with the current study, Cole et al. (2003) noted similar results. Cole stated that there was an increase in DMI in steers that were fed higher CP diets (14% CP vs. 12% CP and oscillating 10 and 14% CP). Krehbiel et al. (1998) also reported that the inclusion of soybean meal to a bromegrass hay diet fed to sheep supported higher DMI. Similar results were seen in Collins and Pritchard (1992) and Archibeque et al. (2007a) in regards to increasing DMI with increasing CP supplementation.

In respect to oscillated CP diets, Ludden (2003) and Archibeque et al. (2007b) observed no difference in DMI compared to feeding a constant protein source. In contrast, Archibeque and his colleagues (2007c) reported an increase in DMI with respect to oscillated CP diets compared to lower CP diets.

Carcass Merit and Ultrasound Data

Raw means and standard error describing carcass data are shown in Table Appendix E. Least squares means describing the effect of CP treatment on carcass merit are presented in Table 4.7. Initial weight was a significant (*P < 0.10*) source of variation describing most carcass measurements and was therefore included as a covariate in the analysis of carcass data. Crude

protein treatment had no effect of HCW (*P > 0.41*), dressing percentage (*P > 0.63*), fat depth (*P > 0.99*), ribeye area (*P > 0.95*), average USDA Yield Grade (*P > 0.65*), Yield Grade category (*P > 0.89*), marbling score (*P > 0.74*), Quality Grade category, (*P > 0.58*), or the likelihood that an individual liver showed signs of liver abscesses (*P > 0.49*). Evaluation of the carcass data indicate that the steers fed as part of this study could have used more days on feed. Dressing percentage averaged only 63.1% rather than greater than 63.5% typically observed for steers fed at SECRC. No carcasses weighed over 453.6 kg and very few were observed that weighed more than 430.5 kg. In addition, less than 5% of the total carcasses qualified for the Yield Grade 4 and 5 categories.

In contradiction to the results from this study, Cole et al. (2003) reported that steer fed a 14% CP diet had lower dressing percents, smaller REA, and higher quality grades compared to steers fed an oscillated CP diet (10% and 14% CP). There was also a smaller percentage of steers on the oscillated CP diet that reached higher choice or above (Cole et al., 2003).

The ultrasound measurements taken on d 30 or 31, 73 or 74, 106 or 107, and 141 (replicates 1 through 6 only) and the camera carcass data were used to determine if CP treatment and days on feed impacted fat depth at the 12^{th} rib, marbling score, or ribeye area. Regression equations were developed to predict changes in 12^{th} rib fat (Figure 4.7), marbling score (Figure 4.8), and ribeye area (Figure 4.9). Although individual prediction equations for each treatment are shown, statistical evaluations of the regression coefficients indicate that treatment had no effect on the intercept or slopes of the equations (Tables 4.8, 4.9, and 4.10). The equation predicting 12^{th} rib fat depth, marbling score, and ribeye area are:

$$\text{Fat depth (centimeters)} = 0.5388 + (-0.00375*\text{DOF}) + (0.000038*\text{DOF}^2)$$

Marbling score (3.00 = Slight^{00}, 4.00 = Small^{00}) = 3.5882 + (-0.02217*DOF) + (0.00015*DOF^2)

Ribeye area (square centimeters) = 68.1839 + (0.1912*DOF) + (-0.00046*DOF^2)

As expected, fat accretion increases at an increasing rate with additional days on feed while muscling begins to level off with increasing days on feed. These equations may be used predict common compositional outcomes for research cattle in the future. For example average ultrasound fat depth readings obtained for a pen of cattle at approximately d 120 could be used in the above equation to predict the additional days required for the pen to achieve 1.27 centimeters of 12th rib fat depth.

Nitrogen and Dry Matter Digestibility

The least square means for N and DM digestibility calculated using two different methods are presented in Tables 4.5 and 4.6. Treatment was not applied to the LLCP and LICP treatment groups during the time of fecal sample collection; therefore, these treatments are excluded from the analysis.

Digestibility calculated using Method 1 resulted in a treatment by days on feed interaction for N digestibility ($P < 0.01$) and N digestibility increased ($P < 0.01$) with days on feed for all treatments. Treatment differences were not significant ($P > 0.10$) for N digestibility. Similar results were seen with DM digestibility. There was a significant effect with days on feed ($P < 0.01$) and the treatment by days on feed interaction was significant ($P < 0.01$) for DM

digestibility. Although DM digestibility was numerically lower for the diets with lower N concentration, differences were not statistically significant (P > 0.10).

The results from Method 1 (Eq2) were higher than results for Method 2 for dry matter digestibility (Table 4.5). Similar results have been reported in the literature for calculating digestibility with AIA versus estimates made from actual or estimated fecal output (Sunvold and Cochran, 1991; Penning and Johnson, 1985). Nitrogen digestibility was more consistent between the two methods (Table 4.6).

Thonney et al. (1979) suggested that the AIA technique resulted in biased estimates of DM digestibility when used with diets of low AIA concentration such as found in high grain diets. The AIA content of feed samples were relatively low for all rations in this study (0.6318% AIA). Thonney et al. (1985) reported that for diets with less than 0.75% AIA, AIA is a poor indictor of digestibility. Furthermore, Thonney and others noted that with increasing concentrate in the ration there was a decrease in AIA. These values consequently affect the N and DM digestibility values when used in Eq2, therefore Eq4 and Eq5 are more accurate in calculating DM and N digestibility when AIA is first used to determine fecal output.

Figures 4.5 and 4.6 represent N and DM digestibility using Method 2. Raw means are displayed in Table A.3 There was no treatment by days on feed interactions for N ($P > 0.10$) or DM ($P > 0.10$) digestibility. Nitrogen and DM digestibility increased ($P < 0.01$) as days on feed increased. Treatment effects were not significant ($P > 0.10$) for DM digestibility; however, significant ($P < 0.01$) treatment differences were observed for N digestibility. Nitrogen digestibility was higher for the HCP (82.3%) versus the OCP (76.6%, $P < 0.01$), EICP (78.8%, $P < 0.06$), and ELCP (74.8%, $P < 0.0001$) treatments. Similar results for N digestibility have been

reported by Ludden et al. (2002a,b) and Archibeque (2007b). However, other authors suggest that DM digestibility also increases with increasing dietary CP (Cole, 1999; Archibeque, 2007b).

Nitrogen Intake, Retention, and Excretion

Nitrogen intake, retention, and excretion results are summarized in Table 4.11. Treatments LICP and LLCP were not included in this analysis because the treatments had not been applied when the samples were taken. Nitrogen intake was determined on an average per pen basis based on DM delivery and theoretical CP level (N conversion factor 6.25). As expected, N intake increased ($P < 0.0001$) with increasing CP concentration and averaged 182.9, 171.8, 166.9, and 154.8 g per steer daily for the HCP, OCP, EICP, and ELCP treatments, respectively. Daily N retention, expressed as g per steer, was similar ($P > 0.4203$) among all treatments (23.0, 23.3, 22.5, and 23.1 g per steer daily for the HCP, OCP, EICP, and ELCP treatments, respectively). When expressed as a percentage of N intake, retained N increased ($P < 0.0001$) with decreased N intake and averaged 12.6, 13.6, 14.1, and 15.0% for the HCP, OCP, EICP, and ELCP treatments, respectively. Fecal N calculated from fecal output estimates and the analyzed fecal N concentration was also similar ($P > 0.18$) among treatments and averaged 32.1, 37.4, 35.4, and 37.2 g per steer daily for the HCP, OCP, EICP, and ELCP treatments, respectively. However, fecal N as a percentage of N intake increased ($P < 0.01$) with decrease N intake (17.6, 21.8, 21.3, 24.3% for the HCP, OCP, EICP, and ELCP treatments, respectively). Urinary N, calculated as N intake minus retained N minus fecal N, decreased ($P < 0.0001$) as diet CP concentration decreased (127.8, 111.2, 108.0, and 94.4 g per steer daily for the HCP, OCP, EICP, and ELCP treatments, respectively). Urinary N excretion, expressed as a percentage of N intakes, was increased as N intake increased ($P < 0.001$) averaging 60.7, 64.6, 64.6, and

69.8% for the ELCP, EICP, OCP, and HCP treatments, respectively. The fate of N intake for each of the fecal sampling periods is displayed in Figures 4.10, 4.11, 4.12 and 4.13.

Ammonia Flux

Only cattle on the HCP, OCP and ELCP diets were evaluated for this portion of the study. Ammonia emission difference by treatment and cumulative ammonia volatilization results are presented in Table 4.12 and Figure 4.14 respectively. Ammonia flux results (Galles et al., 2011) closely match the calculated N excretion results from this study.

There was a significant difference *($P < 0.01$)* between the ELCP and HCP treatments for samples collected on d 45 and d 92 and the difference between treatments tended towards significant for d 148 (*$P < 0.21$* for HCP and *$P < 0.13$* for OCP; Figure 4.16). The total ammonia flux for cattle fed ELCP diet over cattle fed HCP diets amounted to a decrease of 40%, 25%, and 21% for d 45, 92 and 148 respectively. The reduction can be explained, but the significant decrease of urinary N between treatments.

Ammonia emissions were analyzed over a 7 d period (Table 4.12). Prior to all sampling days the research feedlot received precipitation events, resulting in all sampling dates being under wet conditions. For this study, ammonia volatilization results were influenced by the high initial water content of the pen surface samples. An advantage of the wet initial sample condition is that a homogenous and we represented sample was obtained. However, the ammonia flux trends that were observed from this study are not typical of what normally would occur under drier conditions. Previous research has shown with drier samples there is a decline in ammonia flux over time, with the highest flux reported on d 1 in the chamber. The samples

from this study showed fluxes that increased with time in the chamber possibly due to the high initial moisture content.

Table 4.1. Analyzed nutrient composition of the finishing diets and supplements used for the oscillated crude protein and protein withdrawal study.

Item[a]	HCP[b]	ICP[c]	LCP[d]	SEM	Prob. > F
Diet					
Dry Matter	67.59	68.48	68.88	0.37	0.1161
Crude Protein	13.01	12.08	11.39	0.18	< 0.0001
Non-Protein Nitrogen	3.18	2.43	1.70	0.08	< 0.0001
Neutral detergent fiber	13.30	12.61	12.37	0.19	0.0204
Ether extract	6.42	6.94	7.25	0.15	0.0106
Calcium	0.74	0.77	0.71	0.04	0.7896
Phosphorus	0.36	0.35	0.35	0.02	0.6019
Potassium	0.67	0.68	0.69	0.01	0.6434
Magnesium	0.32	0.33	0.32	0.01	0.9706
Sulfur	0.17	0.17	0.17	0.01	0.5858
Supplements					
Dry Matter	97.17	96.74	96.46	0.45	0.5432
Crude Protein	85.75	66.90	43.33	2.03	< 0.0001
Non-Protein Nitrogen	83.54	63.73	41.50	1.88	< 0.0001
Calcium	16.37	15.87	16.40	0.31	0.4167
Phosphorus	0.00	0.00	0.01	0.01	0.5121
Potassium	2.77	2.68	2.94	0.09	0.1658
Magnesium	4.30	4.41	4.34	0.07	0.5758

[a] Percentage of dry matter unless stated otherwise

[b]High crude protein diet at 13.5% CP, 3.5% crude protein equivalent (CPE) from non-protein nitrogen (NPN).

[c]Intermediate crude protein diet at 12.56% CP, 2.53% CPE from NPN.

[d]Low crude protein diet at 11.62% CP, 1.55% CPE from NPN.

Table 4.2. Dry matter nutrient composition as determined by laboratory analysis of feed ingredients used in the diets for the oscillated crude protein and protein withdrawal study.

Item[a]	Alfalfa Hay[b]	Corn Steep Liquor[c]	Corn Silage[b]	DDG[cd]	Flaked Corn[b]
Dry Matter[e]	84.33 ± 1.04	46.50 ± 2.08	34.25 ± 1.30	88.85 ± 0.52	75.02 ± 0.68
Crude Protein	16.75 ± 0.66	35.89 ± 1.37	8.77 ± 0.34	29.73 ± 0.91	8.96 ± 0.15
NPN[f]		2.45 ± 0.36		0.27 ± 0.06	
ADF[g]	40.80 ± 1.35		23.69 ± 1.45		2.81 ± 0.13
NDF[h]	50.03 ± 1.51	2.34 ± 0.99	38.67 ± 1.59	30.58 ± 0.88	10.82 ± 0.22
Ether Extract[i]		1.64 ± 0.16		11.64 ± 0.29	
Calcium	1.28 ± 0.06	0.07 ± 0.01	0.49 ± 0.05	0.06 ± 0.02	0.94 ± 0.02
Phosphorus	0.33 ± 0.01	2.63 ± 0.14	0.19 ± 0.02	0.86 ± 0.02	0.73 ± 0.02
Potassium	2.72 ± 0.13	3.74 ± 0.18	1.26 ± 0.05	1.03 ± 0.02	1.05 ± 0.02
Magnesium	0.30 ± 0.02	1.03 ± 0.04	0.22 ± 0.01	0.37 ± 0.02	89.79 ± 1.49
Sulfur		0.82 ± 0.03		0.47 ± 0.03	

[a] Percentage of dry matter ± SEM unless stated otherwise.
[b] Determined by NIRS methodology.
[c] Determined by wet chemistry.
[d] Dried Distiller's Grains plus solubles.
[e] Percentage of as-fed. Dry matter concentration for corn steep water was determined by Karl-Fisher methodology.
[f] Non-protein nitrogen, crude protein equivalent.
[g] Acid detergent fiber.
[h] Neutral detergent fiber.
[i] Determined by acid hydrolysis for corn steep liquor and by ether extract for DDG.

Table 4.3. Least squares means showing the effect of crude protein treatment on feedlot performance.

Item[b]	Treatments [a]							
	High	OSC	EICP	ELCP	LICP	LLCP	SEM	Prob. > F
Initial wt., kg	331.1	330.2	330.0	329.0	329.0	328.7	7.5633	0.1822
Day 30 wt., kg	381.4	382.2	380.3	381.9	381.3	382.5	1.8720	0.9176
Day 74 wt., kg	446.3	449.1	446.2	448.6	444.2	445.8	2.4771	0.6402
Day 106 wt., kg	485.9	489.6	488.9	489.6	481.3	481.2	3.8481	0.2382
Day 141 wt., kg	529.0	534.9	537.3	533.6	528.5	525.5	4.4391	0.2334
Finish wt., kg	548.2	553.4	555.1	547.7	546.8	542.6	5.9358	0.2774
ADG, d1-30, kg	1.70	1.73	1.67	1.72	1.70	1.74	0.0647	0.9020
ADG, d31-74, kg	1.50	1.55	1.52	1.54	1.45	1.47	0.0608	0.5007
ADG, d75-106, kg	1.21	1.23	1.30	1.25	1.13	1.08	0.0932	0.2650
ADG, d107-141, kg	1.13	1.20	1.27	1.13	1.23	1.16	0.1003	0.6905
ADG, d1-finish, kg	1.34	1.37	1.39	1.35	1.34	1.32	0.03112	0.3280
ADG, Final 28d, kg	1.06	1.04	1.10	1.03	1.12	1.04	0.0824	0.8824
DMI, d1-30, kg	8.74	8.80	8.74	8.80	8.59	8.62	0.0952	0.4475
DMI, d31-74, kg	8.84	8.79	8.74	8.65	8.65	8.64	0.0901	0.4504
DMI, d75-106, kg	8.77	8.74	8.65	8.75	8.65	8.46	0.1545	0.6051
DMI, d106-141, kg	8.83	8.72	8.60	8.26	8.55	7.99	0.2197	0.0422
DMI, final 28d, kg	8.64	8.40	8.39	8.00	8.14	7.82	0.2481	0.0401
DMI, d1-finish, kg	8.76	8.70	8.62	8.49	8.53	8.35	0.1311	0.1081
F:G, d1-30	5.24	5.24	5.45	5.17	5.09	5.05	0.1033	0.6485
F:G, d31-74	6.02	5.92	5.88	5.78	6.10	6.07	0.1237	0.7865
F:G, d75-106	7.96	7.48	7.08	7.23	8.64	9.55	0.4255	0.3124
F:G, d107-141	8.24	7.74	6.98	7.56	7.75	7.56	0.2682	0.6504
F:G, final 28d	8.82	8.43	7.92	8.39	7.85	7.89	0.3066	0.6581
F:G, d1-finish	6.54	6.37	6.23	6.30	6.40	6.38	0.0600	0.4830
G:F, d1-30	0.196	0.196	0.191	0.196	0.199	0.204	0.0074	0.7397
G:F, d31-74	0.170	0.177	0.175	0.180	0.169	0.171	0.0077	0.6579
G:F, d75-106	0.137	0.141	0.149	0.143	0.130	0.126	0.0100	0.3201
G:F, d107-141	0.129	0.138	0.148	0.136	0.143	0.143	0.0114	0.6103
G:F, final 28d	0.123	0.125	0.131	0.128	0.137	0.134	0.0095	0.6587
G:F, d1-finish	0.154	0.159	0.161	0.159	0.157	0.158	0.0032	0.4889

[a]Treatments: HCP=high crude protein at 13.5%, OSC=Oscillating crude protein (13.5% CP diets alternating with 11.62% CP diet, EICP= (12.56% CP), -ELCP= (11.62% CP), LICP= HCP diet and ICP diet the last 27d, LLCP=HCP diet and LCP diet the last 27d

[b]ADG = Average daily gain; DMI = Daily dry matter intake; F:G = Feed to gain ratio, kg dry matter/kg gain; G:F = Gain to feed ratio, kg gain/kg dry matter.

Table 4.4. Least squares means showing the effects of crude protein treatment on net energy recovery.

	Treatment [a]							
Item[b]	Control	OCP	EICP	ELCP	LICP	LLCP	SEM	Prob. > F
NEm, d1-30	2.373	2.379	2.334	2.376	2.408	2.444	0.0625	0.7267
NEm, d31-74	2.383	2.458	2.433	2.487	2.387	2.406	0.0725	0.6861
NEm, d75-106	2.289	2.327	2.410	2.346	2.213	2.192	0.0977	0.3201
NEm, d107-141	2.313	2.437	2.550	2.462	2.477	2.559	0.1169	0.4573
NEm, final 28d	2.333	2.400	2.461	2.454	2.530	2.511	0.1090	0.3072
NEm, d1-finish	2.339	2.401	2.433	2.412	2.389	2.403	0.0383	0.4432
NEg, d1-30	1.672	1.677	1.637	1.674	1.702	1.733	0.0548	0.7267
NEg, d31-74	1.686	1.745	1.724	1.771	1.684	1.700	0.0636	0.6861
NEg, d75-106	1.588	1.631	1.703	1.648	1.531	1.513	0.0857	0.3201
NEg, d107-141	1.618	1.728	1.827	1.749	1.762	1.812	0.1025	0.4573
NEg, Final 28d	1.636	1.695	1.749	1.742	1.809	1.792	0.0898	0.3721
NEg, d1-finish	1.641	1.696	1.724	1.705	1.685	1.698	0.0336	0.4432

[a]Treatments: HCP=high crude protein at 13.5%, OSC=Oscillating crude protein (13.5% CP diets alternating with 11.62% CP diet, EICP= (12.56% CP), -ELCP= (11.62% CP), LICP= HCP diet and ICP diet the last 27d, LLCP=HCP diet and LCP diet the last 27d

[b]NEm = Net energy for maintenance derived from performance, Mcal/kg dry matter; NEg = Net energy for gain derived from performance, Mcal/kg dry matter.

Table 4.5. Least square means and standard error of the mean for two different methods of calculating dry matter digestibility for various crude protein regimens.

		Treatment[a]			
Days on Feed	Method[b]	HCP	OCP	EICP	ELCP
30	1	96.07 ± 0.52	95.83 ± 0.52	96.02 ± 0.50	95.52 ± 0.50
	2	81.86 ± 1.78	79.84 ± 1.72	81.14 ± 1.72	77.95 ± 1.72
74	1	95.36 ± 0.49	96.32 ± 0.50	96.07 ± 0.50	96.86 ± 0.50
	2	86.81 ± 1.72	84.27 ± 1.72	83.37 ± 1.72	82.54 ± 1.72
106	1	99.60 ± 0.50	97.62 ± 0.5	97.19 ± 0.54	96.82 ± 0.52
	2	88.30 ± 1.78	86.71 ± 1.78	88.11 ± 1.78	88.55 ± 1.72

Method 1: Treatment, P = 0.2689; Days on feed, P < 0.0001; Treatment by Days on feed, P = 0.0001.
Method 2: Treatment, P = 0.3713; Days on feed, P < 0.0001; Treatment by Days on feed, P = 0.5017.

[a] Treatments: HCP = 13.5% crude protein (CP) and 3.5% crude protein equivalent (CPE) from non-protein nitrogen (NPN) from d 22 through slaughter. OCP = Oscillating CP between the HCP diet fed M, Tu, F, and Sa and LCP fed W, Th, and Su from d 22 through slaughter. EICP = 12.56% CP and 2.53% CPE from NPN from d 22 through slaughter. ELCP = 11.62% CP and 1.55% CPE from NPN from d 22 through slaughter.

[b] Method 1: $DM\ Digestiblity\ (\%) = 100 - (100 \times \frac{\%\ AIA\ in\ feed}{\%\ AIA\ in\ feces} \times \frac{\%\ DM\ in\ feces}{\%\ DM\ \ in\ feed})$;

Method 2: $Fecal\ Output\ (weight: FO) = \frac{(DMI \times Feed\ AIA\ concentration)}{Fecal\ AIA\ concentration}$; $DM\ Digestibilty(\%) = \frac{(DMI - FO)}{DMI} \times 100$

Table 4.6. Least square means and standard error of the mean for two different methods of calculating nitrogen digestibility for various crude protein regimens.

		Treatment[a]			
Days on feed	Method[b]	HCP	OCP	EICP	ELCP
30	1	75.71 ± 4.08	69.20 ± 4.09	72.76 ± 3.92	66.06 ± 3.92
	2	77.60 ± 2.55	72.15 ± 2.46	74.55 ± 2.46	68.15 ± 2.46
74	1	75.62 ± 3.92	75.21 ± 4.09	75.42 ± 3.92	78.16 ± 3.92
	2	83.92 ± 2.46	77.43 ± 2.55	77.03 ± 2.46	73.61 ± 2.46
106	1	88.86 ± 3.99	84.68 ± 4.59	80.57 ± 4.27	77.83 ± 4.08
	2	85.28 ± 2.55	80.13 ± 2.92	84.71 ± 2.65	82.68 ± 2.46

Method 1: Treatment, P = 0.5491; Days on feed, P < 0.0001; Treatment by days on feed, P = 0.0072.
Method 2: Treatment, P = 0.0007; Days on feed, P < 0.0001; Treatment by days on feed, P = 0.3979

[a] Treatments: HCP = 13.5% crude protein (CP) and 3.5% crude protein equivalent (CPE) from non-protein nitrogen (NPN) from d 22 through slaughter. OCP = Oscillating CP between the HCP diet fed M, Tu, F, and Sa and LCP fed W, Th, and Su from d 22 through slaughter. EICP = 12.56% CP and 2.53% CPE from NPN from d 22 through slaughter. ELCP = 11.62% CP and 1.55% CPE from NPN from d 22 through slaughter.

[b] Method 1: $N\ Digestiblity\ (\%) = 100 - (100 \times \frac{\%\ AIA\ in\ feed}{\%\ AIA\ in\ feces} \times \frac{\%\ CP\ in\ feces}{\%\ CP\ \ in\ feed})$;

Method 2: $N\ Digestibility\ (\%) = \frac{Nitrogen\ Intake - Fecal\ Nitrogen}{Nitrogen\ Intake} \times 100$

Table 4.7. Least square means showing the effect of crude protein treatment on carcass merit

Item[a]	HCP	OCP	EICP	ELCP	LICP	LLCP	SEM[b]	Prob. > F
Hot carcass wt, kg	345.2	347.9	350.8	340.7	344.6	343.5	8.17	0.4138
< 273 kg	2.02	0	1.01	2.04	2.02	0		
273 to 429 kg	97.98	98.99	97.98	97.96	97.98	100		
430 to 452 kg	0	1.01	1.01	0	0	0		
≥ 453 kg	0	0	0	0	0	0		
Dressing percent	63.02	62.85	63.21	63.10	63.05	63.35	0.22	0.6396
Fat depth, cm	1.02	1.04	1.04	1.02	1.02	1.02	0.02	0.9904
Ribeye area, cm^2	84.45	83.48	83.68	84.00	84.52	84.64	0.17	0.9593
REA/HCW	1.72	1.69	1.68	1.72	1.73	1.73	0.02	0.2126
USDA YG Category[c]								
YG12	70.08	69.33	66.43	72.41	69.14	72.18	4.85	0.9138
YG3	26.76	24.71	29.48	23.52	25.87	23.71	4.65	0.8979
YG45[f]	4.35	7.22	5.10	4.12	4.08	3.09		
Calc. YG	2.20	2.32	2.32	2.22	2.20	2.20	0.08	0.7076
Marbling score[e]	421.90	434.72	430.91	434.92	431.59	421.76	8.37	0.7498
MARB/FAT[f]	121.09	120.30	114.50	120.79	122.49	118.19	5.00	0.8953
USDA QG Category[c]								
≥ Low Choice	64.59	74.77	71.82	67.42	70.84	65.37	4.82	0.7051
Select	26.29	24.25	22.17	28.54	26.19	26.50	4.56	0.9005
Standard[f]	2.44	0.78	3.13	2.36	2.34	4.86	2.26	0.5811
≥ 30 Months[c,f]	1.07	1.01	0	1.03	0	0		
Abscessed Livers[c]	14.09	14.05	20.02	5.03	10.95	14.15	3.52	0.4957

[a] REA/HCW = ribeye area per cwt hot carcass weight; KPH = kidney, pelvic, and heart fat; Calc. YG = yield grade calculated from carcass measurements; MARB/FAT = marbling units per 0.3 cm 12^{th} rib fat depth; QG = quality grade.
[b] Standard error of the mean.
[c] Percentage likelihood that an individual within each pen qualifies for a specific category.
[d] Data could not be evaluated with PROC GLIMMIX since 1 or more cells equaled 0. Values in the table are the actual percentage of individual carcasses.
[e] Marbling score units, 400 = Small[00], 500 = Modest[00f]

Table 4.8. Prediction of pen ultrasonic and final 12th rib fat depth (cm) from treatment and days on feed for the oscillating crude protein and protein withdrawal study.

Effect	Treatment[a]	Estimate[b]	Standard error	Probability > t
Intercept		0.5388	0.06971	<0.001
Treatment[c]	HCP	0.04703	0.09834	0.6326
Treatment	OCP	-0.00149	0.09818	0.9879
Treatment	ICP	0.01565	0.09848	0.8738
Treatment	ELCP	-0.02459	0.09826	0.8024
Treatment	LICP	0.05336	0.09829	0.5874
Treatment	LLCP	0	.	.
Days on Feed[d]		-.0.00375	0.0010604	0.0197
DOF * TRT[e]	HCP	-0.00166	0.002266	0.4647
DOF * TRT	OCP	0.000082	0.002263	0.9712
DOF * TRT	EICP	0.000901	0.002265	0.6909
DOF * TRT	ELCP	0.001075	0.002262	0.6347
DOF * TRT	LICP	0.000006475	0.002263	0.9977
DOF * TRT	LLCP	0	.	.
DOF * DOF[f]		0.000038	0.000007962	<0.0001
DOF * DOF * TRT[g]	HCP	0.000007291	0.000011	0.5178
DOF * DOF * TRT	OCP	-0.000000988	0.000011	0.9301
DOF * DOF * TRT	EICP	-0.00000582	0.000011	0.6044
DOF * DOF * TRT	ELCP	-0.00000639	0.000011	0.5694
DOF * DOF * TRT	LICP	-0.00000301	0.000011	0.7886
DOF * DOF * TRT	LLCP	0	.	.

[a] HCP = 13.5% crude protein (CP) and 3.5% crude protein equivalent (CPE) from non-protein nitrogen (NPN) from d 22 through slaughter. OCP = Oscillating CP between the HCP diet fed M, Tu, F, and Sa and LCP fed W, Th, and Su from d 22 through slaughter. EICP = 12.56% CP and 2.53% CPE from NPN from d 22 through slaughter. ELCP = 11.62% CP and 1.55% CPE from NPN from d 22 through slaughter. LICP = HCP until 27 d remaining then 12.56% CP and 2.53% CPE from NPN through slaughter. LLCP = HCP until 27 d remaining then 11.62% CP and 1.55% CPE from NPN through slaughter.

[b] Centimeters.

[c] Treatment, P = 0.1184.

[d] Days on Feed, P < 0.0001.

[e] Days on Feed * Treatment, P = 0.9042.

[f] Days on Feed * Days on Feed, P < 0.0001.

[g] Days on Feed * Days on Feed * Treatment, P = 0.8530.

Table 4.9. Prediction of pen ultrasonic and final marbling score from treatment and days on feed for the oscillating crude protein and protein withdrawal study.

Effect	Treatment[a]	Estimate[b]	Standard error	Probability > t
Intercept		3.5882	0.2087	<0.0001
Treatment[c]	HCP	0.03569	0.2948	0.9037
Treatment	OCP	0.05113	0.2942	0.8621
Treatment	EICP	0.1397	0.2950	0.6359
Treatment	ELCP	0.09251	0.2943	0.7533
Treatment	LICP	0.3004	0.2945	0.3080
Treatment	LLCP	0	.	.
Days on Feed[d]		-0.02217	0.004805	<0.001
DOF * TRT[e]	HCP	0.001027	0.006790	0.8799
DOF * TRT	OCP	0.001655	0.006780	0.8072
DOF * TRT	EICP	0.000635	0.006779	0.9254
DOF * TRT	ELCP	0.003345	0.006768	0.6212
DOF * TRT	LICP	-0.00370	0.006774	0.5849
DOF * TRT	LLCP	0	.	.
DOF * DOF[f]		0.000150	0.000024	<0.0001
DOF * DOF * TRT[g]	HCP	-0.00000767	0.000034	0.8206
DOF * DOF * TRT	OCP	-0.00001	0.000034	0.7202
DOF * DOF * TRT	EICP	-0.00000857	0.000034	0.7991
DOF * DOF * TRT	ELCP	-0.00002	0.000034	0.4852
DOF * DOF * TRT	LICP	0.000013	0.000034	0.7077
DOF * DOF * TRT	LLCP	0	.	.

[a] HCP = 13.5% crude protein (CP) and 3.5% crude protein equivalent (CPE) from non-protein nitrogen (NPN) from d 22 through slaughter. OCP = Oscillating CP between the HCP diet fed M, Tu, F, and Sa and LCP fed W, Th, and Su from d 22 through slaughter. EICP = 12.56% CP and 2.53% CPE from NPN from d 22 through slaughter. ELCP = 11.62% CP and 1.55% CPE from NPN from d 22 through slaughter. LICP = HCP until 27 d remaining then 12.56% CP and 2.53% CPE from NPN through slaughter. LLCP = HCP until 27 d remaining then 11.62% CP and 1.55% CPE from NPN through slaughter.

[b] Marbling score, 3.00 = Slight^{00}, 4.00 = Small^{00}.

[c] Treatment, P = 0.4354.

[d] Days on Feed, P < 0.0001.

[e] Days on Feed * Treatment, P = 0.9623.

[f] Days on Feed * Days on Feed, P < 0.0001.

[g] Days on Feed * Days on Feed * Treatment, P = 0.9345.

Table 4.10. Prediction of pen ultrasonic and final ribeye area (cm^2) from treatment and days on feed for the oscillating crude protein and protein withdrawal study.

Effect	Treatment[a]	Estimate[b]	Standard error	Probability > t
Intercept		68.1839	1.9126	<0.0001
Treatment[c]	HCP	-0.00284	2.7016	0.992
Treatment	OCP	-0.3781	2.6962	0.8885
Treatment	EICP	-5.0022	2.7032	0.0646
Treatment	ELCP	-1.2090	2.6975	0.6541
Treatment	LICP	2.3645	2.6985	0.3811
Treatment	LLCP	0	.	.
Days on Feed[d]		0.1912	0.04405	<0.0001
DOF * TRT[e]	HCP	-0.01670	0.06226	0.7886
DOF * TRT	OCP	-0.01040	0.06215	0.8671
DOF * TRT	EICP	0.06790	0.06214	0.2748
DOF * TRT	ELCP	-0.00360	0.06206	0.9537
DOF * TRT	LICP	-0.07572	0.06210	0.2230
DOF * TRT	LLCP	0	.	.
DOF * DOF[f]		-0.00046	0.000219	0.0362
DOF * DOF * TRT[g]	HCP	0.000049	0.000310	0.8740
DOF * DOF * TRT	OCP	0.000035	0.000309	0.9090
DOF * DOF * TRT	EICP	-0.00028	0.000309	0.3697
DOF * DOF * TRT	ELCP	0.000027	0.000309	0.9305
DOF * DOF * TRT	LICP	0.000352	0.000309	0.2541
DOF * DOF * TRT	LLCP	0	.	.

[a] HCP = 13.5% crude protein (CP) and 3.5% crude protein equivalent (CPE) from non-protein nitrogen (NPN) from d 22 through slaughter. OCP = Oscillating CP between the HCP diet fed M, Tu, F, and Sa and LCP fed W, Th, and Su from d 22 through slaughter. EICP = 12.56% CP and 2.53% CPE from NPN from d 22 through slaughter. ELCP = 11.62% CP and 1.55% CPE from NPN from d 22 through slaughter. LICP = HCP until 27 d remaining then 12.56% CP and 2.53% CPE from NPN through slaughter. LLCP = HCP until 27d remaining then 11.62% CP and 1.55% CPE from NPN through slaughter.

[b] Square centimeters.

[c] Treatment, P = 0.3139.

[d] Days on Feed, P < 0.0001.

[e] Days on Feed * Treatment, P = 0.6986.

[f] Days on Feed * Days on Feed, P < 0.0001.

[g] Days on Feed * Days on Feed * Treatment, P = 0.5195.

Table 4.11. Least squares means showing the effect of crude protein treatment on dry matter and nitrogen digestibility and daily nitrogen intake and calculated daily nitrogen retention and excretion in the feces and urine for the oscillating crude protein and early crude protein withdrawal study.

Item	HCP[a]	OCP[b]	EICP[c]	ELCP[d]	SEM[e]	Prob. > F
Dry matter intake, kg	8.76	8.70	8.62	8.49	0.29	0.1081
Fecal output, kg[f]	1.27	1.45	1.38	1.48	0.23	0.3952
DM digestibility, %[g]	85.65	83.61	84.21	83.01	1.25	0.3713
Analyzed CP, %[h]	13.01	12.32	12.08	11.39	0.18	< 0.0001
Nitrogen intake, g	182.9	171.8	166.9	154.8	2.98	< 0.0001
Nitrogen retention, g	23.0	23.3	22.5	23.1	0.48	0.4203
Nitrogen excretion, g	160.0	148.5	143.4	131.7	3.07	< 0.0001
Feces, g	32.1	37.4	35.4	37.2	2.49	0.1801
Urine, g	127.8	111.2	108.0	94.4	4.21	< 0.0001
Nitrogen retention, %[i]	12.6	13.6	14.1	15.0	0.40	< 0.0001
Nitrogen excretion, %[i]	87.4	86.4	85.9	85.0	0.40	< 0.0001
Feces, %[i]	17.6	21.8	21.3	24.3	1.61	0.0049
Urine, %[i]	69.8	64.6	64.6	60.7	1.85	0.0002
Urine excretion, %[j]	79.80	74.7	75.2	71.3	1.96	0.0025
Nitrogen digestibility, %[i,k]	82.26	76.57	78.76	74.81	1.84	0.0007

[a] HCP = High crude protein at 13.5% crude protein (CP) and 3.5% crude protein equivalent (CPE) from non-protein nitrogen (NPN) from d 22 through slaughter.
[b] OCP = Oscillating CP, 13.5% CP diets alternating with 11.62% CP diet.
[c] EICP = 12.56% CP and 2.53% CPE from NPN from d 22 through slaughter.
[d] ELCP = 11.62% CP and 1.66% CPE from NPN from d 22 through slaughter.
[e] Standard error of the LSMean.
[f] Calculated from acid insoluble ash analysis.
[g] [(Dry matter intake – Fecal output) / Dry matter intake] * 100.
[h] CP for the OCP treatment is a weighted average of the HCP and LCP diets [(4 * 13.01) + (3 * 11.39)] / 7.
[i] Percentage of daily nitrogen intake.
[j] Percentage of total nitrogen excretion.
[k] [(Nitrogen intake - fecal nitrogen) / nitrogen intake] * 100

Table 4.12. Ammonia emission differences ($g/m^2/d$) between diet treatments by chamber day intervals[a].

	Treatment		
Interval	HCP[b]	OCP[c]	ELCP[d]
Sampling 1			
Day 1	8.5013[e]	8.1667[e]	4.6370[f]
Days 2-3	8.3987[e]	7.2719[e]	4.2498[f]
Days 4-7	6.1632[e]	5.1572[e]	3.2387[f]
Overall	7.1338[e]	6.2057[e]	3.7160[f]
Sampling 2			
Day 1	8.1053[e]	7.4022[e,f]	5.2136[f]
Days 2-3	9.5240[e]	8.6550[e,f]	6.2713[f]
Days 4-7	9.6828	9.2214	7.7191
Overall	9.4088[e]	8.7387[e]	7.0232[f]
Sampling 3			
Day 1	6.1968	6.1421	4.9983
Days 2-3	6.5797	6.2148	5.2859
Days 4-7	7.8543	8.4937	6.9962
Overall	7.2209	7.4291	6.2691

[a] Galles, k et al. 2011

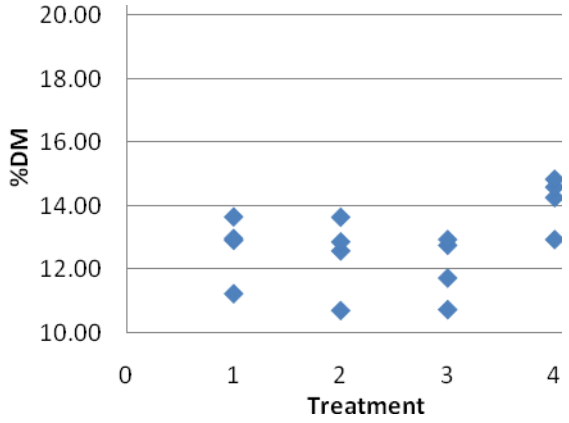
[b]HCP = High crude protein at 13.5% crude protein (CP) and 3.5% crude protein equivalent (CPE) from non-protein nitrogen (NPN) from d 22 through slaughter.

[c] OCP = Oscillating CP, 13.5% CP diets alternating with 11.62% CP diet.

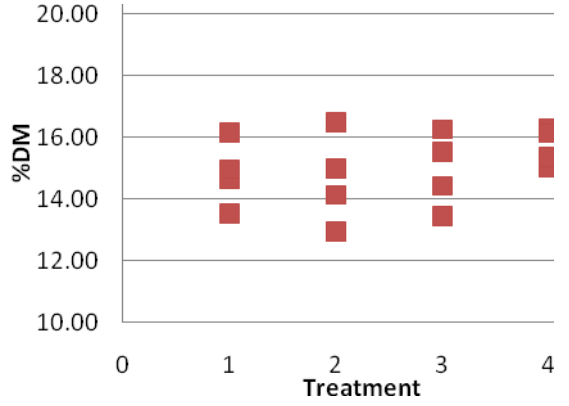
[d] ELCP = 11.62% CP and 1.66% CPE from NPN from d 22 through slaughter.

[e,f] Means in same row with differing superscripts differ, $P < 0.10$.

1A.



1B.



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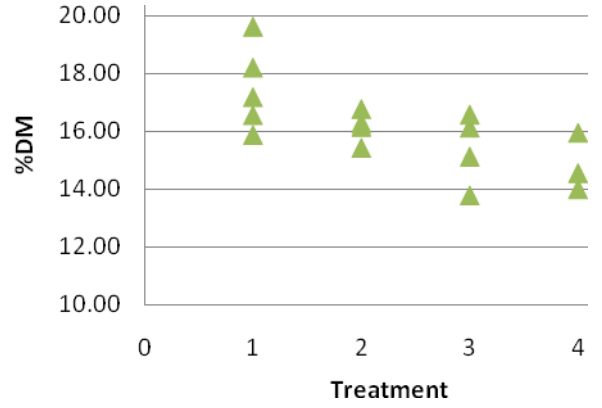
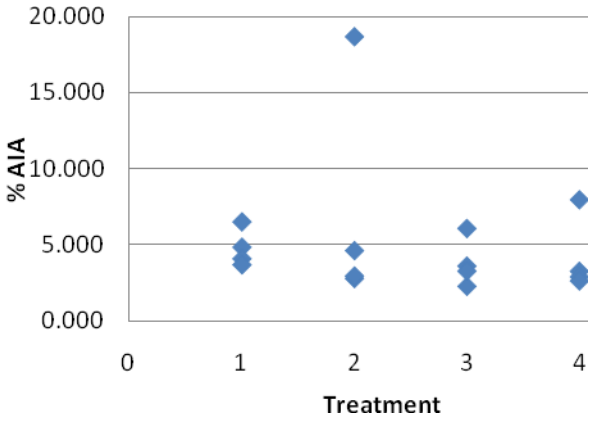


Figure 4.1. Dry matter content in fecal grab samples based on dietary crude protein regimen and days on feed. *Figure 1A.* Fecal grab samples from day 30-31. *Figure 1B.* Fecal grab samples from day 73-74. *Figure 1C.* Fecal grab samples from day 106-107. Treatment 1=HCP = 13.5% crude protein (CP) and 3.5% crude protein equivalent (CPE) from non-protein nitrogen (NPN) from d 22 through slaughter. Treatment 2=OCP = Oscillating CP between the HCP diet fed M, Tu, F, and Sa and LCP fed W, Th, and Su from d 22 through slaughter. Treatment 3=EICP = 12.56% CP and 2.53% CPE from NPN from d 22 through slaughter. Treatment 4=ELCP = 11.62% CP and 1.55% CPE from NPN from d 22 through slaughter. LICP and LLCP not applied at this time. Treatment, $P > 0.0625$. Days on Feed, $P < 0.0001$. Treatment*Days on feed, $P > 0.1801$.

2A.



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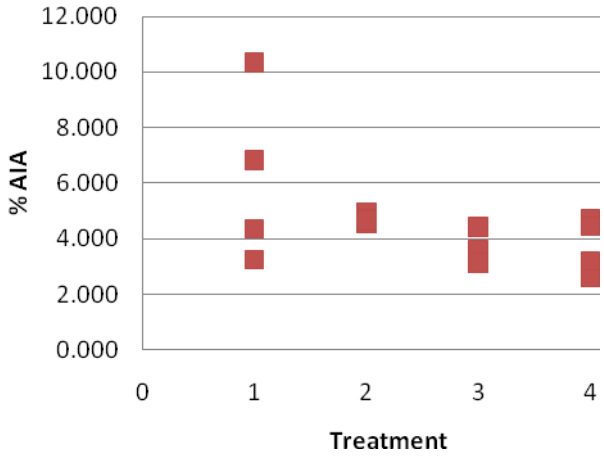

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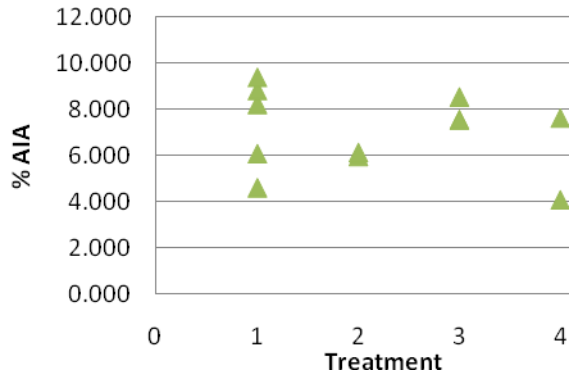
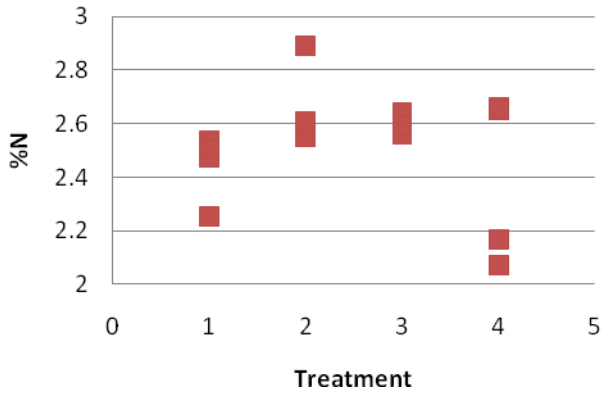
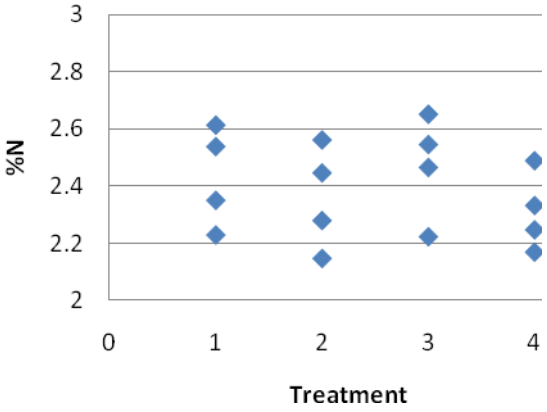


Figure 4.2. Acid-insoluble ash content in fecal grab samples based on dietary crude protein regimen and days on feed. *Figure 2A.* Fecal grab samples from day 30-31. *Figure 2B.* Fecal grab samples from day 73-74. *Figure 2C.* Fecal grab samples from day 106-107. Treatment 1=HCP = 13.5% crude protein (CP) and 3.5% crude protein equivalent (CPE) from non-protein nitrogen (NPN) from d 22 through slaughter. Treatment 2=OCP = Oscillating CP between the HCP diet fed M, Tu, F, and Sa and LCP fed W, Th, and Su from d 22 through slaughter. Treatment 3=EICP = 12.56% CP and 2.53% CPE from NPN from d 22 through slaughter. Treatment 4=ELCP = 11.62% CP and 1.55% CPE from NPN from d 22 through slaughter. LICP and LLCP not applied at this time. Treatment, $P > 0.7521$. Days on Feed, $P = 0.0310$. Treatment*Days on Feed, $P > 0.8972$.

3A.



3B.



3C.

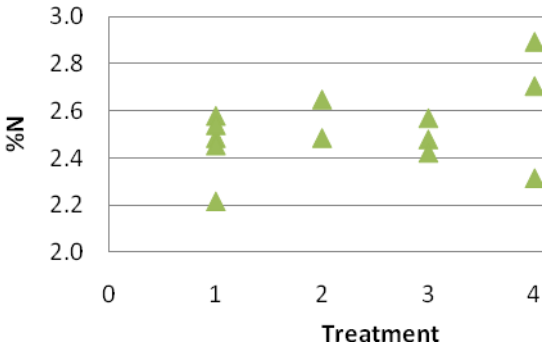


Figure 4.3. Nitrogen content in fecal grab samples based on dietary crude protein regimen and day on feed. *Figure 3A.* Fecal grab samples from day 30-31. *Figure 3B.* Fecal grab samples from day 73-74. *Figure 3C.* Fecal grab samples from day 106-107. Treatment 1=HCP = 13.5% crude protein (CP) and 3.5% crude protein equivalent (CPE) from non-protein nitrogen (NPN) from d 22 through slaughter. Treatment 2=OCP = Oscillating CP between the HCP diet fed M, Tu, F, and Sa and LCP fed W, Th, and Su from d 22 through slaughter. Treatment 3=EICP = 12.56% CP and 2.53% CPE from NPN from d 22 through slaughter. Treatment 4=ELCP = 11.62% CP and 1.55% CPE from NPN from d 22 through slaughter. LICP and LLCP not applied at this time. Treatment, $P > 0.6987$. Days on Feed, $P > 0.0155$. Treatment*Days on feed, $P > 0.4415$.

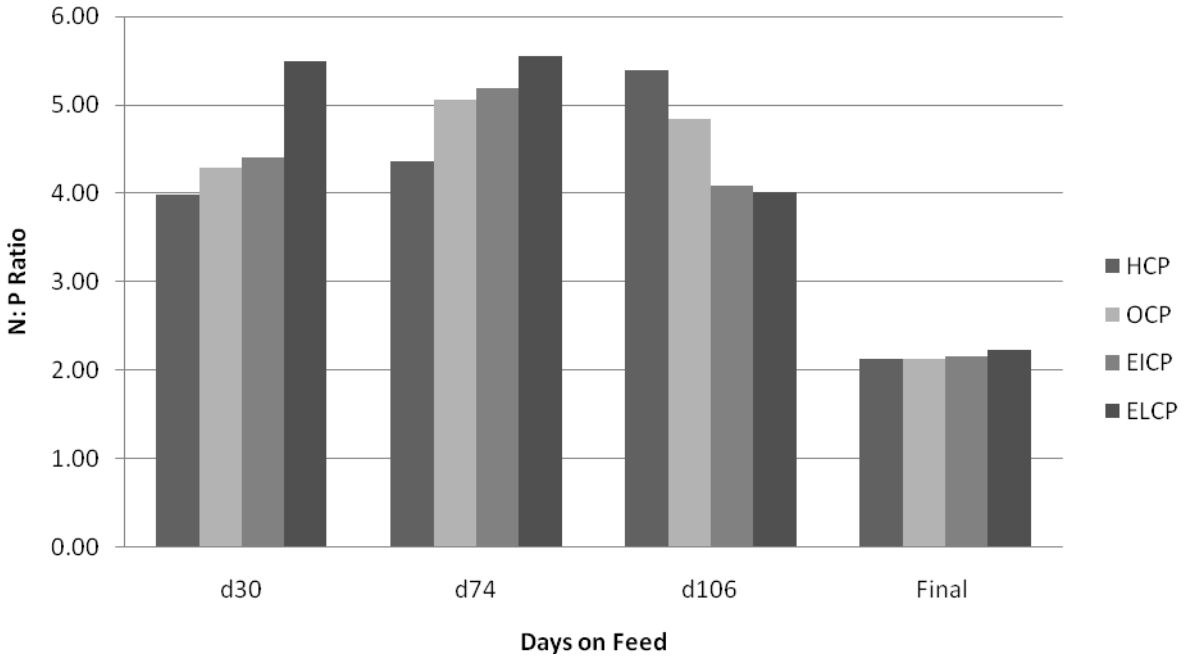


Figure 4.4. Nitrogen: Phosphorus ratio in fecal grab samples compared to final pen surface manure sample from pen surface of steers feed various crude protein regimens. Data set consist of 16 mass balance pens (4 pens/ per treatment) with 9 steers in a pen. Samples were taken on d 30 or d 31, d 73 or d 74, or d 106 or d107. Final manure samples were taken on either d 151 or d 163. HCP = 13.5% crude protein (CP) and 3.5% crude protein equivalent (CPE) from non-protein nitrogen (NPN) from d 22 through slaughter. OCP = Oscillating CP between the HCP diet fed M, Tu, F, and Sa and LCP fed W, Th, and Su from d 22 through slaughter. EICP = 12.56% CP and 2.53% CPE from NPN from d 22 through slaughter. ELCP = 11.62% CP and 1.55% CPE from NPN from d 22 through slaughter. Fecal grab samples: Treatment P = 0.7358; Period P = 0.0965; Period * Treatment P = 0.0869. Final pen surface manure sample: Treatment P = 0.8418; Period P = 0.9774; Period * Treatment P = 01734.

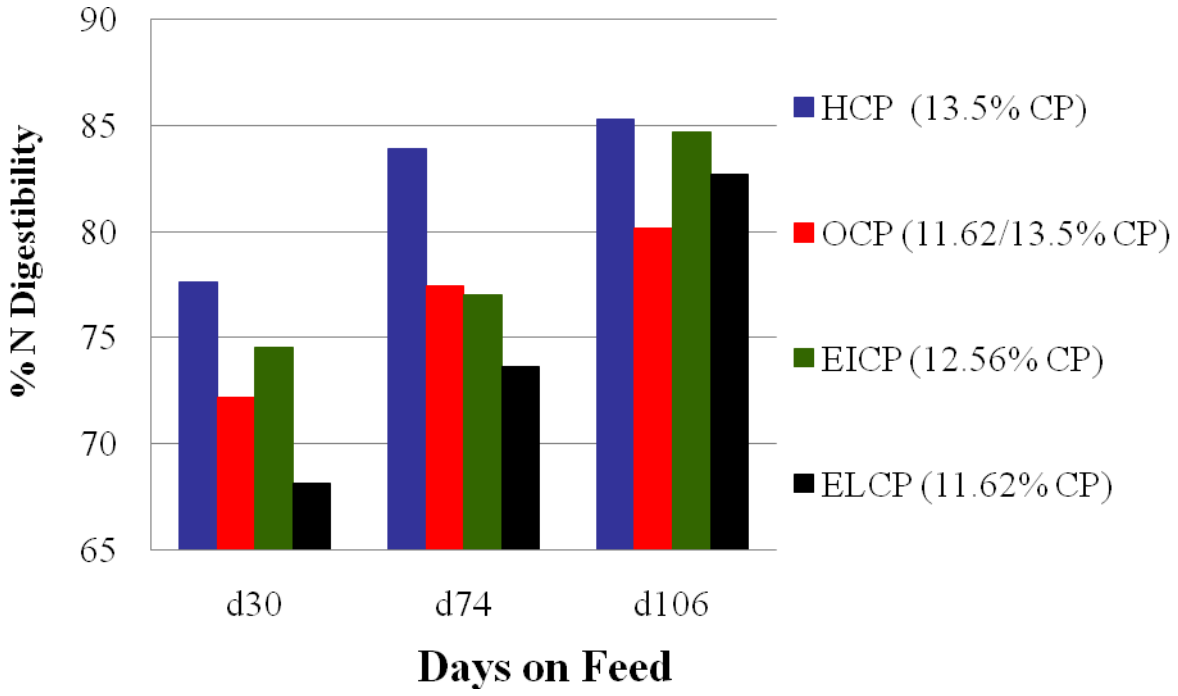


Figure 4.5. Least squares means showing the effect of dietary treatment and days on feed on nitrogen digestibility calculated from dry matter intake, diet crude protein concentration, and calculated total fecal output. HCP = 13.5% crude protein (CP) and 3.5% crude protein equivalent (CPE) from non-protein nitrogen (NPN) from d 22 through slaughter. OCP = Oscillating CP between the HCP diet fed M, Tu, F, and Sa and LCP fed W, Th, and Su from d 22 through slaughter. EICP = 12.56% CP and 2.53% CPE from NPN from d 22 through slaughter. ELCP = 11.62% CP and 1.55% CPE from NPN from d 22 through slaughter. Treatments LICP and LLCP are not displayed because treatment was not applied until the last 27d. Treatment, P = 0.0007; Days on feed, P < 0.0001; Treatment * Days on feed, P = 0.3979. Digestibility determine from the following equations:

$$N\ Digestibility\ (\%) = \frac{Nitrogen\ Intake - Fecal\ Nitrogen}{Nitrogen\ Intake} \times 100$$

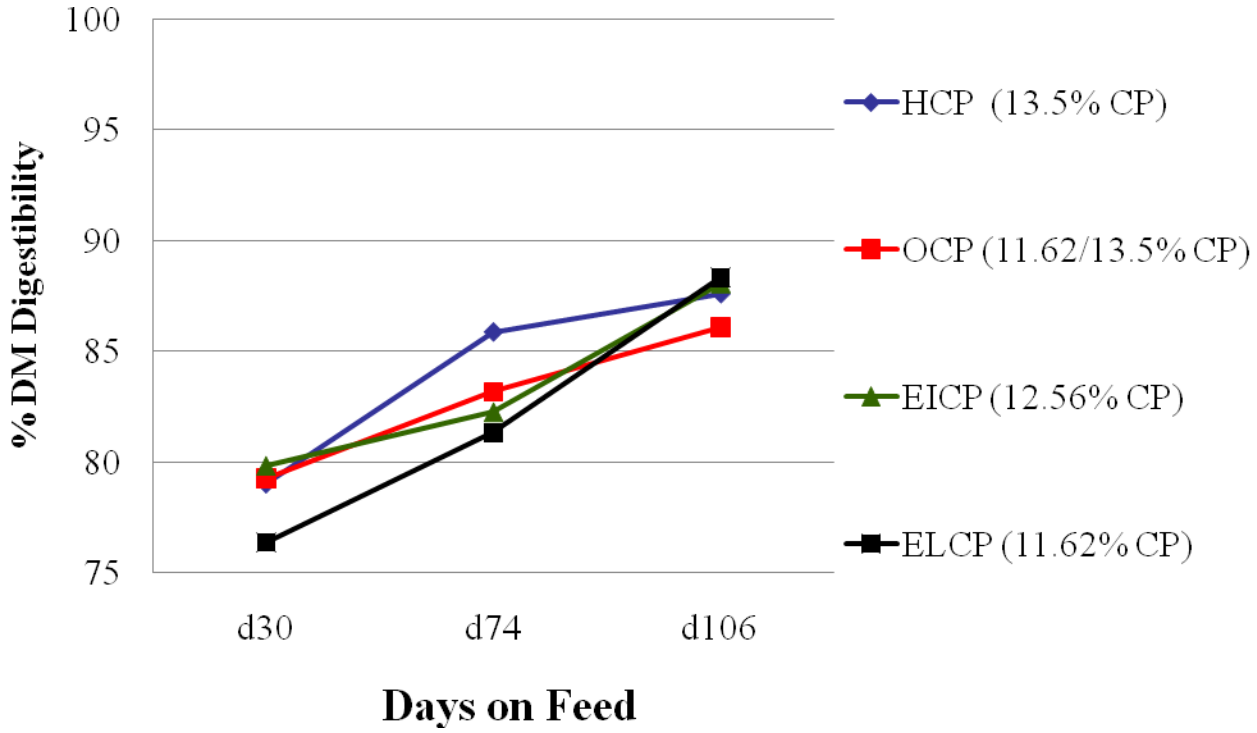


Figure 4.6. Least squares means showing the effect of dietary treatment and days on feed on dry matter digestibility as determined by dry matter intake and calculated total fecal output. HCP = 13.5% crude protein (CP) and 3.5% crude protein equivalent (CPE) from non-protein nitrogen (NPN) from d 22 through slaughter. OCP = Oscillating CP between the HCP diet fed M, Tu, F, and Sa and LCP fed W, Th, and Su from d 22 through slaughter. EICP = 12.56% CP and 2.53% CPE from NPN from d 22 through slaughter. ELCP = 11.62% CP and 1.55% CPE from NPN from d 22 through slaughter. Treatments LICP and LLCP are not displayed because treatment was not applied until the last 27d. Treatment, $P > 0.3713$; Days on feed, $P < 0.0001$; and Treatment*Days on feed, $P > 0.5017$. Digestibility was determined using the following equations:

$$Fecal\ Output\ (Weight)(FO) = \frac{(Dry\ Matter\ Intake\ \times Feed\ AIA\ concentration)}{Fecal\ AIA\ concentration}$$

$$DM\ Digestibilty(\%) = \frac{(Dry\ Matter\ Intake - Fecal\ Output)}{Dry\ Matter\ Intake} \times 100$$

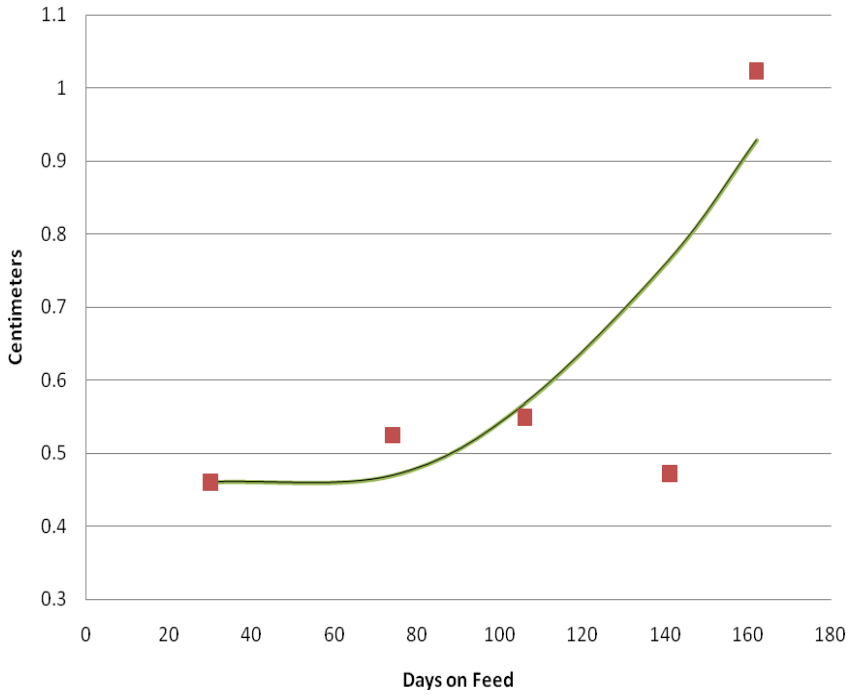


Figure 4.7. Prediction of pen ultrasonic and final 12th rib fat depth (cm) and days on feed (DOF) and average actual ultrasound measurements for all treatments. Treatments included: Control, HCP = 13.5% crude protein (CP) and 3.5% crude protein equivalent (CPE) from non-protein nitrogen (NPN) from d 22 through slaughter. OCP = Oscillating CP between the HCP diet fed M, Tu, F, and Sa and LCP fed W, Th, and Su from d 22 through slaughter. EICP = 12.56% CP and 2.53% CPE from NPN from d 22 through slaughter. ELCP = 11.62% CP and 1.55% CPE from NPN from d 22 through slaughter. LICP = HCP with 12.56% CP and 2.53% CPE from NPN fed the last 27 d. LLCP = HCP with 11.62% CP and 1.55% CPE from NPN fed the last 27 d. Type I tests of fixed effects: TRT, P = 0.1184; DOF, P < 0.0001; DOF*TRT, P = 0.9042; DOF*DOF, P < 0.0001; and DOF*DOF*TRT, P = 0.8530. Centimeters of 12th rib fat depth = 0.5388 + (-0.00375*DOF) + (0.000038*DOF*DOF)

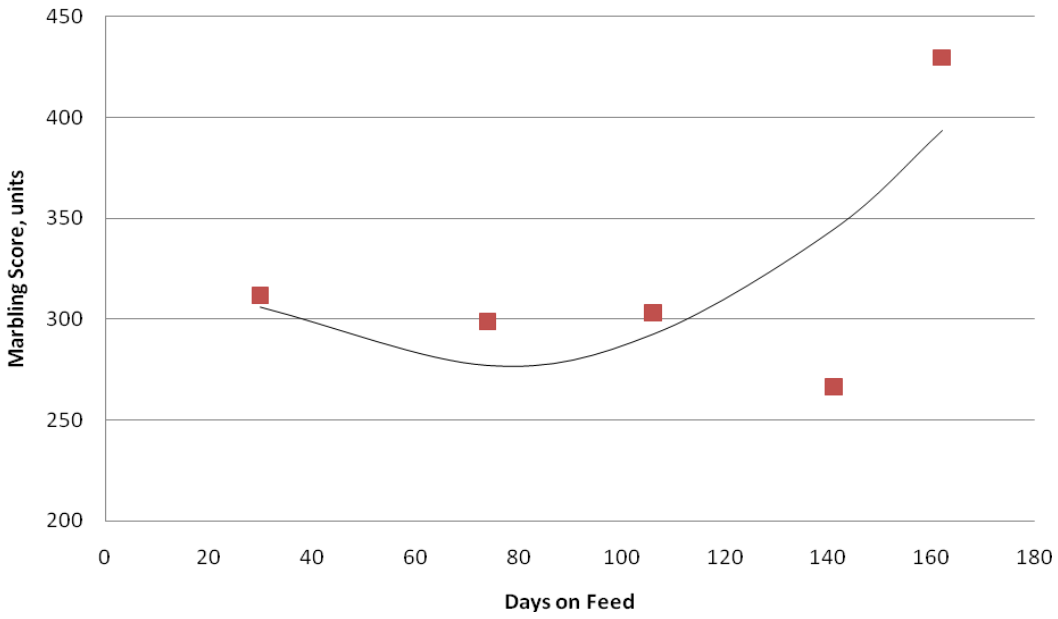


Figure 4.8. Prediction of pen ultrasonic and final marbling score (Units: 300 = Slight^{00}, 400 = Small^{00}) and days on feed (DOF) and average actual ultrasound measurements for all treatments. Treatments included: Control, HCP = 13.5% crude protein (CP) and 3.5% crude protein equivalent (CPE) from non-protein nitrogen (NPN) from d 22 through slaughter. OCP = Oscillating CP between the HCP diet fed M, Tu, F, and Sa and LCP fed W, Th, and Su from d 22 through slaughter. EICP = 12.56% CP and 2.53% CPE from NPN from d 22 through slaughter. ELCP = 11.62% CP and 1.55% CPE from NPN from d 22 through slaughter. LICP = HCP with 12.56% CP and 2.53% CPE from NPN fed the last 27 d. LLCP = HCP with 11.62% CP and 1.55% CPE from NPN fed the last 27 d. Type I tests of fixed effects: Treatment, P = 0.4354; DOF, P < 0.0001; DOF*Treatment, P = 0.9623; DOF*DOF, P < 0.0001; and DOF*DOF*Treatment, P = 0.9345. Units of marbling score = 3.5882 + (-0.02217*DOF) +(0.000150*DOF*DOF).

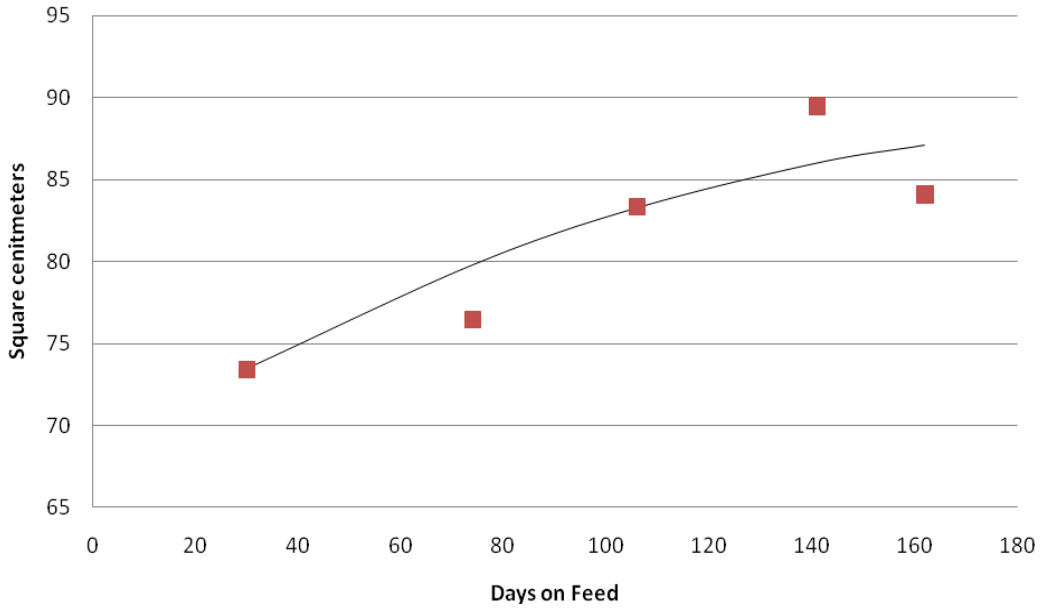


Figure 4.9. Prediction of pen ultrasonic and final ribeye area (square centimeters) and days on feed (DOF) and average actual ultrasound measurements for all treatments. Treatments included: Control, HCP = 13.5% crude protein (CP) and 3.5% crude protein equivalent (CPE) from non-protein nitrogen (NPN) from d 22 through slaughter. OCP = Oscillating CP between the HCP diet fed M, Tu, F, and Sa and LCP fed W, Th, and Su from d 22 through slaughter. EICP = 12.56% CP and 2.53% CPE from NPN from d 22 through slaughter. ELCP = 11.62% CP and 1.55% CPE from NPN from d 22 through slaughter. LICP = HCP with 12.56% CP and 2.53% CPE from NPN fed the last 27 d. LLCP = HCP with 11.62% CP and 1.55% CPE from NPN fed the last 27 d. Type I tests of fixed effects: treatment, P = 0.3139; DOF, P < 0.0001; DOF*Treatment, P = 0.6986; DOF*DOF, P < 0.0001; and DOF*DOF*Treatment,P = 0.5195. Square centimeters of ribeye = 68.1839+(0.1912*DOF)+(-0.00046*DOF*DOF).

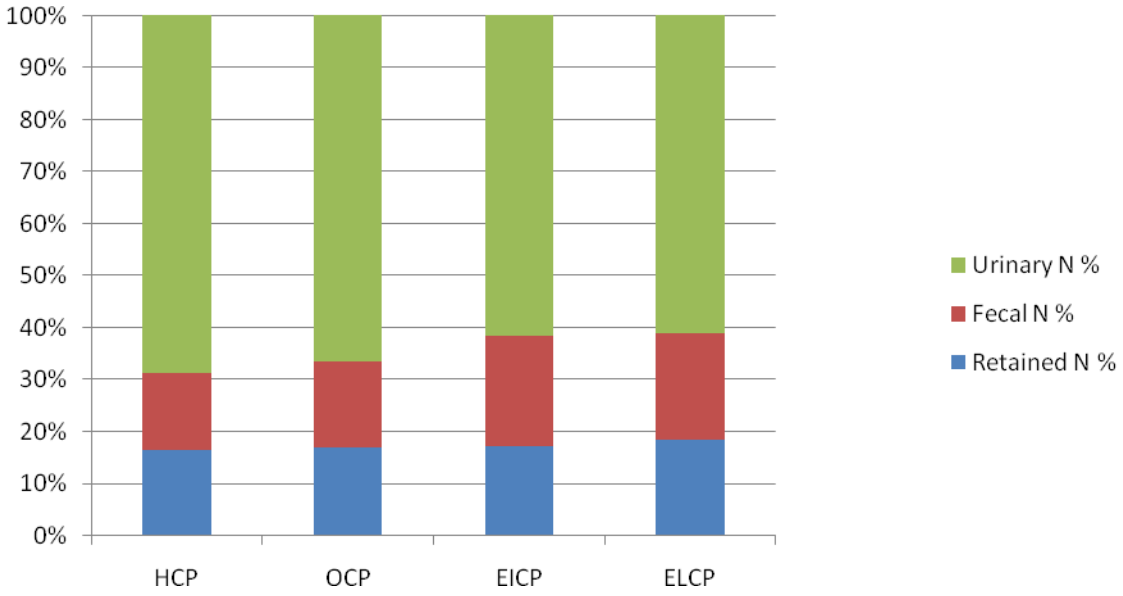


Figure 4.10. The fate of nitrogen intake from day 0 to day 45 based on CP regimen (mass balance pens only). HCP = 13.5% crude protein (CP) and 3.5% crude protein equivalent (CPE) from non-protein nitrogen (NPN) from d 22 through slaughter. OCP = Oscillating CP between the HCP diet fed M, Tu, F, and Sa and LCP fed W, Th, and Su from d 22 through slaughter. EICP = 12.56% CP and 2.53% CPE from NPN from d 22 through slaughter. ELCP = 11.62% CP and 1.55% CPE from NPN from d 22 through slaughter. The series of equations that were used are as followed:

$$\text{Shrunk Body Weight (SBW)} = \text{Weight} * 0.96$$

$$\text{Empty Body Weight (EBW)} = \text{SBW} * 0.891$$

$$\text{Shrunk Weight Gain (SWG)} = \text{Average Daily Gain} * 0.96$$

$$\text{Retained Engery (RE)} = 0.0635 * \text{EBW}^{0.75} * \text{EBG}^{1.097}$$

$$\text{Retained Nitrogen (RN)} = [\text{SWG} * (268 - \left(29.4 * \left(\frac{\text{RE}}{\text{SWG}}\right)\right)]/6.25$$

$$\text{Urinary Nitrogen (UN)} = \text{Nitrogen intake} - \text{RN} - \text{FN}$$

$$\text{Fecal Nitrogen (FN)} = \text{FO} * \frac{\text{FN from fecal samples}}{100}$$

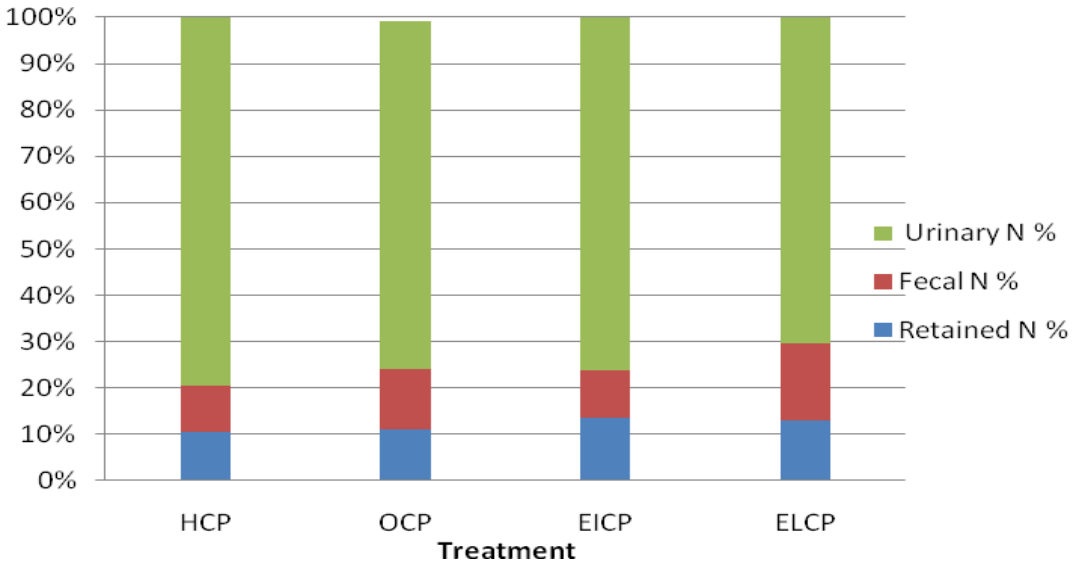


Figure 4.11. Fate of nitrogen intake from day 46 to day 92 based on CP regimen (mass balance pens only). HCP = 13.5% crude protein (CP) and 3.5% crude protein equivalent (CPE) from non-protein nitrogen (NPN) from d 22 through slaughter. OCP = Oscillating CP between the HCP diet fed M, Tu, F, and Sa and LCP fed W, Th, and Su from d 22 through slaughter. EICP = 12.56% CP and 2.53% CPE from NPN from d 22 through slaughter. ELCP = 11.62% CP and 1.55% CPE from NPN from d 22 through slaughter. The series of equations that were used are as followed:

$$\text{Shrunk Body Weight (SBW)} = \text{Weight} * 0.96$$

$$\text{Empty Body Weight (EBW)} = \text{SBW} * 0.891$$

$$\text{Shrunk Weight Gain (SWG)} = \text{Average Daily Gain} * 0.96$$

$$\text{Retained Engery (RE)} = 0.0635 * \text{EBW}^{0.75} * \text{EBG}^{1.097}$$

$$\text{Retained Nitrogen (RN)} = [\text{SWG} * (268 - (29.4 * (\frac{\text{RE}}{\text{SWG}}))]/6.25$$

$$\text{Urinary Nitrogen (UN)} = \text{Nitrogen intake} - \text{RN} - \text{FN}$$

$$\text{Fecal Nitrogen (FN)} = \text{FO} * \frac{\text{FN from fecal samples}}{100}$$

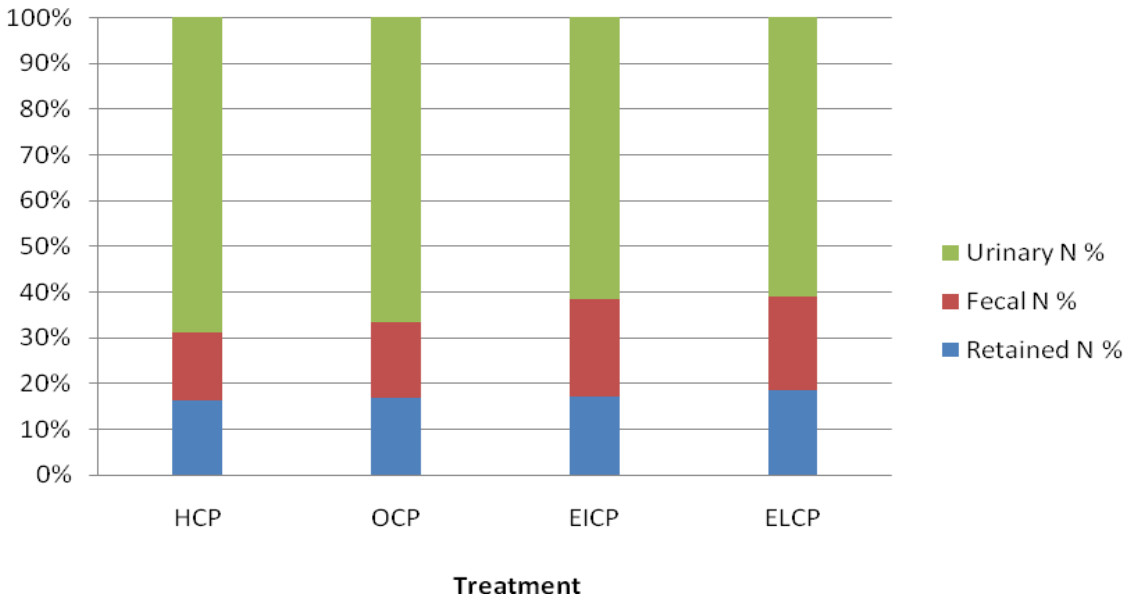


Figure 4.12. Fate of nitrogen intake from day 93 to day 148 based on CP regimen (mass balance pens only). HCP = 13.5% crude protein (CP) and 3.5% crude protein equivalent (CPE) from non-protein nitrogen (NPN) from d 22 through slaughter. OCP = Oscillating CP between the HCP diet fed M, Tu, F, and Sa and LCP fed W, Th, and Su from d 22 through slaughter. EICP = 12.56% CP and 2.53% CPE from NPN from d 22 through slaughter. ELCP = 11.62% CP and 1.55% CPE from NPN from d 22 through slaughter. The series of equations that were used are as followed:

$$\text{Shrunk Body Weight (SBW)} = \text{Weight} * 0.96$$

$$\text{Empty Body Weight (EBW)} = \text{SBW} * 0.891$$

$$\text{Shrunk Weight Gain (SWG)} = \text{Average Daily Gain} * 0.96$$

$$\text{Retained Engery (RE)} = 0.0635 * \text{EBW}^{0.75} * \text{EBG}^{1.097}$$

$$\text{Retained Nitrogen (RN)} = [\text{SWG} * (268 - \left(29.4 * \left(\frac{\text{RE}}{\text{SWG}}\right)\right)]/6.25$$

$$\text{Urinary Nitrogen (UN)} = \text{Nitrogen intake} - \text{RN} - \text{FN}$$

$$\text{Fecal Nitrogen (FN)} = \text{FO} * \frac{\text{FN from fecal samples}}{100}$$

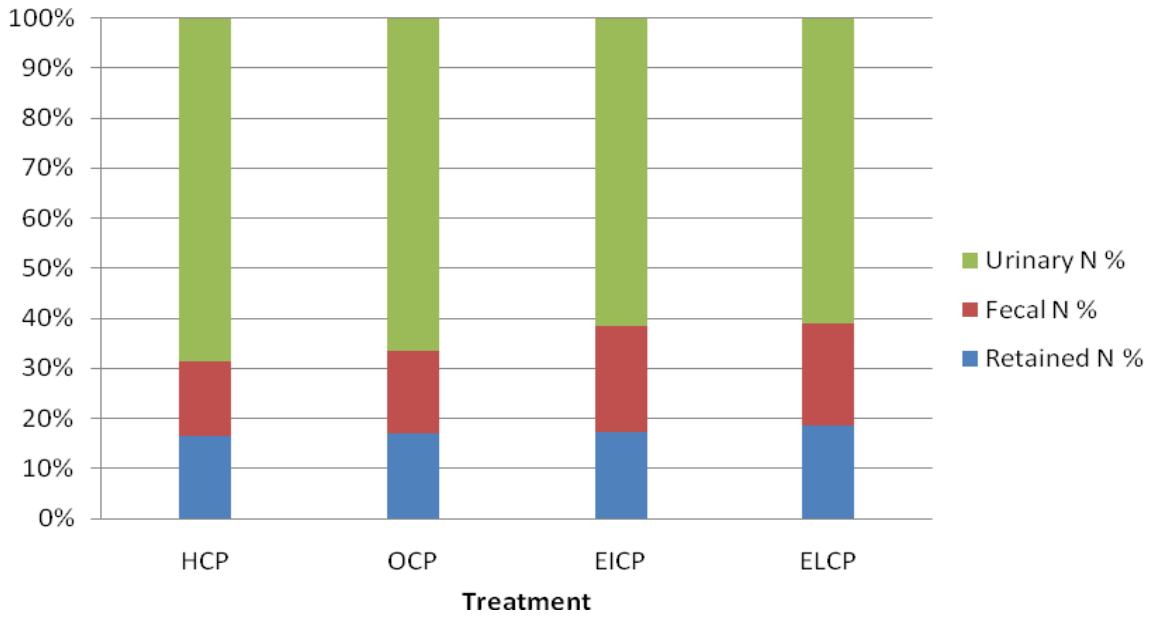


Figure 4.13. Fate of nitrogen intake from day 0 to day 148 based on CP regimen (mass balance pens only). HCP = 13.5% crude protein (CP) and 3.5% crude protein equivalent (CPE) from non-protein nitrogen (NPN) from d 22 through slaughter. OCP = Oscillating CP between the HCP diet fed M, Tu, F, and Sa and LCP fed W, Th, and Su from d 22 through slaughter. Early-ICP = 12.56% CP and 2.53% CPE from NPN from d 22 through slaughter. Early-LCP = 11.62% CP and 1.55% CPE from NPN from d 22 through slaughter. The series of equations that were used are as followed:

$$\text{Shrunk Body Weight (SBW)} = \text{Weight} * 0.96$$

$$\text{Empty Body Weight (EBW)} = \text{SBW} * 0.891$$

$$\text{Shrunk Weight Gain (SWG)} = \text{Average Daily Gain} * 0.96$$

$$\text{Retained Engery (RE)} = 0.0635 * \text{EBW}^{0.75} * \text{EBG}^{1.097}$$

$$\text{Retained Nitrogen (RN)} = [\text{SWG} * (268 - \left(29.4 * \left(\frac{\text{RE}}{\text{SWG}}\right)\right)]/6.25$$

$$\text{Urinary Nitrogen (UN)} = \text{Nitrogen intake} - \text{RN} - \text{FN}$$

$$\text{Fecal Nitrogen (FN)} = \text{FO} * \frac{\text{FN from fecal samples}}{100}$$

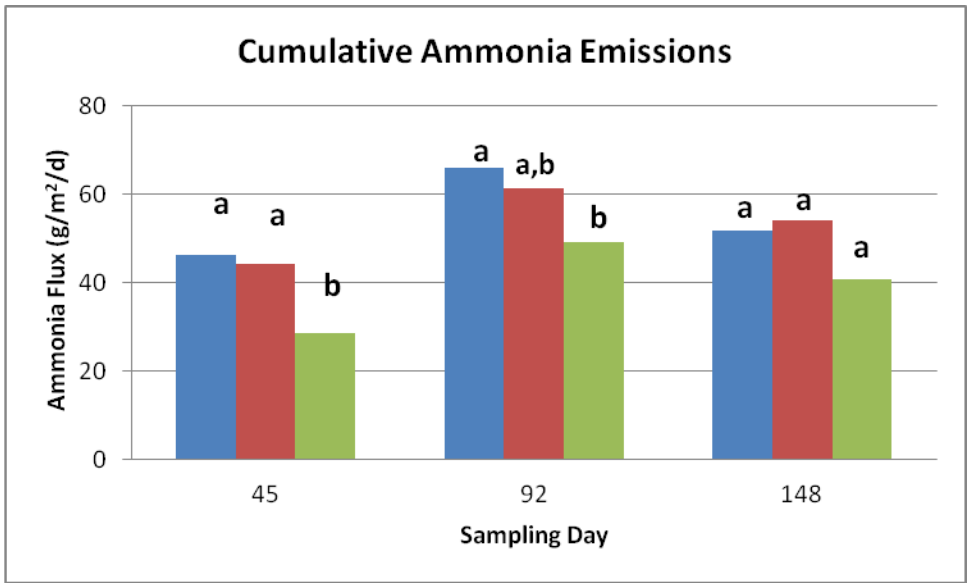


Figure 4.14. Cumulative ammonia emissions for each sampling date for HCP (blue), OCP (red), and Early-LCP (green) diets (Galles et al., 2011). All samples for each treatment for each sampling date (12 per treatment/sampling date) were averaged and daily flux totals were summed to obtain cumulative emissions. For the first 2 sampling dates, the Early-LCP diet significantly reduced total emissions over the control ($P = 0.0036$ for d 45 and $P = 0.0042$ for d 92). For sampling d 148, the differences between the Early-LCP diet and the others were approaching significant ($P = 0.21$ for HCP and $P = 0.12$ for OCP).

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CHAPTER V

CONCLUSIONS AND IMPLICATIONS

A large percentage of cattle on feed are fed in the High Plains region. The location of these confined animal feeding operations coupled with weather patterns accelerates nitrogen deposition in Colorado's alpine region. Nitrogen leeching and volatilization are of concern and can be controlled or diminish through Best Management Practiced for feeding cattle. Altering feedyard diets to eliminate exceeding the cattle's nutritional requirements for maximum growth provides an opportunity to reduce overall nitrogen losses. If nitrogen emission are not addressed and reduced, there could be regulation for ammonia emissions for cattle feeders in the future.

Under the conditions of this study, average daily gain and carcass merit were similar for steers fed oscillated crude protein diet (11.62/13.5% CP 48-hour basis; OCP) and crude protein (CP) withdrawal diets as compared with the high crude protein (13.5%) control diet. Although dry matter intake appeared reduced during the later stages of the finishing period, feed efficiency and net energy recovery were not impacted by OCP or CP withdrawal diets.

Manipulating dietary CP concentrations can be utilized to influence digestibility. Increasing CP concentration increases dry matter (DM) and nitrogen (N) digestibility. However, reducing CP levels to 12.56% CP or oscillating between 11.62 and 13.5% in 48-hour intervals

had no adverse affects on digestibility. Dry matter and N digestibility increase with days on feed. This could indicate that maximum performance from urea occurs later in the feeding period.

Feeding cattle less CP can improve the quality of manure with a more desire nitrogen to phosphorus ratio. All steers retained the same about of N and excreted the same amount of fecal N regardless of diet. However, reduced CP intake weather it was through the OCP or CP withdrawal diets was associated with less urinary N excretion and lower ammonia emissions from the pen surface. Reduced CP diets could potentially be successfully utilized as a Best Management Practice to reduce the amount N available to be emitted from feedlot and reduce the nitrogen deposition in Rocky Mountain National Park, but further research needs to be done. Nitrogen volatilization is significantly affected by seasons and occurs at a higher rate during the spring and summer months due to weather conditions. Results from this study need to be taken with caution due to the sampling conditions for ammonia flux tests. The study was conducted during cooler winter months and prior to sampling the research location received precipitation. The ammonia flux pattern observed would not be typical of an average period at the feedlot.

Further research is needed to determine if reductions in emissions can be sustained with oscillated CP and CP withdrawal diets without affecting animal performance. Cost associated with these Best Management Practices for feeding cattle need to be further investigated.

LIST OF APPENDICES

Appendix A: Equations for calculating net energy recovery.

Energy Recovery. Net energy values for each diet were calculated from estimates of energy expended for maintenance (EM, Mcal/d) and energy retained (EG, Mcal/d) derived from BW, actual growth performance data, and DMI using the following equations for medium-framed yearling steers (NRC, 2000):

EM = 0.077 × mean shrunk $BW^{0.75}$ (kg), where shrunk BW (SBW) = full BW × 0.96;

EG = (0.0557 × ($SBW^{0.75}$) × (shrunk weight $gain^{1.097}$)), where shrunk weight gain (kg/d) is the shrunk daily weight gain.

The NEm and NEg values of the diets were then calculated using the solution for the quadratic equation:

NEm (Mcal/kg DM) = $((-b + \sqrt{(b^2-4ac)}) / 2a)$, where

a = 0.877 × DMI,

b = (-0.877 × EM) - (0.41* DMI) - EG, and

c = 0.41 × EM

NEg (Mcal/kg DM) = 0.877 x NEm - 0.41.

Appendix B: Raw means and standard errors showing nutrient composition of finishing diets and supplements used in the oscillated crude protein and crude protein withdrawal study.

Item [a]	HCP	ICP	LCP
Diets			
Dry Matter	67.59 ± 0.53	68.48 ± 0.51	68.88 ± 0.69
Crude Protein	13.01 ± 0.21	12.08 ± 0.15	11.39 ± 0.29
Non-protein Nitrogen [c,d]	3.18 ± 0.16	2.43 ± 0.10	1.70 ± 0.08
Neutral detergent fiber[e]	13.30 ± 0.23	12.61 ± 0.22	12.37 ± 0.27
Ether Extract[e]	6.42 ± 0.51	6.94 ± 0.47	7.25 ± 0.33
Calcium	0.74 ± 0.03	0.77 ± 0.04	0.71 ± 0.06
Phosphorus	0.36 ± 0.02	0.35 ± 0.01	0.35 ± 0.00
Potassium	0.67 ± 0.01	0.68 ± 0.01	0.69 ± 0.02
Magnesium	0.32 ± 0.01	0.33 ± 0.01	0.32 ± 0.01
Sulfur	0.17 ± 0.00	0.17 ± 0.01	0.18 ± 0.01
Supplements			
Dry Matter	97.17 ± 0.45	96.74± 0.45	96.46 ± 0.45
Crude Protein	85.75 ± 2.02	66.90 ± 2.02	43.33 ± 2.02
Non-protein Nitrogen [c,d]	83.54 ± 1.88	63.73 ± 1.88	41.50 ± 1.88
Calcium	16.37 ± 0.31	15.87 ± 0.31	16.40 ± 0.31
Phosphorus	0.00 ± 0.01	0.00 ± 0.01	0.01 ± 0.01
Potassium	2.77 ± 0.09	2.68 ± 0.09	2.94 ± 0.19
Magnesium	4.30 ± 0.07	4.41 ± 0.07	4.34 ± 0.07

[a] Percentage of dry matter ± SEM unless stated otherwise.
[b] Samples were taken on Wednesday when the low CP ration was fed. When the high CP ration was fed it is estimated to be similar to the control ration.
[c] Diet differences $P < 0.0001$.
[d] Crude Protein Equivalent.
[e] Diet differences $P < 0.05$.

Appendix C: Raw means and standard error of the mean describing the effect of dietary crude protein concentration and days on feed on nitrogen protein and dry matter digestibility.

Item[b]	Dietary Crude Protein Treatments[a]			
	HCP	OCP	EICP	ELCP
DM Digestibility[c]				
Day 30	82.14±1.58	79.84 ±1.73	81.14±1.46	77.95±2.07
Day 74	86.81±1.32	84.27±1.69	83.37±1.32	82.54±1.98
Day 106	88.23±1.49	86.63±2.36	88.05±1.53	88.54±1.37
CP Digestibility[d]				
Day 30	77.97±2.03	72.15±2.52	74.55±2.23	68.15±3.25
Day 74	83.92±1.73	76.98±2.71	77.03±1.90	73.61±3.34
Day 106	85.17±1.96	79.01±4.52	84.57±2.10	82.68±2.26

[a] Treatments: HCP = 13.5% crude protein (CP) and 3.5% crude protein equivalent (CPE) from non-protein nitrogen (NPN) from d 22 through slaughter. OCP = Oscillating CP between the HCP diet fed M, Tu, F, and Sa and LCP fed W, Th, and Su from d 22 through slaughter. EICP = 12.56% CP and 2.53% CPE from NPN from d 22 through slaughter. ELCP = 11.62% CP and 1.55% CPE from NPN from d 22 through slaughter.

[b] Sampling periods; Day 30 was taken on day 30 or 31, Day 74 was taken on 73 or74, Day 106 was taken on day 106 or 107.

[c] $\text{DM Digestibilty}(\%) = \frac{(\text{DMI}-\text{FO})}{\text{DMI}} \times 100$

[d] $\text{N Digestibility}\ (\%) = \frac{\text{NI}-\text{FN}}{\text{NI}} \times 100$

Appendix D: Raw means and standard errors showing the effect of dietary crude protein on feedlot performance.

	Dietary Crude Protein Treatment					
Item[a]	HCP	OCP	EICP	ELCP	LICP	LLCP
Initial wt., kg	331.1 ± 7.39	330.3 ± 7.80	330.0 ± 7.67	329.0 ± 7.71	329.0 ± 7.44	328.7 ± 7.37
Day 30 wt., kg	382.7 ± 6.89	382.6 ± 7.67	380.4 ± 6.76	381.4 ± 7.48	380.8 ± 6.85	381.7 ± 6.44
Day 74 wt., kg	447.2 ± 5.72	449.4 ± 5.76	446.4 ± 5.22	448.2 ± 5.67	443.8 ± 6.35	445.2 ± 5.12
Day 106 wt., kg	487.1 ± 7.62	490.1 ± 6.89	489.1 ± 6.49	489.1 ± 6.58	480.8 ± 8.85	480.5 ± 7.16
Day 141 wt., kg	530.3 ± 8.53	535.4 ± 7.17	537.5 ± 6.80	533.0 ± 8.94	527.9 ± 9.89	524.6 ± 7.82
Final wt., kg	548.7 ± 5.40	553.7 ± 6.71	555.2 ± 4.63	547.45 ± 6.08	546.5 ± 7.76	542.3 ± 6.58
ADG, d1-30, kg	1.70 ± 0.06	1.72 ± 0.08	1.66 ± 0.09	1.72 ± 0.05	1.70 ± 0.05	1.75 ± 0.07
ADG, d31-74, kg	1.49 ± 0.06	1.55 ± 0.09	1.60 ± 0.06	1.54 ± 0.07	1.46 ± 0.06	1.47 ± 0.06
ADG, d75-106, kg	1.21 ± 0.11	1.23 ± 0.09	1.30 ± 0.10	1.25 ± 0.07	1.13 ± 0.11	1.08 ± 0.11
ADG, d106-141, kg	1.13 ± 0.09	1.20 ± 0.10	1.27 ± 0.07	1.13 ± 0.08	1.23 ± 0.13	1.16 ± 0.10
ADG, final 28d, kg	1.06± 0.09	1.04 ± 0.07	1.10 ± 0.07	1.02 ± 0.08	1.12 ± 0.09	1.04 ± 0.08
ADG, d1-finish, kg	1..34± 0.03	1.37 ± 0.03	1.39 ± 0.03	1.35 ± 0.02	1.34 ±0.04	1.32 ± 0.03
DMI, d1-30, kg	8.76± 0.12	8.81 ± 0.11	8.75 ± 0.09	8.79 ± 0.12	8.58 ± 0.11	8.61 ± 0.15
DMI, d31-74, kg	8.85± 0.09	8.79 ± 0.08	8.75 ± 0.09	8.64 ± 0.13	8.64 ± 0.13	8.63 ± 0.12
DMI, d75-106, kg	8.79± 0.18	8.75 ± 0.15	8.65 ± 0.20	8.74 ± 0.15	8.65 ± 0.14	8.45 ± 0.18
DMI, d107-141, kg	8.85 ± 0.19	8.74 ± 0.26	8.60 ± 0.23	8.25 ± 0.25	8.54 ± 0.16	7.98 ± 0.27
DMI, final 28d, kg	8.66 ± 0.22	8.41 ± 0.28	8.40 ± 0.28	7.98 ± 0.33	8.13 ± 0.27	7.81 ± 0.27
DMI, d1-finish, kg	8.78 ±0.13	8.71 ± 0.15	8.63 ± 0.15	8.49 ±0.19	8.53 ± 0.12	8.34 ± 0.18
F:G, d1-30	5.27 ± 0.26	5.25 ± 0.28	5.45 ± 0.35	5.15 ± 0.18	5.08 ± 0.16	5.03 ± 0.26
F:G, d31-74	6.05 ±0.28	5.93 ± 0.39	5.88 ± 0.29	5.77 ± 0.34	6.09 ± 0.33	6.05 ± 0.35
F:G, d75-106	7.92± 0.79	7.46 ± 0.51	7.07 ± 0.56	7.25 ± 0.45	8.65 ± 1.04	9.58 ± 1.72
F:G, d107-141	8.25 ±0.58	7.74 ± 0.56	6.98 ± 0.37	7.56 ± 0.37	7.74 ± 0.79	7.56 ± 1.47
F:G, final 28d	8.83 ±0.85	8.44 ± 0.57	7.93 ± 0.51	8.38 ± 0.76	7.85 ± 0.69	7.88 ± 0.51
F:G, d1-finish	6.56 ±0.14	6.37 ± 0.20	6.23 ± 0.13	6.29 ± 0.12	6.39 ± 0.15	6.37 ± 0.18
G:F, d1-30	0.197 ± 0.01	0.196 ± 0.01	0.191 ± 0.01	0.196 ± 0.01	0.199 ± 0.01	0.204 ± 0.01
G:F, d31-74	0.169 ± 0.01	0.177 ± 0.01	0.175 ±0.01	0.180 ± 0.01	0.169 ± 0.01	0.171 ± 0.01
G:F, d75-106	0.137 ±0.01	0.141 ± 0.01	0.149 ± 0.01	0.143 ± 0.01	0.130 ± 0.01	0.126 ± 0.01
G:F, d107-141	0.128 ± 0.01	0.138 ± 0.01	0.148 ± 0.01	0.136 ± 0.01	0.143 ± 0.01	0.147 ± 0.01
G:F, final 28d	0.127 ± 0.01	0.125 ± 0.01	0.131 ± 0.01	0.128 ± 0.01	0.137 ± 0.01	0.134 ± 0.01
G:F, d1-finish	0.153 ± 0.00	0.158 ± 0.01	0.161 ± 0.00	0.160 ± 0.00	0.157 ± 0.00	0.158 ± 0.01
NEm, d1-30	2.37 ±0.06	2.38 ± 0.07	2.33 ± 0.08	2.38 ± 0.04	2.41 ± 0.04	2.45 ± 0.06
NEm, d31-74	2.39 ±0.07	2.46 ± 0.09	2.12 ± 0.07	2.49 ± 0.08	2.39 ± 0.07	2.41 ± 0.07
NEm, d75-106	2.28 ± 0.11	2.33 ± 0.10	2.23 ± 0.09	2.34 ± 0.08	2.21 ± 0.12	2.19 ± 0.12
NEm, d107-141	2.31 ± 0.09	2.44 ± 0.12	2.55 ± 0.09	2.46 ± 0.08	2.48 ± 0.14	2.56 ± 0.15
NEm, final 28d	2.33 ± 0.10	2.40 ± 0.11	2.46 ± 0.07	2.46 ± 0.09	2.53 ± 0.13	2.51 ± 0.11
NEm, d1-finish	2.34 ± 0.03	2.40 ± 0.05	2.43 ± 0.03	2.41 ± 0.03	2.39 ± 0.04	2.40 ± 0.05
NEg, d1-30	1.67 ± 0.06	1.68 ± 0.06	1.64 ± 0.07	1.68 ± 0.04	1.70 ± 0.04	1.73 ± 0.05
NEg, d31-74	1.68 ± 0.06	1.74 ± 0.08	1.75 ± 0.06	1.77 ±0.07	1.69 ± 0.06	1.70 ± 0.07
NEg, d75-106	1.59 ± 0.09	1.63 ± 0.09	1.70 ± 0.08	1.65 ± 0.07	1.53 ± 0.11	1.51 ± 0.10
NEg, d107-141	1.62 ± 0.09	1.73 ± 0.11	1.83 ± 0.08	1.75 ±0.07	1.76 ± 0.12	1.81 ± 0.13
NEg, final 28d	1.63 ± 0.09	1.69 ± 0.09	1.75 ± 0.06	1.74 ± 0.08	1.81 ± 0.11	1.80 ± 0.09
NEg, d1-finish	1.64 ± 0.02	1.70 ±0.05	1.72 ± 0.03	1.71 ± 0.02	1.69 ± 0.03	1.70 ± 0.04

ADG = Average daily gain; DMI = Daily dry matter intake; F:G = Feed to gain ratio, lb DM/kg gain; G:F = Gain to feed ratio, kg gain/kg DM; NEm = Net energy for maintenance derived from feedlot performance (Appendix A), Mcal/kg DM; NEg = Net energy for gain derived from feedlot performance (Appendix A), Mcal/kg DM.

Appendix E. Raw means and standard error of the mean describing the effect of dietary crude protein concentration on carcass merit.

	Treatments					
Item[a]	HCP	OCP	EICP	ELCP	LICP	LLCP
HCW, lb	345.7 ± 3.08	348.46 ± 3.04	351.7 ± 2.70	345.1 ± 3.10	345.5 ± 2.92	343.9 ± 2.78
HCW category[b]						
< 273 kg	2.02	0	1.01	2.04	2.02	0
273 – 429 kg	97.98	98.99	97.98	97.96	97.98	100
430 – 452 kg	0	1.01	1.01	0	0	0
≥ 453 kg	0	0	0	0	0	0
Dressing percent	62.97 ± 0.19	62.80 ± 0.18	63.21 ± 0.23	63.07 ± 0.20	62.98 ± 0.21	63.32 ± 0.20
Fat depth, cm.	1.02 ± 0.02	1.04 ± 0.2	1.04 ± 0.01	1.04 ± 0.01	1.04 ± 0.02	1.04 ± 0.2
Ribeye area, cm.^{2}	84.26 ± 0.16	83.61 ± 0.15	83.74 ± 0.17	84.26 ± 0.17	84.84 ± 0.16	84.71 ± 0.16
Calc. YG, units	2.21 ± 0.8	2.30 ± 0.07	2.33 ± 0.08	2.22 ± 0.07	2.20 ± 0.07	2.22 ± 0.07
USDA YG Categories[b]						
YG12	67.4	62.9	67.3	72.16	72.4	72.16
YG3	28.3	30.0	27.6	23.71	23.5	24.7
YG45	4.3	7.2	5.1	4.1	4.1	3.1
Marbling score[c]	422.6 ± 8.3	433.2 ± 8.1	432.6 ± 8.1	435.7 ± 9.1	430.3 ± 8.8	422.3 ± 8.3
Quality Grade Categories[b]						
≥Low Choice	68.8	74.8	72.5	68.0	70.7	66.0
Select	28.0	24.2	22.5	28.9	26.3	26.8
Standard	3.0	1.0	4.1	3.1	3.0	6.2
≥ 30 months[b]	1.07	1.01	0	1.03	0	0
Abscessed Livers[d]	14.14	14.14	20.02	5.10	11.11	14.29

[a] HCW = Hot carcass weight; REA/HCW = Ribeye area per cwt HCW; KPH = Kidney, pelvic, and heart fat; Calc. YG = Yield grade calculated from carcass measurements; YG = Yield Grade; MARB/FAT = Marbling units per 0.04 cm fat depth; QG = Quality Grade.

[b] Percentage of individual carcasses.

[c] Marbling score units: 400 = Small^{00}, 500 = Modest^{00}.

[d] Percentage of individual livers exhibiting signs of abscesses.

Appendix F: Cost of total mixed ration used for crude protein study

		Ration[a]		
		Control (13.5% CP)	*Intermediate CP (12.5% CP)*	*Low CP (11.5% CP)*
Item[b]	% of ration	Cost per item		
Corn	76.787	0.1022	0.1022	0.1022
Silage	9.689	0.0019	0.0019	0.0019
CCDS[c]	3	0.0012	0.0012	0.0012
Tallow	3.53	0.0306	0.0306	0.0306
DDG[d]	2.905	0.0051	0.0051	0.0051
Supplement	4.091	0.0419	0.0430	0.0441
Cost per kg of TMR		0.1830	0.1841	0.1852

[a]The oscillated crude protein diet is not included. The cost is a weighted average between the control ration and the low CP ration.
[b]All basal rations were the same. The protein levels were meet in the supplement with a combination of corn meal and urea.
[c]Condense Corn Distiller's with Solubles
[d]Dried Distiller's Grains

Appendix G: The cost per kilogram of gain for steers on various crude protein regimens compared to a control high crude protein diet.

	Treatment[a]			
	Control *(13.5% CP)*	Oscillated CP *(11.5/13.5% CP)*	Intermediate CP *(12.5% CP)*	Low CP *(11.5% CP)*
ADG, d1-finish, kg[b]	1.34	1.37	1.39	1.35
DMI, d1-finish, kg[c]	8.76	8.70	8.62	8.49
Cost per kg of TMR[d]	$0.1830	$0.1840	$0.1841	$0.1852
Cost of TMR per day[d]	$1.6031	$1.6004	$1.5871	$1.5725
Cost per kg gain	$1.1964	$1.1682	$1.1418	$1.1648
Pen Size (cost per pen per day;$)				
25	$29.91	$29.20	$28.54	$29.12
50	$59.82	$58.41	$57.09	$58.24
100	$119.64	$116.82	$114.18	$116.48
150	$179.45	$175.23	$171.26	$174.73
200	$239.27	$233.64	$228.35	$232.97
250	$299.09	$292.04	$285.44	$291.21
Days on Feed (100 animals per pen)				
130	$15,552.59	$15,186.30	$14,842.94	$15,142.89
140	$16,748.95	$16,354.47	$15,984.70	$16,307.73
f150	$17,945.30	$17,522.65	$17,126.47	$17,472.57
160	$19,141.65	$18,690.83	$18,268.23	$18,637.40
170	$20,338.00	$19,859.00	$19,410.00	$19,802.24
180	$21,534.36	$21,027.18	$20,551.76	$20,967.08
190	$22,730.71	$22,195.36	$21,693.53	$22,131.92
200	$23,927.06	$23,363.53	$22,835.29	$23,296.75
Cost Savings Compared to Control *(100 animal pens fed for 160 days)*[e]		$450.82	$873.42	$504.25

[a] *Control:* 13.5% crude protein (CP) diet (3.50% crude protein equivalent (CPE) from non-protein nitrogen (NPN)) through slaughter; *Oscillating CP:* traditional 13.5% CP start-up and step-up rations then alternating an 11.62% CP ration (1.55% CPE from NPN) with a 13.5% CP ration (3.50% CPE from NPN) at 48-hour intervals; *Intermediate CP:* traditional 13.5% CP start-up and step-up rations fed for three weeks then a 12.56% CP diet (2.53% CPE from NPN); *Low CP:* traditional 13.5% CP start-up and step-up rations fed for three weeks and then an 11.62% CP diet (1.55% CPE from NPN) ; The start-up and two step-up diets are not included in this analysis.

[b] In this study there was not difference in average daily gain, net energy requirement for gain or maintenance, and carcass merit. Ammonia emission decreased by up to 21% to 40% for the low crude protein diet compared to the control.

[c] Dry Matter Intake increases with increasing dietary protein (Collins and Pritchard, 1992; Krehbiel et al., 1998; Cole et al., 2003; Archibeque et al., 2007a,c). DMI is based on average DMI for the entire feeding period. Values are from Westover et al., 2011 (DMI, $P > 0.10$)

[d] Total mixed ration

[e] Cattle on this trial were fed for an average of 162 days.

Appendix H: The cost per unit of nitrogen for steers on various crude protein regimens compared to a control high crude protein diet.

	Treatment[a]			
	Control *(13.5% CP)*	Oscillated CP *(11.5/13.5% CP)*	Intermediate CP *(12.5% CP)*	Low CP *(11.5% CP)*
ADG, d1-finish, kg[b]	1.34	1.37	1.39	1.35
Nitrogen Intake, g	182.9	171.8	166.9	154.8
Nitrogen in ration, %	13.50%	12.64%	12.50%	11.50%
Cost per kg of TMR[b]	$0.1830	$0.1840	$0.1841	$0.1852
Cost per g of Nitrogen	$0.0247	$0.0233	$0.0230	$0.0213
Pen Size (cost per pen per day; $)				
25	$0.62	$0.58	$0.58	$0.53
50	$1.24	$1.16	$1.15	$1.07
100	$2.47	$2.33	$2.30	$2.13
150	$3.71	$3.49	$3.45	$3.20
200	$4.94	$4.65	$4.60	$4.26
250	$6.18	$5.81	$5.75	$5.33
Days on Feed (100 animals per pen)				
130	$321.17	$302.34	$299.18	$276.91
140	$345.88	$325.60	$322.20	$298.21
150	$370.58	$348.86	$345.21	$319.51
160	$395.29	$372.11	$368.23	$340.81
170	$419.99	$395.37	$391.24	$362.11
180	$444.70	$418.63	$414.25	$383.41
190	$469.40	$441.88	$437.27	$404.71
200	$494.11	$465.14	$460.28	$426.01
Cost Savings Compared to Control *(100 animal pens fed for 160 days)*[d]		$23.18	$27.06	$54.45

[a] *Control:* 13.5% crude protein (CP) diet (3.50% crude protein equivalent (CPE) from non-protein nitrogen (NPN)) through slaughter; *Oscillating CP:* traditional 13.5% CP start-up and step-up rations then alternating an 11.62% CP ration (1.55% CPE from NPN) with a 13.5% CP ration (3.50% CPE from NPN) at 48-hour intervals; *Intermediate CP:* traditional 13.5% CP start-up and step-up rations fed for three weeks then a 12.56% CP diet (2.53% CPE from NPN); *Low CP:* traditional 13.5% CP start-up and step-up rations fed for three weeks and then an 11.62% CP diet (1.55% CPE from NPN); The start-up and two step-up diets are not included in this analysis.

[b] In this study there was not difference in average daily gain, net energy requirement for gain or maintenance, and carcass merit. Ammonia emission decreased by up to 21% to 40% for the low crude protein diet compared to the control.

[c] Total mixed ration

[d] Cattle on this trial were fed for an average of 162 days.

Appendix I: The cost per unit of urea for steers on various crude protein regimens compared to a control high crude protein diet.

	Treatment[a]			
	Control *(13.5% CP)*	Oscillated CP *(11.5/13.5% CP)*	Intermediate CP *(12.5% CP)*	Low CP *(11.5% CP)*
ADG, d1-finish, kg[b]	1.34	1.37	1.39	1.35
Nitrogen Intake (g)	182.9	171.8	166.9	154.8
Urea (%)	3.55%	2.66%	2.53%	1.55%
Cost per unit of nitrogen	$0.0247	$0.0233	$0.0230	$0.0213
Cost per g of urea	$0.0009	$0.0006	$0.0006	$0.0003
Pen Size (cost per pen per day; $)				
25	$0.02	$0.02	$0.01	$0.01
50	$0.04	$0.03	$0.03	$0.02
100	$0.09	$0.06	$0.06	$0.03
150	$0.13	$0.09	$0.09	$0.05
200	$0.18	$0.12	$0.12	$0.07
250	$0.22	$0.15	$0.15	$0.08
Days on Feed (100 animals per pen)				
130	$11.40	$8.06	$7.57	$4.29
140	$12.28	$8.67	$8.15	$4.62
150	$13.16	$9.29	$8.73	$4.95
160	$14.03	$9.91	$9.32	$5.28
170	$14.91	$10.53	$9.90	$5.61
180	$15.79	$11.15	$10.48	$5.94
190	$16.66	$11.77	$11.06	$6.27
200	$17.54	$12.39	$11.65	$6.60
Cost Savings Compared to Control *(100 animal pens fed for 160 days)*[c]		$4.12	$4.72	$8.75

[a] *Control:* 13.5% crude protein (CP) diet (3.50% crude protein equivalent (CPE) from non-protein nitrogen (NPN)) through slaughter; *Oscillating CP:* traditional 13.5% CP start-up and step-up rations then alternating an 11.62% CP ration (1.55% CPE from NPN) with a 13.5% CP ration (3.50% CPE from NPN) at 48-hour intervals; *Intermediate CP:* traditional 13.5% CP start-up and step-up rations fed for three weeks then a 12.56% CP diet (2.53% CPE from NPN) ; *Low CP:* traditional 13.5% CP start-up and step-up rations fed for three weeks and then an 11.62% CP diet (1.55% CPE from NPN); The start-up and two step-up diets are not included in this analysis.

[b] In this study there was not difference in average daily gain, net energy requirement for gain or maintenance, and carcass merit. Ammonia emission decreased by up to 21% to 40% for the Low CP diet compared to the control.

[c] Cattle on this trial were fed for an average of 162 days.

Appendix J: The cost per unit of nitrogen excreted for steers on various crude protein regimens compared to a control high crude protein diet.

	Treatment[a]			
	Control *(13.5% CP)*	Oscillated CP *(11.5/13.5% CP)*	Intermediate CP *(12.5% CP)*	Low CP *(11.5% CP)*
Dry matter intake, kg	8.76	8.7	8.62	8.49
Nitrogen intake, g	182.9	171.8	166.9	154.8
Nitrogen retention, g	23	23.3	22.5	23.1
Nitrogen excretion, g	160	148.5	143.4	131.7
Feces, g	32.1	37.4	35.4	37.2
Urine, g	127.8	111.2	108	94.4
Nitrogen retention, %[b]	12.6	13.6	14.1	15
Nitrogen excretion, %[b]	87.4	86.4	85.9	85
Cost of Nitrogen	$0.0247	$0.0233	$0.0230	$0.0213
Cost of Nitrogen Retained	$0.0057	$0.0054	$0.0052	$0.0049
Cost of Nitrogen Excreted	$0.0216	$0.0201	$0.0198	$0.0181
Pen Size (cost per pen per day; $)				
25	$0.54	$0.50	$0.49	$0.45
50	$1.08	$1.00	$0.99	$0.91
100	$2.16	$2.01	$1.98	$1.81
150	$3.24	$3.01	$2.97	$2.72
200	$4.32	$4.02	$3.95	$3.62
250	$5.40	$5.02	$4.94	$4.53
Days on Feed (100 animals per pen)				
130	$280.70	$261.22	$257.00	$235.37
140	$302.30	$281.32	$276.77	$253.48
150	$323.89	$301.41	$296.54	$271.58
160	$345.48	$321.51	$316.31	$289.69
170	$367.07	$341.60	$336.07	$307.79
180	$388.67	$361.69	$355.84	$325.90
190	$410.26	$381.79	$375.61	$344.00
200	$431.85	$401.88	$395.38	$362.11
Cost Savings Compared to Control *(100 animal pens fed for 160 days)*[c]		$23.98	$29.18	$55.80

[a] *Control:* 13.5% crude protein (CP) diet (3.50% crude protein equivalent (CPE) from non-protein nitrogen (NPN)) through slaughter; *Oscillating CP:* traditional 13.5% CP start-up and step-up rations then alternating an 11.62% CP ration (1.55% CPE from NPN) with a 13.5% CP ration (3.50% CPE from NPN) at 48-hour intervals; *Intermediate CP:* traditional 13.5% CP start-up and step-up rations fed for three weeks then a 12.56% CP diet (2.53% CPE from NPN); *Low CP:* traditional 13.5% CP start-up and step-up rations fed for three weeks and then an 11.62% CP diet (1.55% CPE from NPN); The start-up and two step-up diets are not included in this analysis.

[b] Percent of nitrogen intake

[c] Cattle on this trial were fed for an average of 162 days.