DETERMINING THE EXISTENCE OF BUNK PREFERENCE IN AN AUTOMATED INDIVIDUAL INTAKE SYSTEM AND THE EFFECTS OF INCREASED ROUGHAGE LATE IN THE FINISHING PERIOD ON FEEDLOT STEER PERFORMANCE, INTAKE, AND EFFICIENCY

By

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Abstract: The objective of the first experiment was to determine the existence of bunk preference and if access to a preferred bunk affects performance, intake, and efficiency of feedlot steers. Angus steers (n = 123; initial BW = 293 ± 33.8 kg), blocked by BW and sire, were randomly assigned to 1 of 4 pens, with unrestricted access to any automated bunk within the pen. Steers consumed a common finishing diet ad libitum. The preferred bunk was defined as the bunk from which the most feed was consumed. In any week, 80% of steers consumed ≤ 29% of the week's total feed intake from the preferred bunk, with a maximum of 57% of weekly feed intake consumed from the preferred bunk. Percentage of total intake from the preferred bunk did not affect ADG, feed intake, or G:F (P > 0.64). Researchers may design experiments, at a stocking density ≤ 5 steers per bunk, without altering performance or intake. The objective of the second experiment was to evaluate effects of increased roughage late in the finishing period on growth performance, carcass traits, and ruminal and fecal characteristics of feedlot steers. Diets contained prairie hay, Sweet Bran, rolled corn, dry supplement, urea, and a liquid supplement. Dietary treatments included control (CON; 6% roughage), intermediate (INT; 12% roughage), and high (HGH; 18% roughage) roughage by adjusting prairie hay and rolled corn in the diet. Crossbred steers (n = 59; BW = 289 ± 35.6 kg) were assigned to treatments the final 58 d (4 pens of INT and HGH, 5 pens of CON; 4 steers per pen). High roughage steers had increased DMI the last 30 days on feed (P = 0.001) and a decreased final fecal pH (P = 0.04). Steers fed the HGH diet tended to have an increased overall DMI and REA (P ≥ 0.06). No other differences in carcass characteristics, performance, or ruminal pH were observed between treatments (P ≥ 0.11). Increasing roughage late in the finishing period did not negatively impact growth performance or carcass characteristics, but may alter ruminal fermentation and post-ruminal digestion.

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CHAPTER I

REVIEW OF LITERATURE

Introduction

Commercial feedlots aim to maximize both dry matter intake and average daily gain of feedlot cattle. Both goals provide the opportunity for the overconsumption of feed which can lead to digestive upsets reducing intake and daily gain. One way to limit the potential for overconsumption is to feed cattle only as much as they will eat, with managers targeting a slick feed bunk the following morning. Another way to limit overconsumption is the use of automated intake systems, which can be utilized to control the amount of feed individual animals receive each day while animals are group housed, which could reduce fluctuations in intake.

New advances in technology such as automated individualized intake systems enable producers to target an individualized rate of gain and feed efficiency within a group setting (Nielsen, 1999). Automated individual intake systems are being utilized more frequently to understand individual cattle feeding behavior and intake variation. Previously, collecting individual feed intake and feeding behavior data on group housed cattle was time and labor intensive (Huzzey et al., 2014). In addition, automated individual intake systems can help alleviate problems associated with pen feeding such as the ability for an animal to over or under consume feed which can alter expected

performance as well as lead to potential digestive problems (Shaver, 2002). In addition, automated individual intake systems can aid the producer in identifying health problems by identifying fluctuations in intake which may indicate an animal is sick (Chapinal et al., 2007).

Beef cattle in the United States are typically fed high-grain diets during finishing with goals of maximizing average daily gain (ADG) while decreasing cost of gain and days on feed. Cattle are most commonly transitioned onto a high grain finishing diet, from approximately 55% concentrate up to 80-90% concentrate, over a period of 14 -28 days (Brown et al., 2006; Samuelson et al., 2016). This diet transition either utilizes a ration blending method or a series of step-up diets. After transitioning onto the finishing diet, cattle will typically remain on the same finishing diet for the remaining days on feed (Samuelson et al., 2016; Meyer and Bryant, 2017). A common finishing diet utilized by commercial feedlots may consist of 55% grain, 30% byproducts, 10% roughage, and 5% urea, vitamins and minerals and additives (NASEM, 2016; Samuelson et al., 2016). While feeding high concentrate diets to cattle can improve animal performance and decrease feed costs, when fed over a long period of time high grain diets have been associated with acidosis and liver abscesses, which can decrease growth performance and negatively impact carcass characteristics (McCann, 2018). Alternatively, feeding increased levels of roughage, such as hay or silage up to 16.0%, has been reported to decrease incidences of acidosis and may improve gain (Calderon-Cortes and Zinn, 1996). However, roughages in ruminant diets are one of the most expensive commodities when priced on a net energy basis and are typically only included in the diet to maintain rumen function and feed intake (Wagner et al., 2014).

Automated Individual Intake Systems

There are several automated intake systems available such as GrowSafe (GrowSafe Systems Ltd, Airdrie, AB, Canada), the Calan Broadbent Feeding System (American Calan; NH, USA), the Super SmartFeed (C-Lock, Inc., Rapid City, SD, USA) and the Insentec Roughage Intake Control System (Insentec RIC, Hokofarm Group, Marknesse, Netherlands). These systems quantify the feeding behaviors of individual animals in a group housed environment (Nielsen, 1999). Group housed cattle exhibit different behaviors than cattle that are individually penned. Previously, collecting individual feed intake and feeding behavior data on group housed cattle was time and labor intensive (Huzzey et al., 2014). With the introduction of the automated intake systems, data collection on the individual intake of group housed cattle is more efficient. Automated individual intake systems do not alter the normal behaviors because animals are group housed while collecting data on individual animals.

Insentec Roughage Intake Control System

The Insentec RIC system has been used in dairy and beef cattle to study feeding behavior and feed and water intake. Insentec RIC system has been documented to have higher specificity and sensitivity compared to other automated systems (Chapinal et al., 2007). The Insentec system used an electronic ID (EID) tag to record steer ID, feed bunk attended, and the beginning and end weight of the feed bunk. In addition, the Insentec system also records the start and end time of each visit, duration of visit, total intake per visit, and total number of visits to the bunks. The Insentec RIC allows for multiple diets to be fed within the same pen by electronically restricting access to specific feed bunks (DeVries and von Keyserlingk, 2009; Ruuska et al., 2014). A trial completed by Swanson

et al. (2017) utilized the Insentec RIC system to control steers access to specific feed bunks. One issue investigated within the literature is cattle consuming feed from feed bunks an animal has been restricted from accessing. Ruuska et al. (2014), evaluated a solution to the consumption of the incorrect feed by constructing a barrier at the top of the gate, which prevented animals from accessing the feed from a bunk the animal was restricted from.

Feed Bunk Preference

Feed bunk preference refers to an animal preferring one individual feed bunk over another feed bunk available in the pen. While experiments investigating bunk preference are limited, preference for free stall space has been reviewed in dairy cattle. Dairy cows preferred certain stalls within a free stall barn, according to Friend and Polan (1974). The same study documented that dominant cows altered the use of free stalls, where subordinate cows would not use the stall a more dominant animal had previously occupied, indicating social rank within the herd played a role in free stall barn use (Friend and Polan, 1974). Dominant steers would theoretically approach the feed bunk first following the addition of feed, and if feeding space is limited, may prevent subordinate animals from accessing the feed bunk (Corkum et al., 1994). Feed bunk preference can give insight into the social hierarchy of a pen of cattle, outside of watching recordings of the animals. The animals that display a higher preference for a feed bunk may be the more dominant animals within the group. Cattle that are fed in groups will, to some degree, inevitably have competition for feed (Olofsson, 1999). Preference for a specific feed bunk has not been documented in the literature and the effects on the performance of

beef cattle have not been investigated. Feed bunk preference has not been reported in the literature to be associated with the feeding behavior of beef cattle

Feeding Behavior of Beef Cattle

Previous literature has confirmed feeding behavior is associated with performance and efficiency in cattle, there are several environmental factors that can affect feeding behavior such as variation in feeding times and weather patterns (Stricklin and Gonyou, 1981; Schwartzkopf-Genswein et al., 2002; Pritchard and Bruns, 2003; Nkrumah et al., 2007; Schwartzkopf-Genswein et al., 2011). Feeding behavior of cattle in an automated feeding system is different compared to trough feeding cattle. Gonyou and Stricklin (1981) reported trough fed cattle consumed feed longer than cattle fed from a single stall, although total feed consumption was not different between groups. Corkum et al. (1994) reported animal concentration was highest around the automated feeders which may affect individual animal intake when animals are fed within in a group. The study by Corkum et al. (1994) suggested slightly competitive feeding groups increased individual animal intake through social competition without negative effects on social stress. DeVries and von Keyserlingk (2009) reported no difference in DMI when 2 heifers were electronically assigned to 1 feed bunk, utilizing an Insentec RIC system to restrict access to feed bunks. The heifers in the DeVries and von Keyserlingk (2009) experiment compensated for the limited access by consuming more feed each time the animal accessed the feeder, which in agreement with an experiment completed by Proudfoot et al. (2009) evaluating the effect of competition on transition dairy cow behavior in an Insentec RIC system. According to Proudfoot et al. (2009) restricting access to feed

increased displacements at the automated feed bunk regardless of parity, although feeding behavior between primiparous and multiparous cows were affected differently.

Stocking density can also affect feeding behavior, an increased stocking density would increase competition for feed, and a decreased stocking density would decrease competition for feed (DeVries et al., 2004). Results from Corkum et al. (1994) suggest that a stocking density of 3 steers per bunk resulted in the greatest amount of time animals spent consuming feed, when compared with a stocking density of 1 steer per bunk. A trial conducted by Olofsson (1999) reported competition increased when stocking density per feeding station was increased from 1 to 4 cows, in addition eating time was reduced and standing times without eating increased. A theory presented by Pritchard and Bruns (2003) suggests that the decrease in satiety would motivate cattle to approach the bunk more than dominance alone and suggests subordinate cattle might wait till later in the day to approach the bunk.

Beef Cattle Finishing Diets

Roughage levels in feedlot diets are limited in order to promote body weight (BW) gain and reduce the cost of gain (Calderon-Cortes and Zinn, 1996). High concentrate diets are easier to deliver in a commercial feedlot, allowing more feed to be delivered per truckload. Although high concentrate diets cost less on an energy basis and are easier to deliver, there is an increased chance of acidosis associated with cattle fed high concentrate diets compared to cattle fed diets with increased roughage. Schwartzkopf-Genswein et al. (2003) noted increasing the amount of roughage in the diet decreased the incidence of ruminal acidosis in feedlot cattle. Bines and Davey (1970) reported faster rumen turnover rates in cattle consuming finishing diets with increasing

roughage levels. Increasing roughage in the diet can increase the frequencies of meals throughout the day which can help stabilize ruminal pH (González et al., 2012). Reducing fluctuations in ruminal pH can prevent incidences of subacute and acute acidosis (Meyer and Bryant, 2017). However, extensive use of roughages may depress intake due to physical fill and can dilute the energy content of the diet (Church, 1988; Calderon-Cortes and Zinn, 1996).

Roughage Levels in Finishing Diets

Typical roughage levels in a finishing diet can range from 0 - 13.5% on a DM basis (Galyean and Hubbert, 2014; Wagner et al., 2014; NASEM, 2016). According to a 2015 Survey of feedlot nutritionist survey, the typical range of roughage included in feedlot finishing diets is between 8.0 - 12.0% on a dry matter (DM) basis (Samuelson et al., 2016). Roughage is included in finishing diets to maintain rumen health and motility as well as stimulate voluntary intake, although roughages are bulky and can be difficult to process and store (Wagner et al., 2014). Beside traditional silages and hay, other ingredients such as grain byproducts can provide fiber and have particle sizes large enough to stimulate ruminal contractions. A study by Calderon-Cortes and Zinn (1996) evaluated the effects of dietary forage levels and length of grind on the growth and digestive function of feedlot steers. Results indicated that the digestible energy value of the diet and nitrogen digestibility increased as forage level decreased (Calderon-Cortes and Zinn, 1996). Gill et al. (1981) reported that for every 1% increase in roughage, comprised of alfalfa hay and corn silage, there is a 0.35% decrease in metabolizable energy content of the diet. An alternative to the traditional approach of feeding roughage in finishing feedlot diets, while decreasing overall roughage use, would be to increase

roughage every third day, change source of roughage, or feed small quantities of long stem hay with the traditional low roughage diet (Galyean and Hubbert, 2014).

Reasons for Inclusion

Roughage is included in beef cattle finishing diets to maintain rumen health and function, although roughage inclusion is limited due to cost per unit of energy (Galyean and Defoor, 2003; Gentry et al., 2016). Reducing particle size by grinding forage improves performance by increasing voluntary intake of the diet, which increases the rate of passage from the rumen and reduces the extent of carbohydrate digestion (Church, 1988). In ruminants, roughage stimulates chewing and rumination, furthers extent of digestion of the feed, and elevates rumen pH (NASEM, 2016). Long-fiber particles ($\geq$ 1 cm; Hall, 2007) in a ruminant diet stimulate saliva production and provide buffering to the rumen environment (NASEM, 2016). Roughage inclusion can be decreased by increasing the particle size of the roughage without sacrificing animal performance (Church, 1988; Gentry et al., 2016). The positive associative effect increases voluntary intake and ADG through low levels of roughages added to typical finishing diets (Wise et al., 1968). The positive associative effect occurs when the consumption of roughage increases the consumption of the diet.

Roughage Inclusion Effects on Performance

Increased levels of roughage in finishing diets can decrease the performance of ruminant animals, as nutrients become more diluted in diets with increased roughage. Swanson et al. (2017) reported gain to feed (G:F) and ADG decreased linearly as roughage level increased in the diet. Trials conducted by Turgeon et al. (1983) and Galyean and Defoor (2003), reported an increased dry matter intake (DMI) and decreased

G:F as roughage level increased in the diet. The literature is in agreement that energy density is thought to be the primary regulator of DMI when feeding high concentrate diets while physical fill is the primary regulator of DMI when feeding high roughage diets (Krehbiel et al., 2006; Mertens, 1987). Physical fill of the rumen will limit the intake of high roughage diets to the rumen's physical capacity whereas physiological fill of the rumen is determined by an animals' nutrient intake. According to Swanson et al. (2017), physical fill of the rumen might be impacting DMI when roughage was included at 20%, however a quadratic effect was observed on DMI with forage levels ranging from 5-15%. Previous literature is in agreement low levels of roughage in finishing diets increases DMI (Zinn et al., 1994; Galyean and Defoor, 2003; Galyean and Hubbert, 2014). Large increases in roughage level, greater than 5% DM, increased DMI to maintain level of energy intake (Galyean and Defoor, 2003).

Roughage Inclusion on Carcass Traits

Increased levels of forage in the diet can play a role in reducing carcass traits, which would reduce producer's profits and customer satisfaction with retail beef products (Craig et al., 1959). In general, forage finished cattle have a darker meat color compared to grain finished cattle (Apaoblaza et al., 2020). Gill et al. (1981) reported a slightly higher dressing percentage in steers consuming less roughage. According to Gill et al. (1981), the optimal roughage level varied with type of grain and processing, ranging from 7 – 16% roughage for steam-flaked corn and high-moisture corn, respectively. Swanson et al. (2017) reported a linear decrease in hot carcass weight and dressing percentage as forage level increased for cattle fed 5% forage compared to cattle fed 20% forage; however, kidney, pelvic heart fat (KPH), back fat thickness, marbling score, and rib eye

area were not affected by increased roughage. Although the rate of roughage inclusion can influence carcass characteristics, it does not appear that roughage source decreases carcass quality. As reported by Swanson et al. (2017) no differences were observed in the carcass characteristics of steers fed different forage sources at similar neutral detergent fiber (NDF) content.

Effects of Roughage Inclusion on Digestibility

The passage rate out of the rumen is influenced by level of feed intake as well as roughage level of the diet (Südekum et al., 1995). Passage rate of ruminal liquid from the rumen increased as the roughage percentage of the diet increased (Church, 1988). With an increase in roughage level in the diet, there is an increase in DMI which can increase rate of passage and decrease the digestibility of the diet. An increase in chewing during eating caused by the roughage can result in increased saliva production, which provides buffers the rumen of cattle fed high-concentrate diets (Owens et al., 1998). A study conducted by Cole et al. (1976) observed differences in the DM digestion of steers as the roughage level increased from 0 to 21% roughage. The coefficient of DM ruminal digestion was increased for 0% roughage diet compared to the 7%, 14%, and 21% roughage diets (Cole et al., 1976). An increased rate of passage and a decrease in concentrate digestion was observed on the 14% roughage diet, which also tended to have the lowest total digestion coefficients for starch, DM, and cellulose (Cole et al., 1976). Increasing the proportion of forage in the diet decreases the starch content of the diet and shifts the site of starch digestion from the rumen to the small intestine (Yang and Beauchemin, 2006).

Nutrient Digestibility

Digestibility Markers

Both internal and external markers can be utilized to determine rate of passage and digestibility of an ingredient or of the total diet. In cases where total fecal collections cannot be completed, markers can be utilized to determine passage rate and digestibility (Church, 1988; Südekum et al., 1995). External markers, including titanium dioxide (TiO2) and chromic oxide, are dosed orally through the feed, often attaching the external marker to one feedstuff and is dosed at specific intervals (Church, 1988). To be considered an acceptable marker it must display the characteristics developed by Faichney (1975); it must be un-absorbable, the marker must not affect or be affected by the GI tract or the microbial population of the gastrointestinal tract, the marker must be physically similar to the material it is to mark, the methods of marker estimation within digesta samples must be specific and sensitive, and it must not interfere with other analyses (Kotb and Luckey, 1972). There are some inherent errors in recovering external markers including but not limited to: administration of the marker, method of fecal collection, and percent recovery rate of the marker (Owens and Hanson, 1992; Lippke, 2002). Following the dosing of the external marker, fecal samples are collected at specific intervals to determine rate of passage (Church, 1988).

Concentrations of the marker are calculated based off the dosing rate and marker concentration in the collected fecal samples. The normal passage rate for beef cattle is between 2-6% per hour (NASEM, 2016). To determine passage rate external markers can be either orally dosed in the diet or dosed directly into the rumen (Owens and Hanson, 1992; NASEM, 2016). Following dosing, fecal samples are collected over a period of time, which are then analyzed for marker concentrations. Orally dosing the marker can

reduce the need for cannulated animals in digestibility trials (NASEM, 2016). In addition to external markers there are also internal markers, such as lignin and acid insoluble ash that are present within the diet which can be utilized to determine passage rate and digestibility of the diet (Church, 1988). Internal markers such as indigestible acid detergent fiber (ADF) and NDF (Cochran et al., 1986) are used to estimate passage rate from the rumen. In some trials, both an internal and external marker are used to determine passage rate and digestibility.

Titanium as an External Marker

Titanium dioxide is a rare earth metal and is one of several external markers utilized in animal nutrition research to determine nutrient digestibility, passage rate, and intake. Previous literature reports other external markers that have been utilized to estimate passage rate of cattle are chromium oxide, ytterbium, lanthanum, cerium, and dysprosium (Church, 1988). Titanium dioxide is an alternative to chromic oxide utilized in digestibility trials, although a number of the studies also use chromic oxide as a standard to compare the TiO2 recovery against (Titgemeyer et al., 2001). Titanium dioxide has been successfully used in ruminant digestibility trials as an external digestibility marker, with 99% recovery of TiO2 reported in dairy cows consuming mixed rations (Hafez et al., 1988; Titgemeyer et al., 2001). Titanium dioxide has also been approved for use in monogastrics (Jagger et al., 1992) and poultry (Short et al., 1996) to estimate digestibility. Titgemeyer et al. (2001) reported that steers fed a forage-based diet had decreased TiO2 recovery compared to steers fed a grain-based diet. Titgemeyer et al. (2001) also reported the TiO2 recovered led to an underestimation of diet digestibility with the greatest underestimation of diet digestibility in the forage

treatment, while another trial by Hafez et al. (1988) reported 99% recovery of TiO2 in a high concentrate diet containing both corn and hay silage.

Rate of Passage in Beef Cattle

Previous literature reports external markers have been utilized to estimate passage rate of cattle using several different elements, with a few of the most common elements including chromium oxide, ytterbium, and titanium dioxide (Church, 1988). Titanium dioxide has been utilized as an alternative to chromium oxide and is legally approved for use in the United States (Titgemeyer et al., 2001). Passage rate in ruminant animals is important since rate of passage can affect the extent of digestion and methane loss, voluntary feed intake, the amount of protein escaping ruminal degradation, microbial growth efficiency, and susceptibility of animals to bloat (Okine et al., 1998).

Passage rate out of the rumen is influenced by level of feed intake as well as roughage level of the diet with ruminal liquid passage rate increases from the rumen as the roughage percentage in the diet increased (Church, 1988; Südekum et al., 1995). Particle size and density of the feed ingredients are reported as the most important factors affecting ruminal particle distribution and passage out of the rumen (Kaske et al., 1992). With an increase in roughage level of the diet, there is an increase in DMI which can increase rate of passage and decrease digestibility of the diet. Greater chewing during mastication and rumination might result in greater saliva production, which could buffer the rumen of cattle consuming high-concentrate diets (Owens et al., 1998). Conversely, greater rumination might increase mastication of grain in some diets, thereby increasing rate and extent of fermentation in the rumen (Owens et al., 1998).

Neutral Detergent Fiber

Fiber is an important aspect of ruminant diets; dietary fiber stimulates ruminal contractions and aids in digestion of feed within the rumen. The roughage NDF component is considered to be the most important for maintaining rumen health and function (González et al., 2012; Plaizier et al., 2008). Neutral Detergent Fiber is negatively associated with digestibility, therefore including forage in the diet would increase the NDF content of the diet and slow the rate of carbohydrate digestion (Church, 1988; Yang and Beauchemin, 2006). Literature suggests that when formulating finishing diets, it is more effective to include dietary roughage on an NDF basis as opposed to a DM basis (Galyean and Defoor, 2003; Salinas-Chavira et al., 2013). Previous literature has reported no effect of forage level (7-20%) on ruminal digestion of ADF, starch, nitrogen, or organic matter (Zinn, 1986; Zinn et al., 1994).

Physically effective fiber is important in maintaining a healthy ruminal environment, improving nutrient digestion, and has been recently considered the most important aspect of fiber content in ruminant diets (Mertens, 1997; Zebeli et al., 2012). Physically effective NDF (peNDF) was first introduced by Mertens (1997) and relies solely on the particle size of feedstuff as an indicator of potential to stimulating chewing activity (NASEM, 2016). Physically effective NDF is calculated as the total retained proportion on the top three screens of the Penn State Particle Separator (PSPS) multiplied by the NDF content of the feed (Yang and Beauchemin, 2006; NASEM, 2016). Zebeli et al. (2012) evaluated the roles peNDF and dietary fiber play in the level of production of dairy cattle, which investigated both particle size and peNDF content of the feed in the digestibility, ruminal mat formation and the contribution of peNDF to rumen metabolism.

Zebeli et al. (2012) reported the limitations to utilize solely peNDF to determine fiber content of total mixed rations (TMR) for dairy cattle. They indicated that the particle size of individual ingredients can differ from the particle size of the total mixed rations and can impact the overall fiber content of the total diet (Zebeli et al., 2012). However, Zebeli et al. (2012) also determined the DM of the samples did not affect the PSPS results of a TMR. Current recommendations suggest that 5-8% peNDF is required in the diet to keep rumen pH above 5.7 (NASEM, 2016). While some feedlot diets might fall below the current recommendations, some peNDF can be provided by the grain portion of the diet (NASEM, 2016). Over 70% of the ruminal pH variations can be accounted for by the peNDF content of the diet, according to Mertens (1997).

Fecal Scoring as a Predictor of Digestibility

For a basic insight into the digestibility of ruminant animals, fecal consistency scores and pH can be utilized to give a relatively quick determination of nutrient digestibility. A fecal scoring system was developed by Ireland-Perry and Stallings (1993) for use in dairy cattle and an adapted fecal scoring system for use in beef cattle was developed by Woolsoncroft et al. (2018). The fecal scoring system evaluated how much the fecal sample spread and splattered upon impact on a clean floor from a height of 1 meter. Based upon the degree of spread and splatter, each fecal sample was assigned a number on a scale from 1 to 4; 1 = runny: consistency of liquid which splatters on impact, to 4 = dry: hard consistency that does not distort upon impact. This system was created on the idea that when feces have a greater moisture content, digestion of nutrients may be more complete (Ireland-Perry and Stallings, 1993). This fecal scoring system was adapted for use in feedlot cattle by Woolsoncroft et al. (2018). Fecal samples obtained via

rectal palpation are evaluated by both physically handling and visually appraising the sample without dropping it. With this method, the fecal samples are assigned a number between 1 and 5; 1 = firm, hard, dry appearance such as a cow on dry hay, 3 = soft and moist, but not runny, 5 = very thin and watery, cannot be caught in an open hand. The optimal fecal score is considered to be a 3 for feedlot cattle (Woolsoncroft et al., 2018).

Effect of Roughage on Fecal Scores or Consistency

Fecal output increases as level of roughage intake increases (Church, 1988). Fecal consistency may vary due to various factors unrelated to diet such as environment and stress but is still indicative of the extent of digestibility of the diet and fecal consistency can aid producers in evaluating cattle performance, health and behavior (Kononoff et al., 2002). If the fecal consistency is more liquid, that can be indicative of a shorter ruminal retention time or decreased fiber in the diet. Cattle fed the same diet should have similar fecal consistencies, however, about 5% of the cattle can be expected to have different looking manure from the rest of the herd (Hall, 2007).

When the passage rate increases the hindgut fermentation and fecal consistency appears more “loose” compared to a cow consuming dry hay (Kononoff et al., 2002; Hall, 2007). While both the rumen and hindgut ferment carbohydrates into volatile fatty acids (VFA), the retention time in the hindgut is lower compared to the rumen, (13 h vs. 30 h; Yang et al., 2002) and the digesta in the hindgut has already been fermented by the microbial populations in the rumen and small intestine (Gressley et al., 2011). Steers consuming high grain diets have increased microbial nitrogen output because higher levels of starch are arriving in the hindgut (Hammond, 1997). Higher levels of fermentable carbohydrates reaching the hindgut can result in hindgut acidosis,

characterized by a decreased fecal pH, increased lactic acid and VFA production, and the appearance of mucin casts in the feces (Gressley et al., 2011). Increased rumination increases mastication of concentrates in some diets, increasing the rate and extent of fermentation in the rumen, preventing excess starch from escaping ruminal fermentation (Owens et al., 1998). Therefore, increasing the amount of forage in the diet can shift the site of digestion from the rumen to the small intestine and hindgut.

Fecal pH and Roughage Inclusion

Fecal pH can help estimate the extent of feed digestion as an indicator of total tract digestion of the diet, and is measured immediately following collection using a pH meter. Turgeon et al. (1983) evaluated the performance of finishing feedlot cattle experiments and one digestibility experiment, reported no relationship between roughage level (5%, 10%, and 15% roughage) and fecal pH when feeding mixed corn diets. According to Turgeon et al. (1983), comparing roughage levels with whole shell corn reported inconsistent correlations between ADG and both fecal starch and fecal pH. Previous literature reports inconsistent results regarding fecal pH, Fredin et al. (2014) observed no relationship between fecal starch and fecal pH. However, study by Wheeler and Noeller (1976) reported a decreased fecal pH with increasing fecal starch concentrations.

Ruminal pH of Finishing Beef Cattle

Optimal pH for beef cattle in literature has been recorded between 5.6-5.8 although pH fluctuates throughout the day (Owens et al., 1998; Beauchemin et al., 2001; Nagaraja and Titgemeyer, 2007). Ruminal pH is indicative of the rate of digestion as well as health of the rumen and rumen environment. Roughage particles that are long (≥ 1 cm;

Hall, 2007) promote both rumination and chewing during eating which increases saliva production as well as increases ruminal pH (NASEM, 2016). Low roughage diets reduce rumen motility because less saliva is entering the rumen and saliva contains buffers which help stabilize rumen pH and slow the rate of carbohydrate digestion thus decreasing volatile fatty acid production (Church, 1988; NASEM, 2016). As the roughage percentage in finishing feedlot diets is increased, mainly through the use of corn byproducts, ruminal pH can be stabilized and the negative associative effects of feeding high concentrate diets can be reduced (Galyean and Hubbert, 2014). Diets containing increased levels of roughage promote the production of acetate which increases the pH of the rumen, decreasing the risk for acidosis (Church, 1988). In contrast, high concentrate diets promote the production of propionate which will decrease the pH of the rumen, increasing the risk of acidosis (Church, 1988). Methanogenic and cellulolytic bacteria, which are able to digest roughage, are affected at a rumen pH below 6.0 (Church, 1988).

Alternatives to utilizing cannulated animals for research are becoming more popular as the use of cannulated animals can be expensive and numbers are typically smaller. Animals that have permanent rumen cannulas will typically be utilized on multiple studies during the animal's lifespan. One method to obtain rumen fluid without the use of ruminally cannulated animals is using the oral – stomach tubing method. The oral – stomach method may not provide reliable results because pH may vary depending on intra-ruminal localization, time of sampling in relation to feeding and saliva contamination (Enemark et al., 2002). To account for these drawbacks, disposing of the rumen fluid that is first collected after intubating can reduce the nitrogen contamination

from the saliva and having the same individual perform the intubation with every collection can reduce variation with sampling.

Rumen Lactate

Lactic acid is one of the intermediates resulting from pyruvate production in the catabolizing of glycerol, protein, and carbohydrates. Lactate is a byproduct of fermentation and is produced and utilized by different bacterial populations in the rumen. Depending upon the environment of the rumen, lactate can be rapidly converted into the volatile fatty acids acetate and propionate; although concentrations of lactate in the rumen are generally low except in cases of acidosis (Bruno and Moore, 1962; Piveteau, 1999). Acidosis is often defined by a decreased ruminal pH but acidosis can also be identified by alterations in ruminal lactate concentrations. Diets containing high levels of easily digestible carbohydrates will cause lactate concentrations to increase up to 80 mmol/l and cause rumen pH to fall to 5.0 (Møller et al., 1997). The accumulation of lactic acid in the rumen is followed by a drop in pH < 5.0, according to Dunlop and Hammond (1965). Concentrations of ruminal lactate were not as high during a bout of subacute acidosis when steers were abruptly fed a 70% concentrate diet (≤ 10 mM, Harmon et al., 1984; > 5 mM, Aschenbach et al., 2011).

Between 2-5% of the propionate produced in the rumen is converted to lactic acid (Church, 1988). According to Møller et al. (1997), the rumen epithelium has a great capacity to absorb L-lactate through passive diffusion, but lactate absorption is slower than the rate of short chain fatty acid absorption. L-lactate turnover and absorption rate increased when lambs were switched from low to high concentrate diets, although conversion of L-lactate to glucose remained the same (Huntington et al., 1980). The

rumen fluid of cattle fed only roughage contained low levels of lactic acid, confirming results of Ahrens (1967) and Bruno and Moore (1962). When Ahrens (1967) overfed large amounts of wheat or ensiled pears to heifers, they observed increased lactate concentrations in the rumen, and rumen pH decreased. An in vitro study conducted by Bruno and Moore (1962) evaluated the conversion and production of lactic acid within the rumen environment. Their results observed within the first hour of in vitro incubation, lactic acid values peaked at 8.2% of the total acids (Bruno and Moore, 1962). In addition, Bruno and Moore (1962) also observed lactic acid accumulation when large amounts of carbohydrates were present in vitro.

Volatile Fatty Acids in Finishing Beef Cattle

Within the rumen, multiple fermentation end products are produced by anaerobic microorganisms including methane, carbon dioxide, microbial cells and volatile fatty acids (NASEM, 2016). Ruminal fermentation transforms carbohydrate components in the forage into short-chain VFA, which are absorbed passively through the rumen wall and can be readily absorbed for energy production (Bird et al., 1996; Adewuyi et al., 2005; Lorenz, 2015). Approximately 75-85% of energy from feed is converted to VFA during rumen fermentation (Sutton, 1979). Volatile fatty acids under normal conditions will dissociate rapidly causing a decrease in rumen pH (NASEM, 2016). Volatile fatty acid concentrations represent the balance between production and removal of end products and thus VFA concentrations do not reflect VFA production (NASEM, 2016). The concentration of VFA can change with the proportion of roughage and grain in the diet. As dietary roughage level increases, there is a decrease in amylolytic bacteria while celluloytic and fibrolytic bacteria increase. Normal VFA concentrations in beef cattle can

fluctuate from 30 to 200 mM, depending on rumen environment and diet composition (Sutton, 1979; France and Siddons, 1993).

Throughout the literature there are three VFA discussed most commonly: butyrate, propionate, and acetate. While all three provide energy to the ruminant, acetate and propionate are more energetically important compared to butyrate. Cattle consuming high concentrate diets have increased propionate concentrations and decreased acetate concentrations, whereas high roughage diets promote the production of acetate, and high acetate concentrations have been associated with an increased ruminal liquid passage rate; (Church, 1988; NASEM, 2016).

Effect of Roughage Inclusion on VFA Concentrations

Diets with higher starch contents will produce more propionate which is readily converted to glucose, which could explain an increased glucose availability for cattle consuming high concentrate diets (Evans et al., 1975). The amount of carbohydrates and roughages fed can determine the ratios of VFA within the rumen and increasing the forage level in a diet can increase the acetate:propionate ratio in the rumen (Zinn et al., 1994). Increasing the dietary roughage level, increased the molar proportions of acetate (13.0%) while decreasing the proportions of propionate (10.2%), according to Zinn et al., (1994). The VFA acetate:propionate:butyrate ratio concentrations in the rumen of cattle consuming high roughage diets are typically 70:20:10 as compared to feedlot cattle fed high concentrate diets which are typically 50:40:10 (Owens and Goetsch, 1988; France and Siddons, 1993). When consuming high roughage diets, the ratio of acetate:propionate is approximately 3:1 in the rumen fluid compared with a roughly 2:1 ratio in high concentrate diets (Owens and Goetsch, 1988; France and Siddons, 1993). The

acetate:propionate ratio is biologically important since propionate is the only VFA that contributes to glucose formation with roughly 27-54% of overall glucose production coming from propionate (Lindsay, 1970). Penner et al. (2009), reported a higher ruminal VFA concentration in cows fed a high concentrate diet, however VFA absorption and passage out of the rumen was not affected. Volatile fatty acid concentrations of steers fed roughage diets are only 0.5-1.5% of the ruminal liquid, compared to approximately 2% of the ruminal liquid of steers fed high concentrate diets (Church, 1988).

Overall, previous literature reports increased acetate production and decreased propionate production with increasing roughage. A significant diet by time interaction in VFA patterns was observed between high (80%) and low (40%) roughage dietary treatments, as stated by Evans et al. (1975). Average propionate and isobutyrate levels were higher in sheep consuming a low roughage diet compared to a high roughage diet; while acetate levels in sheep were increased after feeding but decreased to pre-feeding levels quicker for the low roughage diet (Evans et al., 1975). In a study by Zinn (1986), increased acetate and reduced propionate were observed in feedlot cattle consuming a 20% forage diet, whereas propionate was increased and acetate was reduced in feedlot cattle consuming a 15% forage diet. An experiment completed by Evans et al. (1975) stated feeding a 60% concentrate diet resulted in an increase in plasma insulin, glucose, and propionate in both sheep and dairy cattle. While a diet consisting less than 20% concentrate increased circulating plasma acetate levels. Level of roughage included in the diet did not affect butyrate concentrations in either species (Evans et al., 1975).

Blood Metabolites

Blood Glucose

Glucose is the main form of energy utilized for tissues within the body (Cerrilla and Martínez, 2003). The main pathway for fermentation of hexose polymers in ruminant diets such as starch, cellulose, fructans, and pentose polymers is the Embden Meyerhof pathway which results in the formation of pyruvate from glucose (Baldwin, 1965). Glucose can be absorbed via passive diffusion into the paracellular pathway (Bird et al., 1996). Cattle fed high roughage diets have small quantities of alpha-linked glucose polysaccharides pass from the rumen into the small intestine (Bird et al., 1996). There are three modes of glucose transport; a Na-dependent active transport on the brush border, facilitated diffusion on the basolateral membranes, and by passive diffusion via the paracellular pathway (Madara, 1991). On high-roughage diets the amount of glucose available for absorption in the small intestine is minimal. Glucose requirements are different for growing animals compared to mature animals, but are significantly influenced by the concentration and type of VFA produced in the rumen (Reynolds et al., 2003). As the concentration of starch in the diet increases, a greater amount of starch escapes ruminal digestion and is absorbed in the small intestine (Church, 1988). Blood glucose is of diagnostic value for the assessment of nutritional status because glucose can vary in blood concentration. Blood glucose provides insight into starch utilization, digestion, and metabolism in cattle.

Blood Lactate

L-lactate is a byproduct of propionate metabolism in the rumen that can enter the bloodstream, and has been investigated as a symptom of systemic acidosis (Church,

1988). High concentrate diets cause a build-up of excess lactate in the rumen, and the additional lactate can be absorbed into the blood stream, which is why analyzing blood samples to assess lactate concentrations in the blood is a reliable method to provide insight to lactic acid utilization in the rumen (Dunlop and Hammond, 1965). Literature reports normal blood lactate concentrates between 0.5-2.0 mmol/L (0.09-0.36 g/L; Dunlop and Hammond, 1965). According to Dunlop and Hammond (1965) blood lactate increases as a subsequent response to a rise in ruminal lactate concentrations, although another study by Suber et al. (1979) reported a low correlation between plasma and ruminal lactate. Dunlop and Hammond (1965) investigated the effects of increasing ruminal lactate concentrations and the sequence of biochemical events in the ruminoreticulum and the blood of cattle suffering from lactic acidosis. Their results indicate accumulating blood lactate titrated most of the bicarbonate out of the blood to stabilize rumen pH, causing a fall in blood pH from 7.44 to $\leq$ 7.04 and if the lactic acidosis was severe, causing the animal to succumb to the lactic acidosis (Dunlop and Hammond, 1965).

Serum Urea Nitrogen

Serum urea nitrogen is measured in ruminants and other production species as an indicator of nitrogen intake (Preston et al., 1965), nitrogen utilization (Egan and Kellaway 1971; Kohn et al., 2005), and nitrogen intake (Nolan et al., 1970). Ruminal ammonia concentration increases when there is an excess of nitrogen relative to energy within the rumen, and the unused ammonia is transported through the rumen wall into the bloodstream where it is detoxified by conversion to urea by the liver (Hammond, 1997). Serum urea nitrogen is regarded as one of the most effective retrospective measurement

of the short-term protein status in ruminants (Hammond, 1997; Herdt, 2000). Normal urea nitrogen concentrations in healthy beef steers range from 7-20 mg/dL (Hammond, 1997). Plasma urea concentrations increased with differing levels of cracked corn and urea (Huntington et al., 1996). Their results indicated both limited intake and use of urea in the diet resulted in ammonia concentrations that exceeded the needs of the ruminal microorganisms (Huntington et al., 1996).

Serum Amyloid A

Serum amyloid A (SAA) is one of several important positive acute phase proteins in cattle and is produced by the liver in response to endogenous release of glucocorticoids and pro-inflammatory cytokines (Takahashi et al., 2007). The acute phase serum protein response is recognized as an indicator of inflammation, trauma as well as other clinical conditions (Kushner and Rzewnicki, 1994; Baumann and Gauldie, 1994). While more intensively studied in dairy cattle, SAA levels are now being investigated in beef cattle as an indicator of inflammation; SAA has been reported with beta-hydroxybutyrate and haptoglobin concentrations in dairy cattle (Alsemgeest et al., 1994; Kushner and Rzewnicki, 1994; Baumann and Gauldie, 1994). The relevance for acute phase proteins used to monitor the health status of domestic animals has been increasingly studied (Eckersall et al., 1999; Gruys et al., 1993). Serum amyloid A is one of several acute phase proteins found in the serum of various mammalian species, increasing around 2-5 times during an acute phase response and is a useful diagnostic tool (Boosman et al., 1989; Gruys et al., 1993; Alsemgeest et al., 1994; Takahashi et al., 2007; Werling et al., 1996). Bovine SAA has been studied most recently by Gruys et al. (1993) and literature documented normal average SAA levels in healthy cows range from 0.3 and 48.59 µg/ml

(Tourlomoussis et al., 2004; Takahashi et al., 2007; Wiese et al., 2017). Additionally, Eckersall et al. (2006) reported SAA concentrations 1.30 ± 0.44 μg/mL in healthy dairy cattle. Cows with chronic inflammatory diseases had SAA levels between 17.1 and 298.2 μg/ml (Tourlomoussis et al., 2004; Takahashi et al., 2007). Takahashi et al. (2007) reported cows suffering with bovine amyloidosis had high SAA levels but cows with chronic inflammation had significantly higher SAA levels.

Non-esterified Fatty Acid

Non-esterified fatty acid (NEFA) concentrations are one of the most common metabolites used to estimate the nutrient status of cattle and are utilized as an indicator of negative energy balance, most often used in dairy cattle undergoing transition (Bowden, 1971; Chapinal et al., 2011; Ospina et al., 2010). During times of fasting or high energy requirements, NEFA in bloodstream increase as a result of mobilization of adipose tissue (Bowden, 1971; Reid and Hinks, 1962). When compared to other blood metabolites, NEFA are less sensitive to time of collection (Eicher et al., 1999). In fresh dairy cows, NEFA concentrations were between 0.8-1.2 mM prior to calving and after calving decreased and values ≥ 0.7 mM indicate the animal had an increased risk for disease after calving, such as a displaced left abomasum (Ospina et al., 2010). In positive energy balance dairy cattle, normal NEFA concentrations are < 0.2 mM (Adewuyi et al., 2005). Non-esterified fatty acids in beef cattle are metabolized in the liver are either converted completely into Acetyl-CoA, incompletely into ketone bodies such as beta-hydroxybutyrate, or turned into triglycerides (Chapinal et al., 2011). The bovine liver can only mobilize a limited amount of NEFA into triglycerides (Adewuyi et al., 2005). High

levels of NEFA can impair the normal liver functions and can lead to metabolic disorders if not treated in time (Adewuyi et al., 2005).

Summary of Literature

In summary, automated individual intake systems are being utilized more frequently to understand individual cattle feeding behavior and intake variation by quantifying the feeding behaviors of individual animals in a group housed environment. Previous literature has shown the feeding behavior of cattle in an automated individual intake system is different compared to traditional trough or bunk feeding of cattle. The Insentec RIC system is one of many automated individual intake systems that have been used in both dairy and beef cattle to study feeding behavior, feed intake, and water intake. The impacts of feed bunk preference on performance and feeding behavior of feedlot cattle has not been well documented in the literature. Feed bunk preference is a result of an animal preferring one individual feed bunk over another feed bunk available in the pen.

Roughage levels in finishing feedlot diets typically range from 0 to 13.50% DM to maintain rumen health and function as well as increase ADG and voluntary intake. Physically effective NDF levels in the diet are important for maintaining a healthy ruminal environment and improving nutrient digestion. Dietary fiber helps stimulate ruminal contractions and aids in the extent of digestion. Increasing the amount of roughage in the diet decreases the incidences of ruminal acidosis in feedlot cattle. However, high levels of roughage in the diet, > 20% of the diet, may play a role in decreasing performance. Previous literature is in agreement that low roughage diets reduce rumen motility and decrease ruminal pH, whereas high roughage diets stimulate

ruminal contractions and increase ruminal pH. As dietary roughage level increases, there is a decrease in amylolytic bacteria while celluloytic and fibrolytic bacteria increase. Volatile fatty acid ratios within the rumen are influenced by the type and quantity of carbohydrates in the diet and increasing the dietary roughage level may increase the acetate to propionate ratio. Cattle consuming high-roughage diets have minimal amounts of glucose available for absorption in the small intestine because a most of the glucose is absorbed in the form of VFA, mainly propionate. The rate of lactate production changes with the level of concentrate in the diet, and when large amounts of carbohydrates are present in the rumen, lactic acid concentrations within the rumen increased. Another way to estimate the digestibility of ruminant dies is the use of fecal consistency scores and fecal pH which can be utilized to give an estimation of nutrient digestibility. Fecal consistency changes can provide a producer with a quick estimation of the digestibility of a diet, which can be confirmed with the use of external markers. External digestibility markers, can be utilized to determine both rate of passage and digestibility of the diet. External markers, including titanium dioxide, can be dosed orally, through the feed, directly into the rumen, or by marking one feedstuff within a diet. With all methods, animals are dosed at specific intervals to examine passage rate.

CHAPTER II

DETERMINING THE EXISTENCE OF BUNK PREFERENCE IN AN AUTOMATED INDIVIDUAL INTAKE SYSTEM AND THE EFFECTS OF BUNK PREFERENCE ON PERFORMANCE, INTAKE, AND EFFICIENCY OF FEEDLOT STEERS

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ABSTRACT: Automatic individual intake systems are being used more frequently to understand individual cattle behavior and intake variation when cattle are group housed. The objective of this experiment was to evaluate if bunk preference exists, and if so, how access to a preferred bunk affects performance, intake, and efficiency of feedlot steers. Angus steers [*n* = 123; initial body weight (BW) = 293 ± 33.8 kg] were blocked by BW and sire and randomly assigned to 1 of 4 pens. Each pen contained 6 automated intake feed bunks [Insentec Roughage Intake Control (RIC); Hokofarm Group, Marknesse, Netherlands]. Steers were fed a common finishing diet and were free to consume feed from any bunk within the pen ad libitum. A steer's preferred bunk was defined as the bunk from which the most feed was consumed during the bunk preference test period (60 d). In any week, 80% of steers consumed less than 29% of that week's total feed intake from the preferred bunk, indicating no strong preference for a specific bunk. The

maximum weekly feed intake consumed from a preferred bunk was 57%. Further, the percentage of total intake from the preferred bunk did not affect overall average daily gain (ADG), feed intake, or gain to feed (G:F; $P > 0.64$). These results suggest that while a few steers may have a relatively strong preference for a specific feed bunk, this preference was not associated with differences in gain, intake, or efficiency. Researchers are free to design experiments, at a stocking density of up to 5 steers per individual bunk, that restrict or alter an individual animal's access to any specific bunk, because such access, or lack of access, does not seem to alter the animal's performance or efficiency.

INTRODUCTION

Automated individual intake systems are being utilized more frequently to understand individual cattle feeding behavior and intake variation. There are several automated feeding systems commercially available including the GrowSafe (GrowSafe Systems Ltd; Airdrie, AB, Canada), the Calan Broadbent Feeding System (American Calan; Northwood, NH, USA), the SmartFeed Pro (C-Lock; Inc., Rapid City, SD, USA) and the Insentec Roughage Intake Control [Insentec Roughage Intake Control (RIC); Hokofarm Group, Marknesse, Netherlands]. The Insentec RIC system has been utilized in dairy and beef cattle to evaluate intake and feeding behavior (Chapinal et al., 2007; Huzzey et al., 2014; Allwardt et al., 2017). Automated intake systems are able to quantify feed intake and feeding behaviors of individual cattle in a group-housed environment, which was extremely labor and time intensive to do before these systems were available (Nielsen, 1999; Huzzey et al., 2014). This is important as group-housed cattle exhibit different social and eating behaviors than cattle that are individually penned (Nielsen, 1999).

Previous literature has confirmed feeding behavior is associated with performance and efficiency in cattle. It is well established that environmental factors such as variation in feeding times and weather patterns can affect feeding behavior (Stricklin and Gonyou, 1981; Schwartzkopf-Genswein et al., 2002; Pritchard and Bruns, 2003; Nkrumah et al., 2007; Schwartzkopf-Genswein et al., 2011). Furthermore, restricting feeding space can also alter feeding behavior by increasing instances of displacements and aggressive behaviors (McBride, 1968; Stricklin and Gonyou, 1981; DeVries et al., 2004). To our knowledge, no data have been published about preference for individual feed bunks in an automated individual intake system. The objective of this experiment was to evaluate if bunk preference exists, and if so, how access to a preferred bunk affects performance, intake, and efficiency of feedlot steers.

MATERIALS AND METHODS

All procedures were approved by the Oklahoma State University Institutional Animal Care and Use Committee (ACUP # AG-15-21).

Animals and Management

One hundred and forty-seven artificial insemination (AI)-sired Angus steers of similar age [initial body (BW) = 293 ± 33.8 kg] were obtained from Oklahoma State University Field and Research Service Units to undergo a gain test and sire evaluation. Animals arrived at the Willard Sparks Beef Research Center (WSBRC) in Stillwater, Oklahoma on 2 consecutive days, d -97 and d -96. Upon arrival, steers were weighed and held in a dry lot pen overnight with ad libitum access to prairie hay and fresh water. The following morning, steers were individually weighed and allocated by BW to 29, 3.65-m × 12.19-m pens. On d -21 all animals were treated for external parasites with gamma-

cyhalothrin (StandGuard; 15 mL/steer, Elanco, Greenfield, IN, USA) and for internal parasites with fenbendazole (Safe-Guard; 13.8 mL/steer, Merck Animal Health, Madison, NJ, USA). On d -8, all 147 steers were weighed and implanted with 80 mg trenbolone acetate and 16 mg estradiol (Revalor-IS; Merck Animal Health).

From the initial population, 123 steers were utilized for the experiment. The selected steers were blocked by d -8 BW and sire. Steers received an electronic identification (EID) tag (Allflex; Dallas/Ft. Worth, TX, USA) on the top of the left ear, and allocated to 1 of four, 11.9-m × 30.5-m soil-surfaced feedlot pens with 6.10-m^2 of the pen covered. Each pen contained 6 Insentec automated individual feed bunks. Steers were allowed 8 d to adapt to the automated intake system before the experiment began.

Insentec Roughage Intake Control

The experiment utilized the Insentec RIC automatic feeding system. Previous literature indicates the Insentec RIC system has a greater specificity and sensitivity compared to other automated systems (Chapinal et al., 2007; Allwardt et al., 2017). The Insentec RIC system also has the ability to restrict access to specific feeders allowing multiple diets to be fed within the same pen (DeVries and von Keyserlingk, 2009; Ruuska et al., 2014). The recommended stocking rate for the Insentec RIC system varies depending on how the pens the automated feed bunks are located in are set up, but recommended rate is 5 animals per feed bunk (Insentec; Hokofarm Group). Each feed bunk was 1.00-m wide, 0.75-m tall, and 0.84-m in depth. Cattle had ad libitium access to each of the 6 individual feed bunks in the pen. The shared fence line water trough was 0.76 m wide, 0.53 m tall, and 0.84 m in depth and cleaned 2 times per week. The Insentec system used an EID tag to record steer visual ID, feed bunk attended, and the beginning

and end weight of the feed bunk once a steer entered the bunk. In addition, the Insentec system also recorded the start and end time of each visit, duration of visit, total intake per visit, and total number of visits to the bunks. The Insentec system recorded all feeding events within a 24 h period and reset between 2345 h and 2400 h. Data files for the previous 24 h were downloaded the following morning and saved to a computer until further analyses were completed. Files were also downloaded into an Excel spreadsheet, and reviewed each morning to ensure all animals were attending the bunks from the previous day. In the case an animal's EID was not read in the data file the animal was located in the appropriate pen and the EID was replaced if needed.

Cattle Health

Body weights were collected on d -8, 36, 37, 76, 88, 89, and 108 of the experiment. Cattle were observed daily for health status as described by Wilson et al. (2015) and were treated according to standard WSBRC protocols, when necessary. Five steers were removed from the experiment: 2 steers were unable to adapt to the Insentec system, 1 steer was removed due to mobility issues, 1 steer was placed in the incorrect pen, and 1 steer died due to complications from bloat. All steers removed from the experiment were excluded from all data analysis. Cattle were shipped for harvest on d 108 to Creekstone Farms in Arkansas City, KS.

Diets

Steers were fed a common total mixed ration (TMR) ad libitum. The TMR were formulated to meet or exceed the NASEM requirements for finishing cattle (NASEM, 2016; Table 2.1). The common receiving diet before the experiment began and during the adaptation period consisting of 15.00% dry-rolled corn, 51.36% Sweet Bran®, 28.44%

prairie hay, and 5.20% dry supplement on a dry matter (DM) basis. At the beginning of the transition period, dry-rolled corn in the diet was increased in percentage while Sweet Bran® and prairie hay were decreased in percentage utilizing four, 6 d step-up rations. After the 28 d transition, all steers were fed a common finishing diet. Steers remained on the finishing diet for the remainder of the experiment, which consisted of 62.0% dry-rolled corn, 20.0% Sweet Bran®, 8.0% prairie hay, 5.0% dry supplement, and 5.0% liquid supplement on a DM basis. Ractopamine hydrochloride (Optaflexx; Elanco) was included in the diet for 28 d from d 80 to shipping (actual calculated ractopamine hydrochloride intake = 330 mg·steer^{-1}·d^{-1}). Pens were fed starting at feed bunk 1. All bunks were manually locked prior to feeding and unlocked after feeding. Locking the feed bunks prevented the steers from accessing the bunk during feeding. Mean actual feeding times were 0840 h [first feeding; 1FDNG], 1308 h [second feeding; 2FDNG], and 1407 h [third feeding; 3FDNG]. Feeding times were determined each day when feed was delivered to the feed bunks.

Experiment

The experiment consisted of 4 periods: adaptation (5 d), transition (30 d), bunk preference test (BPT; 60 d) and restriction (RES; 7 d). The preferred bunk was defined as the feed bunk from which the most feed was consumed by each individual steer. A day was defined as the time between the first feeding of one day to the first feeding of the next day. Within each period, each day was separated into time of feeding for evaluation of data (Metz et al., 1975). Time of feeding was defined as: 1FDNG to 2FDNG (ToF1); 2FDNG to 3FDNG (ToF2); 3FDNG to sunset (ToF3); sunset to 1FDNG of the next day (ToF4). Sunset was fixed as the average sunset time, 19:24 h, for the duration of the

experiment. When any time of feeding data were missing or in the case of bunk malfunctions, the whole day was excluded from analysis. Within day and period, steer data were analyzed to evaluate which 2 bunks a steer visited most frequently, total feed intake, total feed intake from preferred bunk and total number of visits to the 2 preferred bunks. The purpose of the RES period was to evaluate changes in behavior and intake when the 2 preferred bunks were not available to each steer. During the BPT period the 2 preferred bunks for each steer were identified and the 2 most frequently preferred bunks were chosen to use during the RES period. Each steer was restricted from the 2 most frequently preferred bunks following the end of the BPT period before RES data collection began. Steers were electronically restricted from accessing the preferred bunks (DeVries and von Keyserlingk, 2009) 12 h before data collection began with the first feeding the following morning. During RES, animals had ad libitum access to the 4 remaining bunks in the pen for the 7 d period.

Data Cleaning

Following the end of the experiment, raw data files were obtained from the Insentec RIC system and uploaded into R v 3.5 (R Core Team; 2018). The raw data consisted of 345,000 rows. Each row of the data file intends to report cattle feeding events; however, the raw data must be cleaned to eliminate events that do not result from an actual feeding event, and to assign actual cattle feeding events to categories of interest (period of the experiment, feeding of the day, etc.). The first task was to determine times of each of the 3 daily feedings. Time of feeding events were identified when the beginning weight of the bunk was more than 5 kg greater than the ending weight of the bunk in the previous event. Thus, it was assumed that feed was placed in the bunk

between these 2 visits. Records of feed deliveries occurring after 2000 h (n = 22) were considered equipment malfunctions and deleted. Each remaining record was assigned to the cumulative feeding for the day. Any feeding event recorded prior to the 1FDNG was assigned to ToF4 for the previous day. The total number of feedings and the total amount fed were calculated for every bunk each day. Because it was known that only 3 feedings were conducted per day and each feed bunk could not hold more than 40 kg of feed on an as-fed basis (Figure 2.1), day × bunk combinations that recorded more than 4 feedings or more than 150 kg of feed delivered were assumed to be equipment malfunctions (n = 4), and all data file rows which contained more than 4 feedings or in cases of more than 150 kg fed (n = 1000) were deleted from the database. This process of removing records that were not actual animal feeding events was similar to a process used by Wang et al. (2006).

A steer visit to a bunk was identified as an event duration ≥ 5 sec (Parson et al., 2004); any attendance to the feed bunk less than 5 sec in duration was removed from analysis. Defining cattle visits was intended to represent events where cattle intentionally attempted to consume feed; instead of inadvertent tag readings which could occur as an animal passed by a feed bunk, or when the steer is displaced without feed consumption. A feeding event is defined as any consumption of 0.1 kg or greater (Schwartzkopf-Genswein et al., 2011; Green et al., 2013). Any record of a single feeding event above 3.7 kg was excluded and considered erroneous because it fell outside of 99.5% of the total feeding events (Schwartzkopf-Genswein et al., 2011; Green et al., 2013; Haskell et al., 2019). Deleting all feeding events that did not meet the qualifications above removed

53,650 rows from the database. The remaining 291,350 rows of data in the database were analyzed.

Data Analysis

Data were summarized by combinations of period, day, feeding, bunk, and animal. Preferred bunks were determined for both visits and intake in the same manner. For each animal, the preferred bunk percentage was the number of visits from feed bunk that recorded maximum visits or intake, divided by the total visits or intake. Animal performance data and bunk preference percentage were analyzed utilizing linear correlation models in R with the Kendall method correlation matrix for preferred bunk intake.

RESULTS AND DISCUSSION

No correlations between animal performance and bunk preference were observed throughout the duration of the experiment ($P \geq 0.63$). Figure 2.2 indicates half of the animals in this experiment consumed at least 25% of total feed intake from the preferred bunk. If no preference existed, a steer would theoretically consume 16.7% of the animal's total feed from each of the 6 feed bunks in the pen. The maximum amount of feed consumed from a preferred bunk was 57% of weekly feed intake, while the minimum amount of feed consumed from a preferred bunk was 18% of weekly feed intake as indicated in Figure 2.2. The overall average dry matter intake (DMI) for this experiment was 13.8 kg/d and the average final BW was 662 kg. The results from this experiment indicate there was no correlation between bunk preference and intake ($P = 0.54$; Figure 2.3).

During the experiment, some steers appeared to have a preference for a specific feed bunk while other steers did not appear to have a preference. Figure 2.4, depicts 6 randomly selected animals' total intake from the feed bunks within the pen to visualize differences in bunk attendance and intake. Some of the differences in feed bunk intake observed in Figure 2.4 could be explained by animals unable to access the preferred bunk if another animal is at the feed bunk, or the preferred bunk may have been empty in between feedings because each time feed was delivered it was evenly distributed between the 6 feed bunks. The bunk preference results in this experiment, are similar to a trial by Friend and Polan (1974) which reported that some dairy cows preferred certain stalls within the free stall barn. The same study reported that dominant cows altered the use of free stalls, where subordinate cows would not use a stall a more dominant animal previously occupied (Friend and Polan, 1974). In this experiment there was also no correlation between number of visits to the bunk and feed intake ($P = 0.81$; Figure 2.5), which indicates the number of times a steer visited a bunk was not indicative of the steer's overall feed intake. Figures 2.2 and 2.5 illustrate intake from preferred bunk and visits to the preferred bunk follow a similar pattern, indicating the two may have been related.

Previous studies have reported that dominant animals spend more time uninterrupted at the feed bunk (Arave and Albright, 1981; Grant and Albright, 2000; Schwartzkopf-Genswein at al., 2011) and had priority access to feed, thereby restricting access of subordinate animals (Friend and Polan, 1974; Stricklin and Gonyou, 1981; Llonch et al., 2018). Since the Insentec RIC system utilized in this experiment only allows one animal to access a feed bunk at a time, steers have to wait or displace the

current occupant to access feed. Over 50% of the steers had an average meal duration of ≥ 500 sec (Figure 2.6), which indicates steers were able to access the feed bunks long enough to consume adequate feed. The steers were able to consume enough feed as evidenced by an overall average daily gain (ADG) of 2.03 kg/d and an overall average gain to feed (G:F) of 0.1431. There was no correlation between bunk preference and G:F observed in this experiment ($P \geq 0.63$; Figure 2.7).

While dominance was not directly measured in this experiment, dominance could impact feeding behavior. In theory, dominant steers approach the feed bunk first following the addition of feed, and may prevent subordinate animals from accessing the feed bunk until after the dominant animals left the feed bunk (Corkum et al., 1994). With 3 feedings each day, a subordinate animal may not attend the feed bunk until after the 2FDNG or 3FDNG, which in theory, would still allow subordinate animals to perform at the same level as dominant animals since these steers were fed ad libitum. Stocking density could also affect feeding behavior, an increased stocking density would increase competition for a feeding space, and a decreased stocking density would decrease competition for feed (DeVries et al., 2004). Cattle that are fed in groups will, to some degree, inevitably have competition for feed (Olofsson, 1999). Previous literature has reported that dominance does not affect DMI, because subordinate cattle were able to access the feed bunks later (McPhee et al., 1964; Arave and Albright, 1981; Stricklin and Gonyou, 1981).

During the RES period, the steers adapted to the reduced access to the preferred bunks by attending another available feed bunk. The results from the restriction period are in agreement with a study by DeVries and von Keyserling (2009), which utilized an

Insentec RIC system to restrict access to feed bunks and observed no difference in DMI between groups. The heifers in the study by DeVries and von Keyserlingk (2009) compensated for the restricted access to feed by consuming more feed each time the heifer accessed the feeder (Proudfoot et al., 2009). Corkum et al. (1994) evaluated changes in social behavior, eating behavior, and intake when the feeding space was reduced using the Calan Broadbent Feeding System. Results from their study suggested a stocking density of 3 steers per bunk resulted in the greatest amount of time animals spent consuming feed, when compared with a stocking density of 1 steer per bunk (Corkum et al., 1994). A theory presented by Pritchard and Bruns (2003) suggests that the decrease in satiety would motivate cattle to approach the bunk more than dominance alone. In the current experiment, steers were fed 3 times a day to maintain ad libitum access to feed. According to the theory by Pritchard and Bruns (2003) subordinate cattle might wait for a later feeding in the day to approach the bunk and may be the first ones to approach the feed bunk at a later feeding.

CONCLUSION

The results of this experiment can help in the interpretation of data collected using an automated individual intake system with the knowledge that bunk preference does not significantly affect performance. The results of the RES period demonstrate finishing steers can perform at the same level whether restricting access to specific feed bunks or not. Preference for a specific Insentec RIC feed bunk within a pen was detected, however bunk preference had no effect on DMI, ADG, or G:F. Results suggest researchers can restrict access of feed bunks using an automated individual intake system, which could allow multiple treatments or diets to be fed within a pen and the restriction will not

negatively impact the performance of the animals. Researchers can design experiments with a stocking density of up to 5 steers per feed bunk that restrict or alter an individual animal's access to any specific bunk without negatively impacting animal performance, intake, or efficiency.

Future Directions

Additional research is warranted to evaluate the effect of restricting an animal's access to specific bunks within in the pen on the performance, feeding behavior, and efficiency of animals under different stocking densities and different environmental conditions. Longer durations of restriction (greater than 7 d), could be evaluated to understand the impact of long term restriction on performance and efficiency.

AKNOWLEDGEMENTS

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Table 2.1. Diet composition

Ingredient, % of DM[1]	Receiving	Step 1	Step 2	Step 3	Step 4	Finishing
Dry-rolled corn	15.00	24.40	33.90	44.20	54.60	62.00
Sweet Bran®[2]	51.36	46.25	40.80	34.52	28.50	20.00
Prairie hay	28.44	24.35	20.30	16.28	11.90	8.00
Dry supplement[3]	5.20	5.00	5.00	5.00	5.00	5.00
Liquid supplement[4]	-	-	-	-	-	5.00

Nutrient analyses were completed at an offsite laboratory (Servi-Tech Laboratories; Dodge City, KS)

[1]Dry matter

[2] Cargill, Dalhart, TX

[3] Dry supplement was formulated to contain (% DM basis) 40.00% ground corn, 29.60% limestone, 20.00% wheat middlings, 7.00% urea, 1.00% salt, 0.53% magnesium oxide, 0.51% zinc sulfate, 0.17% manganese oxide, 0.13% copper sulfate, 0.08% selenium premix (0.6%), 0.0037% cobalt carbonate, 0.32% vitamin A (30,000 IU/g), 0.10% vitamin E (500 IU/g), 0.009% vitamin D (30,000 IU/g), 0.20% tylosin (Tylan-40, Elanco Animal Health, Greenfield, IN), and 0.33% monensin (Rumensin-90; Elanco Animal Health)

[4] Liquid supplement was formulated to contain (% DM basis) 45.86% corn steep, 36.17% cane molasses, 6.00% hydrolyzed vegetable oil, 5.46% 80/20 vegetable oil blend, 5.20% water, 1.23% urea (55% solution), and 0.10% xanthan gum.

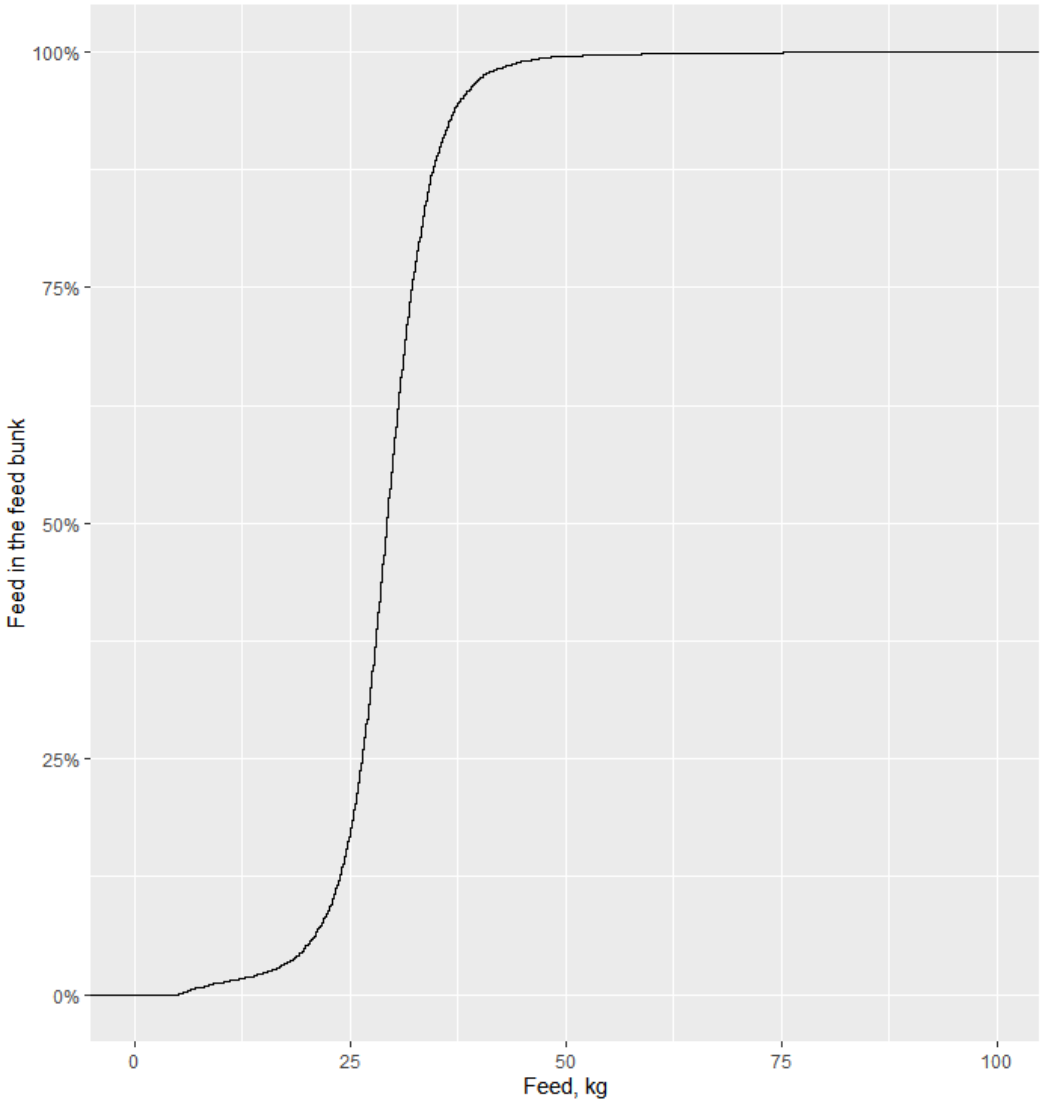

Figure 2.1: Amount of feed delivered to each feed bunk for each feeding. The maximum amount of feed each feed bunk could hold was 40 kg on an as-fed basis.

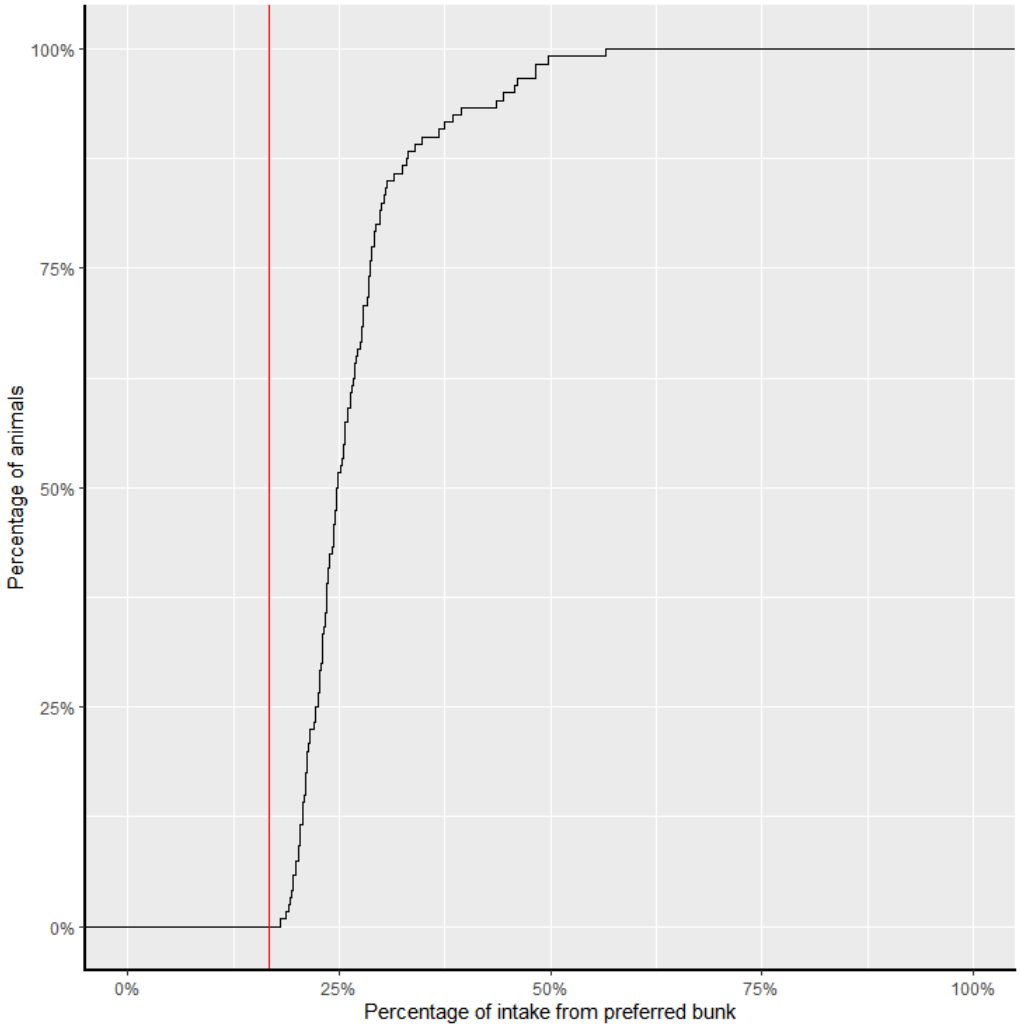

Figure 2.2: Determining the existence of bunk preference. A preferred bunk was defined as the feed bunk from which the most feed was consumed. The vertical line represents the amount of feed consumed from each feed bunk if no preference was observed.

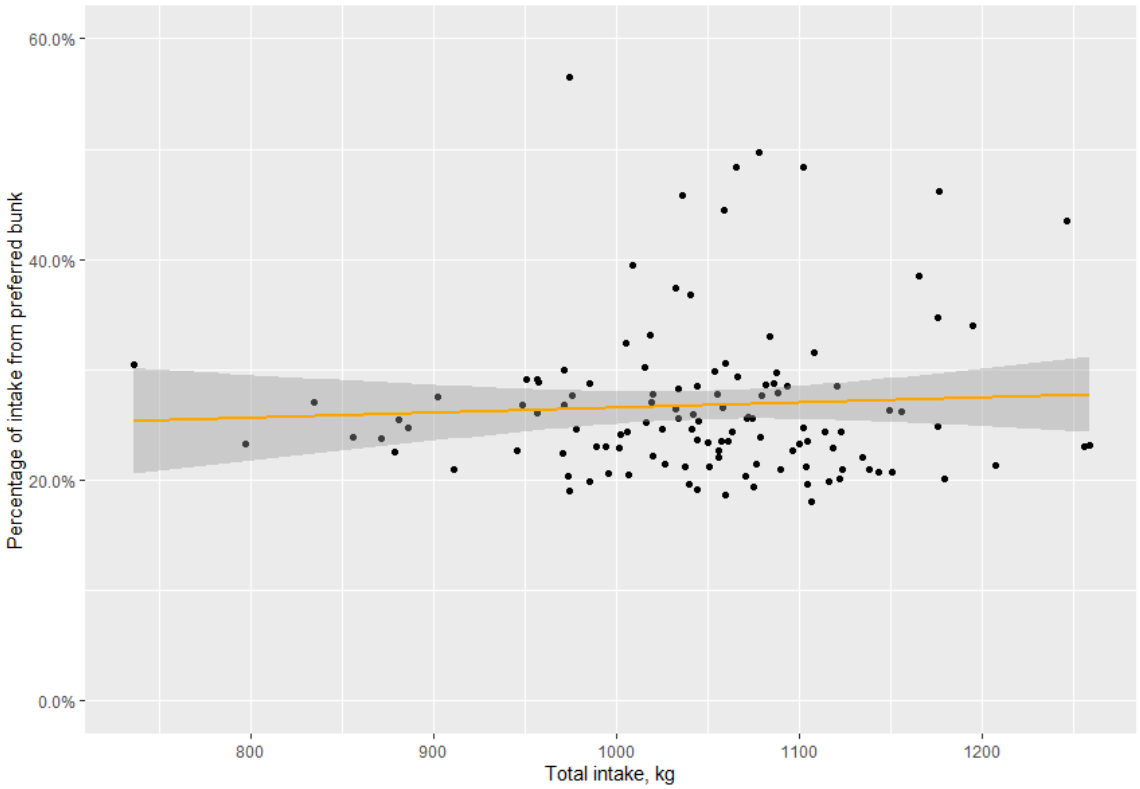

Figure 2.3. Intake from preferred bunk percentage compared to total intake. A preferred bunk was defined as the feed bunk from which the most feed was consumed. The shaded range represents the confidence interval of the linear model. No correlation between bunk preference and intake was observed in this experiment ($P = 0.54$).

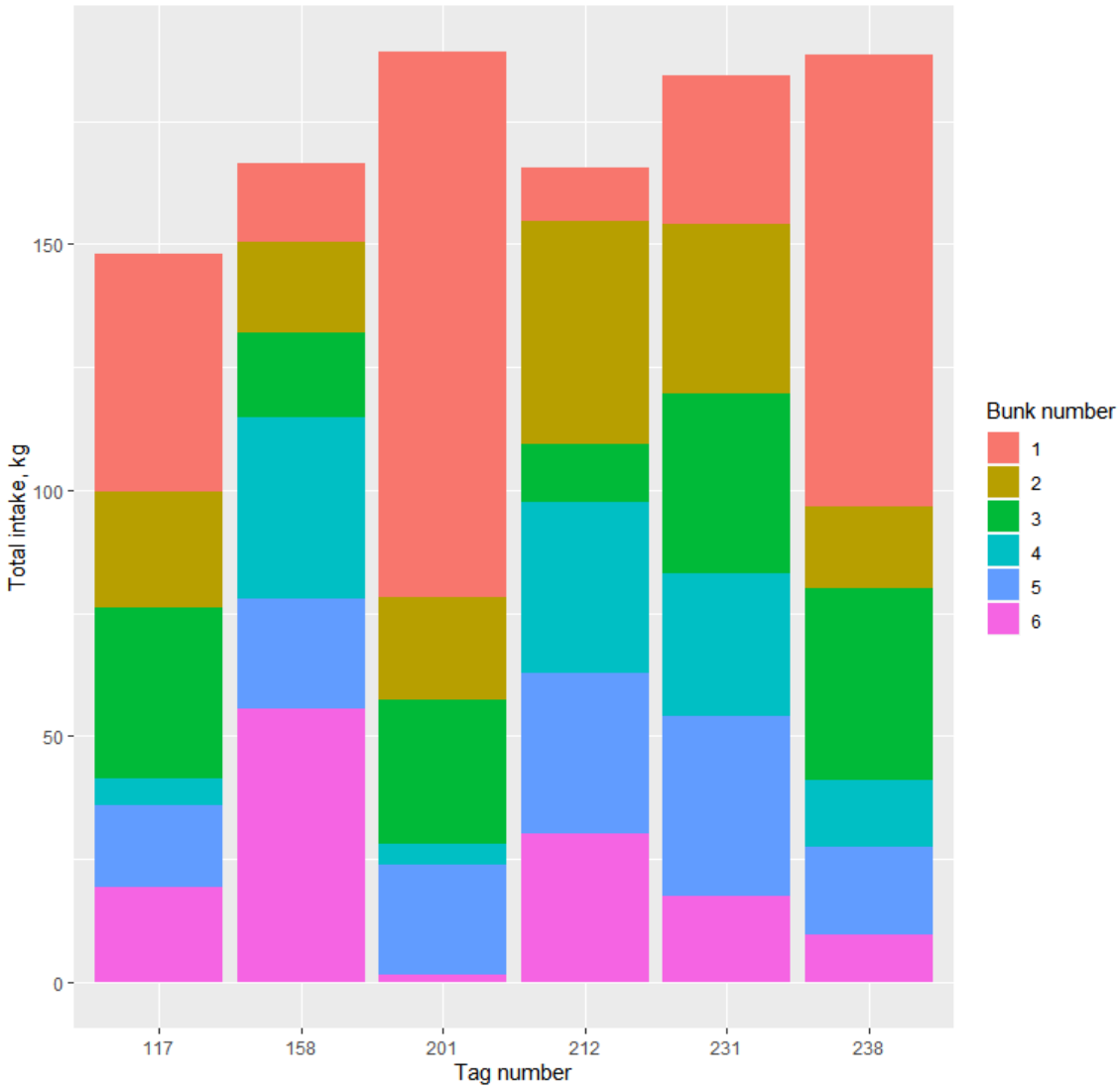

Figure 2.4. Six animal's total intake from each feed bunk within a pen.

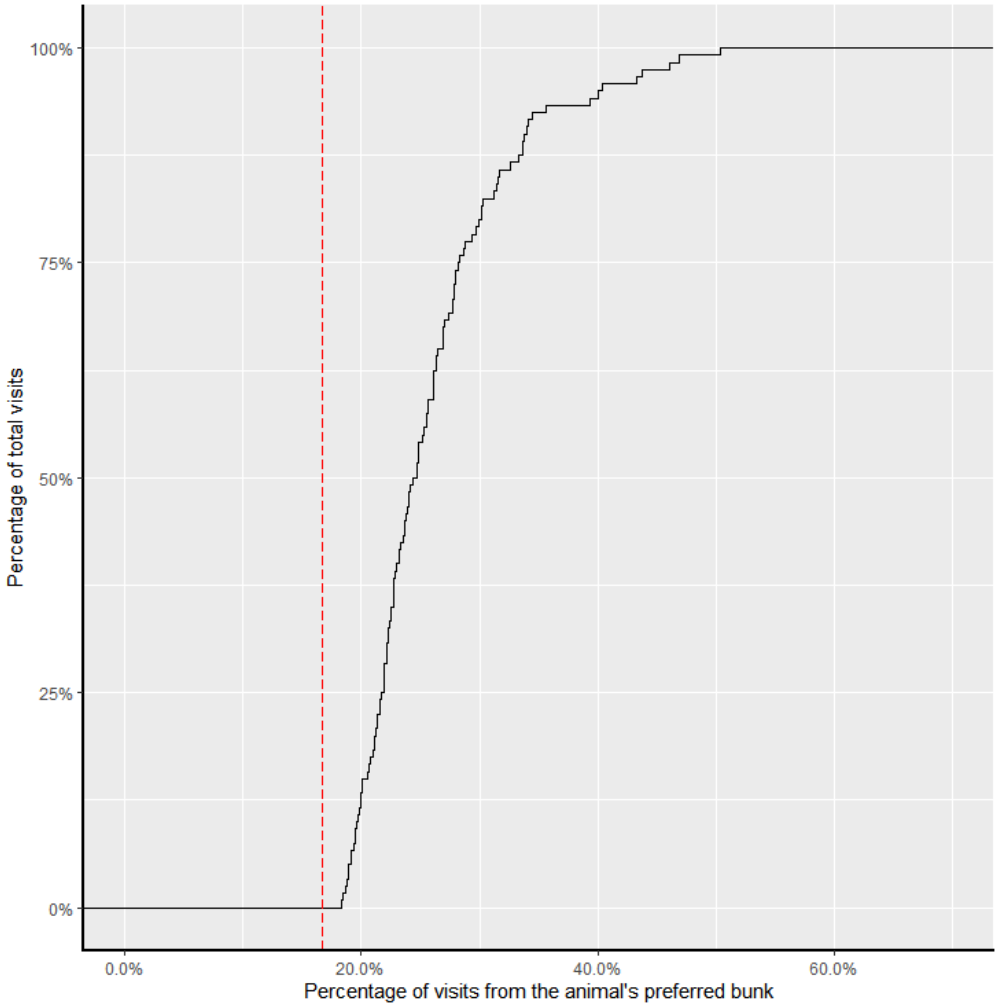

Figure 2.5. Total feed bunk visits compared to percentage of visits to a preferred bunk. A preferred bunk was defined as the feed bunk from which the most feed was consumed. The vertical line represents the number of visits to each feed bunk if no preference was observed. No correlation between number of visits to the bunk and feed intake was observed in this experiment ($P = 0.81$).

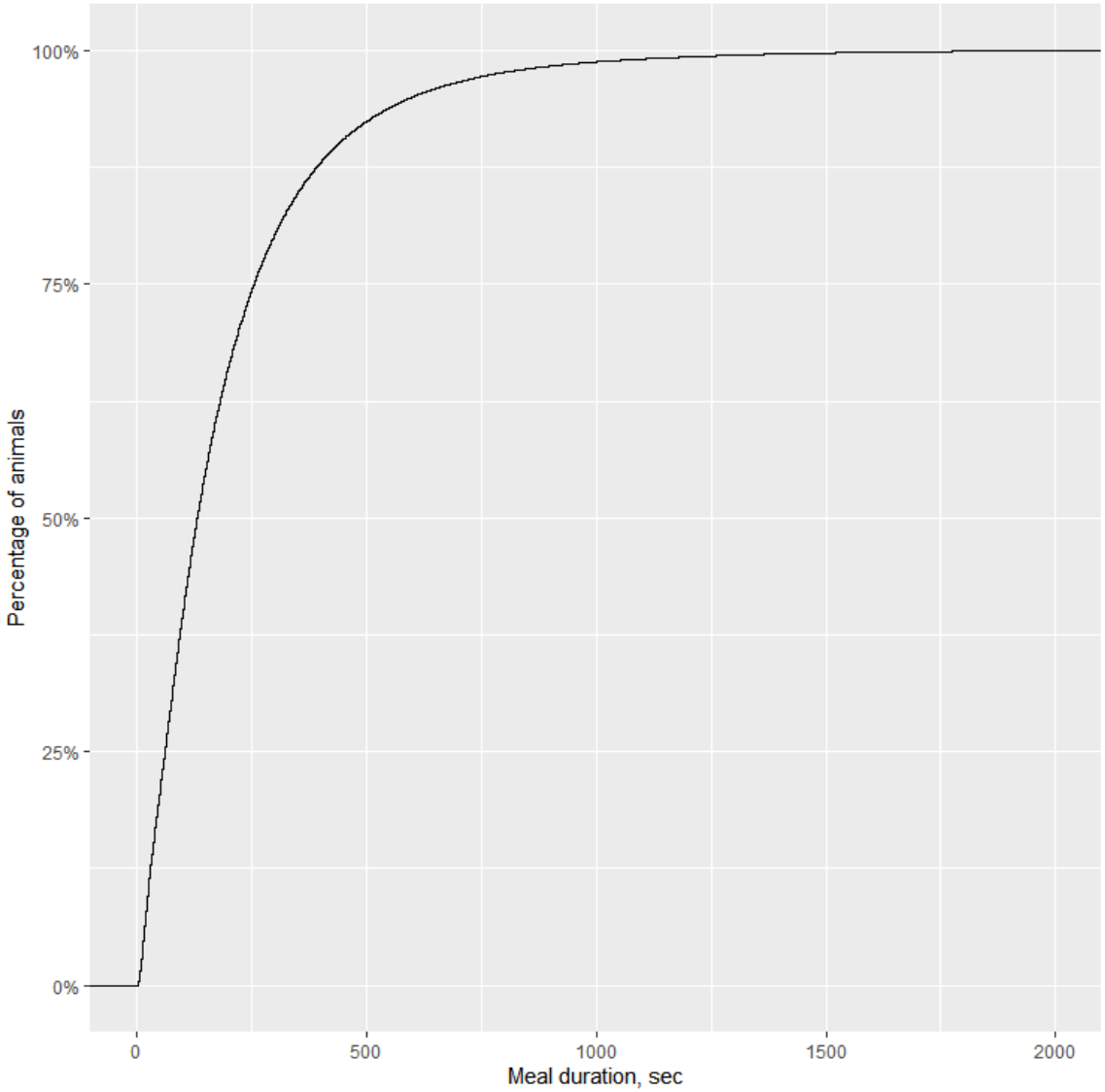

Figure 2.6. Meal duration. Meal duration was determined by compiling the feeding events which were defined as any consumption of 0.1 kg or greater. Any record of a single feeding event was excluded if it fell outside of 99.5% of the total feeding events.

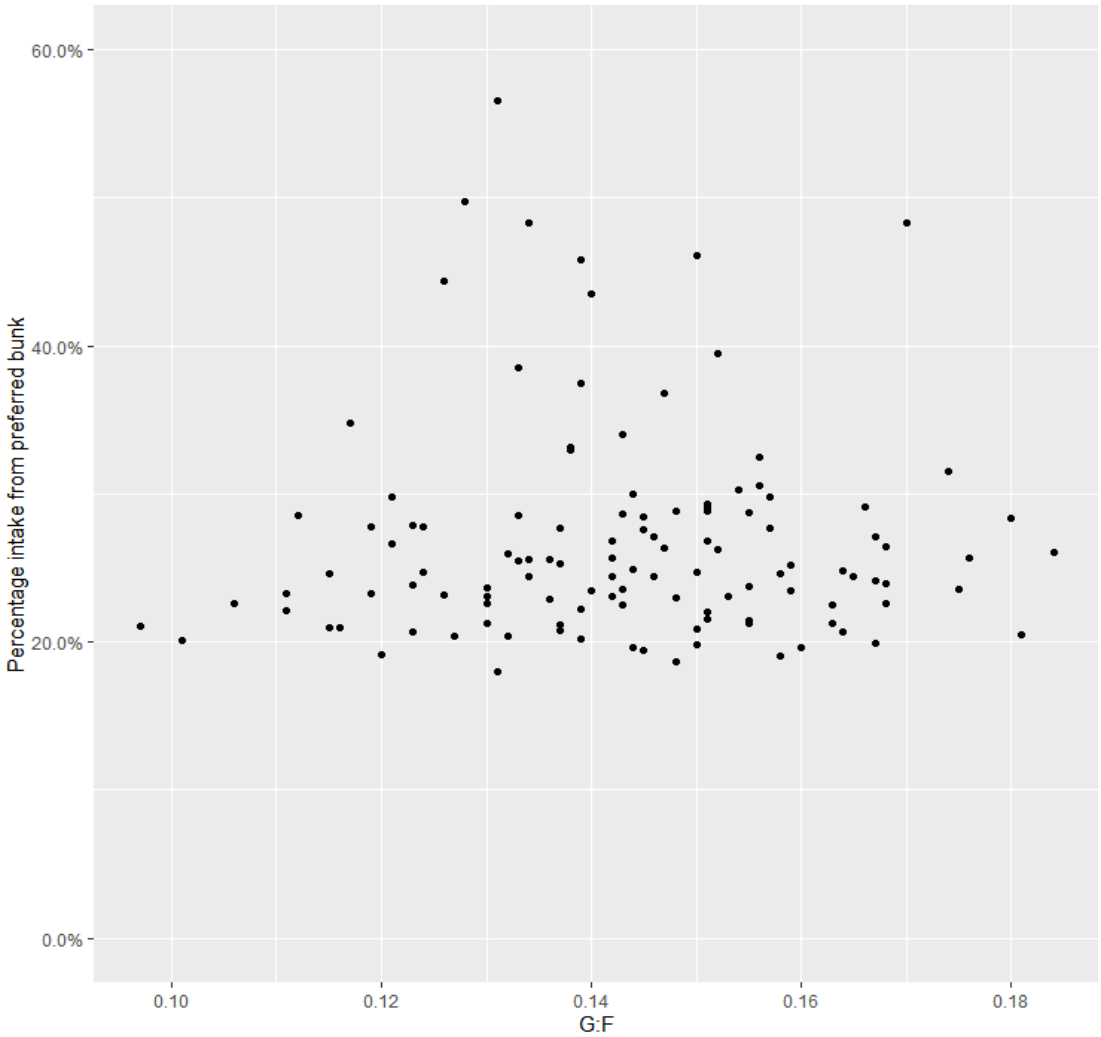

Figure 2.7. Intake from preferred bunk compared to gain:feed (G:F) of each steer. A preferred bunk was defined as the feed bunk from which the most feed was consumed. No correlation between bunk preference, determined during the bunk preference test period, and overall G:F was observed in this experiment ($P \geq 0.63$).

CHAPTER III

EFFECTS OF FEEDING INCREASED ROUGHAGE TO FEEDLOT STEERS LATE IN THE FINISHING PERIOD

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ABSTRACT: Finishing cattle consume high concentrate diets to efficiently deposit both muscle and adipose tissue while decreasing cost of gain during finishing. The objective of this experiment was to evaluate the effects of increased roughage inclusion late in the finishing period on growth performance, carcass traits, and ruminal and fecal characteristics of feedlot steers. Treatments included control (CON; 6% roughage dry matter (DM)), intermediate (INT; 12% roughage DM), and high (HGH; 18% roughage DM) roughage diets. Crossbred beef steers [n = 59; initial body weight (BW) = 289 ± 35.6 kg] were assigned to treatments during the final 58 d on feed in a randomized complete block design (CON = 5 pens and INT and HGH = 4 pens; 4 steers per pen). Experimental diets contained prairie hay, Sweet Bran, rolled corn, dry supplement, urea, and a corn steep and molasses-based liquid supplement. The inclusion rate of roughage and rolled corn were adjusted for each treatment diet. Steers on HGH tended to have

increased overall dry matter intake (DMI; $P = 0.06$). No differences in BW, overall average daily gain (ADG), or gain to feed (G:F) were observed ($P \geq 0.72$). Steers consuming the HGH diet had the greatest rib eye area (REA; $P = 0.03$). Fat thickness, hot carcass weight (HCW), marbling, liver score, and kidney, pelvic, and heart fat (KPH) did not differ ($P \geq 0.29$) among treatments. Steers consuming the HGH diet had a lower fecal pH at the end of finishing ($P = 0.05$) compared to CON and INT steers. Ruminal lactate was increased on d 14 for CON steers compared to other treatments ($P < 0.001$). No differences were observed for ruminal pH ($P \geq 0.11$) among treatments at any collection. Results from this experiment suggest that increasing roughage late in the finishing period does not negatively impact growth performance or carcass characteristics, but may alter ruminal fermentation and post ruminal digestion.

INTRODUCTION

Finishing programs transition cattle onto high concentrate diets to increase deposition of both muscle and adipose tissues and decrease the cost of gain. However, when cattle consume high concentrate diets for a long period of time, detrimental effects such as liver abscesses, acidosis, and a reduction in feed intake have been observed (NASEM, 2016; Brown et al., 2006). Although high concentrate diets cost less on a unit of energy basis and are easier to deliver, there is an increased risk of acidosis associated with high concentrate diets early in the feeding period compared to cattle consuming diets with increased roughage. Fiber particles longer than 4 mm in ruminant diets help stimulate saliva production and provide buffering to the rumen environment, which decreases the risk for digestive upsets (Kononoff et al., 2003; NASEM, 2016). In feedlot diets, roughages are often included at minimal levels to reduce incidences of acidosis and

liver abscesses, while stimulating intake and increasing average daily gain (ADG; Wise et al., 1968). Typical roughage levels in feedlot finishing diets range from 0 to 13% on a dry matter (DM) basis, and average 10% DM in commercial feedlot diets (Brown et al., 2006; Galyean and Hubbert, 2014; Samuelson et al., 2016).

Including increased levels of roughage in finishing diets increases the bulkiness of the diet and decreases animal performance, as nutrients become more diluted in diets with increased roughage (Galyean and Hubbert, 2014). Previous literature has reported increased dry matter intake (DMI), decreased ADG, and decreased gain to feed (G:F) when roughage levels were increased from 0% to 30% DM (Galyean and Defoor, 2003; Swanson et al., 2017). The objectives of this experiment were to evaluate the effects of increased roughage levels late in the finishing period on performance, carcass characteristics, blood metabolites, and ruminal and fecal characteristics of feedlot steers.

MATERIALS AND METHODS

All procedures were approved by the Oklahoma State University Institutional Animal Care and Use Committee (ACUP # AG-19-8).

Pre-Experiment Animal Management

Sixty-two crossbred beef steers [initial body weight (BW) = 289 ± 35.6 kg] were transported approximately 589 km from the University of Arkansas Livestock and Forestry Research Station in Batesville, AR to the Willard Sparks Beef Research Center (WSBRC) in Stillwater, OK. Prior to arrival, steers were weighed, and 15 mL/steer of permethrin and piperonyl butoxide (Permectrin CDS; Bayer Corporation, Whippany, NJ) was applied on d -104 in Batesville, AR. Upon arrival at the WSBRC, steers were held overnight in dry lot pen with ad libitum access to fresh water and prairie hay. The

following morning, steers were individually weighed, vaccinated against clostridial (Vision with SPUR; Merck Animal Health, Madison, NJ) and viral and bacterial respiratory (Titanium 5 + PH-M; Elanco Animal Health, Greenfield, IL) pathogens, administered an anthelmintic (Safeguard; 14 mL/steer, Merck Animal Health), implanted with 80 mg trenbolone acetate, 16 mg estradiol, and 29 mg tylosin tartrate (Component TE-IS with Tylan; Elanco Animal Health), and had tail switches clipped. Steers were reimplanted on d -27 prior to start of dietary treatments with 120 mg trenbolone acetate, 24 mg estradiol, and 29 mg tylosin tartrate (Component TE-S with Tylan; Elanco Animal Health). Steers were blocked by d -104 BW and randomly allocated to pens within block. Steers were housed in fifteen 4.57 × 13.24 m partially covered soil surfaced feedlot pens with a shared 76-L concrete water tank between 2 adjacent pens (model J 360-F; Johnson Concrete, Hastings, NE).

Diets and Feed Management

Within block, steers were randomly allocated to 15 pens (5 pens/treatment; 4 steers/pen). Steers were blocked by BW for shipping for harvest into 2 groups, the 3 heaviest blocks (n = 9 pens; 183 total days on feed) and the lightest 2 blocks 35 d later (n = 6 pens; 218 total days on feed). All steers were fed a common receiving diet (RCV) for 7 d before a 21 d transition onto the pre-trial diet (PTD) using a two-ration blending system. All steers were consuming the PTD (97 d heavy block; 132 d light block) until the experimental treatments were implemented for the last 58 d prior to shipping (Table 3.1). The experiment had 3 dietary treatments all balanced to a targeted 13.4% crude protein (CP). Diets were formulated using historical data on all diet ingredients. The control (CON) diet consisted of 6.00% prairie hay, 63.84% dry-rolled corn, 20.00%

Sweet Bran® (Cargill, Dalhart, TX), and 0.16% urea on a DM basis (Table 3.2). The intermediate roughage (INT) diet consisted of 12.00% prairie hay, 57.77% dry rolled corn, 20.00% Sweet Bran®, and 0.23% urea on a DM basis (Table 3.2). The high roughage (HGH) diet consisted of 18.00% prairie hay, 51.70% dry-rolled corn, 20.00% Sweet Bran®, and 0.30% urea on a DM basis (Table 3.2). Urea was added in an attempt to balance for CP and to meet degraded intake protein (DIP) requirements. All dietary treatments included 5.00% dry supplement and 5.00% liquid supplement. Ractopamine hydrochloride (Optaflexx 45; Elanco Animal Health) was included in the diet for the last 30 d before harvest (actual calculated ractopamine hydrochloride intake = 292 $mg \cdot steer^{-1} \cdot d^{-1}$).

At 0500 h each morning, feed bunks were visually appraised to determine the quantity of feed remaining from the previous day. The feed to be delivered was adjusted daily so that cattle left no more than 0.45 kg of feed in the bunk. Diets were delivered once daily at 0900 h, using a trailer mounted feed mixer to mix and deliver the experimental diets (274-12B feed mixer; Roto-mix, Dodge City, KS). Samples of the experimental diets were collected 2 times per wk and diet DM was calculated after drying samples for 48 h in a forced air oven at 60 °C. A monthly composite sample was created after DM was calculated and frozen until nutrient analysis could be completed. Following the end of the experiment, sub samples of each monthly composite were taken to make a composite of the diet over the duration of the experiment. Feed refusals were weighed back prior to feeding on weigh days or if excessive orts remained in the bunk. Refusal samples were dried to determine DM content and were subtracted from DM delivered to calculate DMI.

Cattle Health

Animals were observed for health status daily as described by Wilson et al. (2015) and were treated according to WSBRC protocols, when required. Three steers on the CON diet were treated prior to the start of experimental treatments: one steer was treated for symptoms of bovine respiratory disease with tilmicosin (Micotil 300; 34 mL, Elanco Animal Health), another steer was treated for a hematoma on the left hip by a veterinarian, and the final steer was treated for symptoms of bloat prior to the start of experimental treatments. One steer on the INT diet was treated for foot rot with oxytetracycline (Liquamycin LA 200; 43 mL, Zoetis, Parsippany, NJ) prior to start of experimental treatments and returned to pen. A steer on the INT diet was injured by another animal in the pen, and was evaluated by a veterinarian and treated with flunixin meglumine (Prevail; 20 mL, VetOne, Boise, ID) and oxytetracycline (Noromycin 300 LA; 54 mL, Norbrook, Newry, Ireland) and was not removed from the experiment. One steer on the CON diet died during the experiment for reasons not associated with experimental treatments. None of the treated animals were removed from the experiment. All data from the dead animal were excluded from analyses.

Experiment Data Collection

After transitioning to the PTD diet, animals were weighed every 35 d until 98 d on feed to determine the start of experimental treatments for each shipping block. After the 98 d weigh day steers were reallocated to the experimental treatments for the final 58 d on feed. Following a 27 d readjustment period, the heaviest 3 weight blocks began experimental treatments (n = 9 pens). The lighter 2 blocks began experimental treatments 35 d after the heavy blocks began experimental treatments (n = 6 pens). The start of

experimental dietary treatments will be referred to throughout the remainder of the manuscript as d 0.

Body weights were collected on d 0, 14, 28, and final for each group. Body weights were measured prior to feeding at approximately 0500 h with no withdrawal from feed or water. All BW were adjusted using a calculated 4% pencil shrink (BW × 0.96) to account for fill. Individual ADG was calculated by dividing individual shrunk BW gain, in kg, by days on feed for each period. Pen ADG was calculated as the average of the individual ADG for each steer in the pen for that period. Dry matter intake was calculated from total DMI for the pen for that period divided by the number of steers and the days on feed in that period. Gain to feed ratio was calculated by dividing the average ADG for the pen by the average daily DMI for the pen for each respective period.

A fecal grab sample was collected via rectal palpation on d 0, 14, 28 and final. The pH of the fecal sample was recorded using a portable pH meter (pH 6+ Meter; Oakton Instruments, Vernon Hills, IL). Fecal samples were also scored for consistency using a method from Woolsoncroft et al. (2018). This method utilizes a 1 to 5 scale: 1 = firm, hard, and dry, 2 = slightly less firm and hard, 3 = relatively soft and moist, but not runny, 4 = loose, very moist and runny; consistency of pancake batter, 5 = very thin and watery, cannot be caught in hand (Woolsoncroft et al., 2018). Samples were handled and visually appraised by the same evaluator at each collection. The changes in fecal score and fecal pH were calculated by subtracting the earlier date value from the subsequent date value for each steer, then an average change for the pen was determined.

On d 0, 14, and 28, a ruminal fluid sample was collected using oral lavage technique similar to processes described by Raun and Burroughs (1962) and Lodge-Ivey

et al. (2009). The same individual conducted the oral lavage sample collection at each collection day. The first 50 mL of rumen fluid collected was discarded to reduce nitrogen contamination of saliva before collecting the sample. In cases where blood appeared in the oral lavage tube, the tubing and collection flask were exchanged for clean samples. If the second attempt produced blood in the oral lavage tube the tube was immediately removed and the animal was recorded as a no sample. Immediately following ruminal fluid collection, the rumen fluid was strained through a layer of cheesecloth into a labeled 50 mL container. Rumen fluid pH was recorded immediately following straining, using a benchtop pH meter (Fisherbrand Accumet AE150 Benchtop pH Meter; Fisher Scientific, Pittsburgh, PA), then stored on ice for subsequent preparation of the samples (Wiese et al., 2017). Samples were handled by the same individuals at each collection. Two microcentrifuge tubes each containing 1 mL of rumen fluid were stored for each animal from each collection day. One microcentrifuge tube contained 1 ml of rumen fluid for subsequent lactate analysis. Following preparation, samples were stored at −20 °C until analysis of lactate concentrations could be completed. The lactate samples were centrifuged at 21,100 × g for 30 min at 8°C (Sorvall Legend Micro 21R Microcentrifuge; Thermo Scientific, Waltham, MA). After centrifuging, a 200 µL rumen fluid sample was analyzed for $_{L}$ - Lactate using an immobilized enzyme system (YSI Model 2950 D; YSI Inc., Yellow Springs, OH).

On d 0, 14, 28, and final, two 10-mL blood samples were collected via jugular venipuncture (BD Vacutainer; Franklin Lakes, NJ). Whole blood was allowed to clot for an average of 1.5 h prior to centrifuging. Blood tubes were centrifuged at 3,000 × g for 20 min at 4 °C (Sorvall RC6; Thermo Scientific, Waltham, MA). Following centrifuging,

serum was collected and stored at −20 °C until subsequent analysis for glucose, lactate, serum urea nitrogen (SUN), and non-esterified fatty acid (NEFA) concentrations.

On d 58 of the experiment, the 3 heaviest blocks (n = 9 pens) were shipped approximately 522 km to Tyson Fresh Meats (Amarillo, TX) for harvest, while the 2 lightest blocks (n = 6 pens) were shipped approximately 600 km to Caviness Beef Packers (Hereford, TX). Due to complications from COVID-19 the lightest 2 blocks were unable to be harvested at Tyson Fresh Meats. For the remainder of the manuscript, "final" will represent the data collected before shipping to harvest (d 58 of experimental treatments). Carcass data were collected by trained personnel from the West Texas A & M University Beef Carcass Research Center (Canyon, TX) for both groups at harvest.

Laboratory Analysis

For all rations, a 400-g sample from the middle of the feed batch was collected from the mixer twice weekly. Within each month, the weekly samples were composited and stored until further analysis could be completed. The composited diet samples were sent to a commercial laboratory for mineral analysis (Table 3.1 and 3.2; Servi-Tech, Dodge City, KS). To conduct proximate analysis on both treatment diets, samples of diets were composited from the monthly composites, dried in a 55 °C oven for 48 h, and then ground through a 1 mm screen (Pulversiette 19; Fritsch Milling and Sizing, Inc., Pittsboro, NC). Diets were analyzed for DM, CP, neutral detergent fiber (NDF), acid detergent fiber (ADF), crude fiber (CF), ether extract (EE), and physically effective NDF (peNDF). Laboratory DM was calculated by weight difference when samples were dried at 55°C for 48 h. Acid detergent fiber and NDF were analyzed using an ANKOM 2000 automated fiber analyzer (ANKOM Technology; Macedon, NY) according to

manufacturer's instructions. Acid detergent lignin (ADL) was conducted using ANKOM ADL protocol (ANKOM Technology). Petroleum ether was used to analyze fat content of the diet using an automated ether extractor (XT 15 Extractor; ANKOM Technology) according to manufacturer's instructions. Nitrogen was determined by a dry combustion analysis utilizing a Carbon Nitrogen analyzer (TruSpec Carbon Nitrogen analyzer; LECO, St. Joseph, MI). Crude protein was calculated by multiplying % nitrogen × 6.25.

Physically effective NDF was calculated using the Penn State Particle Separator (PSPS) 3 sieve model. The peNDF for whole diets was estimated by calculating the percent of the sample remaining in the top 3 sieves (all ≥ 4 mm) and multiplying by the NDF (DM basis) content of the diet (Table 1.3; NASEM, 2016). Mixed rations can have a falsely inflated physical effectiveness value due to whole grains and supplement pellets becoming trapped on the 4-mm sieve (NASEM, 2016). Composite grab samples were taken from the top 3 sieves (all ≥ 4 mm) for each dietary treatment to determine the NDF content of the peNDF portion of the diet.

Serum samples were thawed at room temperature immediately before analysis. Serum urea nitrogen was analyzed according to the methods described by Marsh et al. (1965) adapted for a 96-well plate. Blood glucose and lactate concentrations were analyzed using an immobilized enzyme system using undiluted serum samples pipetted into a 96 well plate (YSI Model 2950 D; YSI Inc., Yellow Springs, OH). For SUN analysis, samples were pipetted into a 96 well plate and read at 520 nm (SpectraMax M3; Molecular Devices, San Jose, CA). Non esterified fatty acid concentrations were determined using a commercial kit (HR Series NEFA HR 2; Wako Pure Chemical Industries, Osaka, Japan) following manufacturer instructions.

Statistical Analysis

The experiment was organized in a randomized complete block design. For all data measurements, pen served as the experimental unit (n = 15). All data were analyzed using the MIXED procedure of SAS 9.4 (SAS Institute Inc., Cary, NC). The fixed effects of treatment, day, and treatment × day and the random effect of block were used to analyze blood metabolites. Day was included as a repeated measure. If a treatment × day interaction was detected, the least square means were compared across days to determine on which day treatments differed. Significance was declared when $P \leq 0.05$ and tendencies were considered when $P > 0.05$ and $P \leq 0.10$. All performance, ruminal measurements, fecal characteristics, and carcass traits were analyzed with the fixed effect of treatment and the random effect of block. All data from the dead animal were excluded from all analyses (deads and removals out data). The data from 2 pens were removed from all final time point analyses because the animals were incorrectly penned after the d 28 weigh day, resulting in 13 pens (5 pens for CON, 4 pens for INT, and 4 pens for HGH) for the final data collection.

RESULTS AND DISCUSSION

Performance

No differences were observed in BW throughout the experiment (Table 3.3; $P \geq 0.86$). There were also no differences in ADG or G:F were observed among treatments during throughout the experiment ($P \geq 0.36$; Table 3.3). A study by Swanson et al. (2017) reported that as roughage level in the diet increased, ADG and G:F decreased linearly. Although there were no differences in ADG in the current experiment ($P \geq 0.41$), ADG numerically decreased as roughage level increased from d 0 to d 14 with the CON steers

having the greatest numerical ADG (1.15), followed by the INT (0.993) and HGH (0.892) steers ($P = 0.49$; Table 3.3). Despite the fact there were no differences in G:F were observed in the current experiment ($P \geq 0.36$), G:F also numerically decreased as roughage level increased from d 0 to d 14 with the CON steers having the highest G:F (0.114), followed by the INT (0.101) and HGH (0.092) steers ($P = 0.36$; Table 3.3). Sample size may have influenced the ability to detect differences in performance and efficiency between treatments in the current experiment. Removing the 2 pens from the final data collection resulted in 13 pens (5 pens for CON, 4 pens for INT, and 4 pens for HGH) compared to the original 15 pens (5 pens per treatment), which also may have reduced the statistical power making treatment differences more difficult to detect if such differences existed. For the rest of the experiment, both ADG and G:F did not continue with the same pattern, indicating that during the first 14 d of treatment adaptation the steers on the INT and HGH diets may have been adjusting to the increased roughage diets, which may have impacted ADG as the rumen environment adjusted to the increased roughage (Table 3.3). Table 3.3 shows there was no pattern in G:F or ADG following d 14.

Dry matter intake increased from d 29 to final for HGH steers ($P = 0.001$; Table 3.3) in which steers' DMI increased linearly as roughage level increased ($P = 0.001$; Table 3.3). The HGH steers also tended to have increased overall DMI ($P = 0.06$; Table 3.3) compared to INT and CON steers. With an increase in roughage level of the diet, there is an increase in DMI which can increase rate of passage and decrease digestibility of the diet. An increase in chewing during eating caused by the roughage, can result in an increased saliva production, which buffers the ruminal pH of cattle consuming high-

concentrate diets (Owens et al., 1998). The literature is in agreement that energy density is thought to be the main regulator of DMI when feeding high concentrate diets while physical fill is the main regulator of DMI when feeding high roughage diets (Krehbiel et al., 2006; Mertens, 1987). Galyean and Defoor (2003) and Cole et al. (1976) reported increased DMI as roughage level increased. During the finishing period, physical fill of the rumen might be impacting DMI when roughage was included at 20%, with a quadratic effect observed on DMI between 5-15% roughage, according to Swanson et al. (2017). With the experimental diets ranging from 6% roughage to 18% roughage in the current experiment, a quadratic effect was not observed indicating physical fill was likely not limiting DMI.

Experimental Diets

Experimental diets were formulated to balance for CP, with the only adjustments between experimental diets being corn, hay, and urea percentages. All ingredient analysis results conducted following the completion of the trial were similar to historical values, except for the protein analysis. The protein content of the prairie hay was almost 2 times historical values (Table 3.1 and Table 3.2). The increased protein in the prairie hay resulted in the experimental diets being unequal in CP percentage as intended when formulated, with HGH diet having 14.20% CP, the INT diet having 14.10% CP, and the CON diet having 13.10% CP (Table 3.2).

Literature has reported that peNDF is an important factor in maintaining a healthy ruminal environment, improving nutrient digestion, and has been recently considered the most important aspect of fiber content in ruminant diets (Mertens, 1997; Zebeli et al., 2012). The experimental diet peNDF results are reported in Table 3.4, with increased

peNDF percentage in the diet as roughage level increased. The tendency for an increased overall DMI in HGH steers compared to the CON and INT steers ($P = 0.07$) may partially be explained by the 8.7% peNDF difference between the HGH and CON diets (NASEM, 2016).

Carcass Traits

Similarly to final BW, there were no differences in hot carcass weight (HCW; $P = 0.35$) or dressing percentage ($P = 0.24$; Table 3.5). A linear decrease in HCW and dressing percentage as forage level increased was observed by Swanson et al. (2017) for cattle consuming 5% forage compared to cattle consuming 20% forage. While there were no differences in HCW, the CON and INT steers had a numerically higher HCW than the HGH steers. There were no differences in marbling, kidney, pelvic, and heart fat (KPH), or liver scores, ($P \geq 0.29$) among treatments. Although no differences in fat thickness were observed ($P = 0.38$), the CON steers had the highest numerical fat thickness (1.30 cm^2), followed by the INT steers (1.17 cm^2), and the HGH steers (1.03 cm^2; Table 3.5). Again, the ability to detect differences among the experimental treatments may have been impacted due to the statistical power making treatment differences more difficult to detect if such differences existed. These results are in agreement with Swanson et al. (2017), who indicated KPH, fat thickness, and marbling score were not affected by increased roughage. Steers consuming the HGH diet tended to have a larger rib eye area (REA; $P = 0.06$; Table 3.5). Although the rate of roughage inclusion can affect carcass traits, the tendency to increase REA for the HGH steers ($P = 0.06$; Table 3.5) was an unexpected result. Craig et al. (1959) reported that increasing forage level reduced lean color of carcasses and producer profits.

Fecal Characteristics

To approximate the extent of digestion of experimental diets fecal grab samples were evaluated for consistency. Fecal consistency appears more "loose" when passage rate and hindgut fermentation increases (Kononoff et al., 2002; Hall, 2007). No differences in fecal score or fecal score change were detected throughout the trial ($P \geq 0.13$; Table 3.6). Fecal consistency may also vary due to various factors unrelated to diet, but are still indicative of experimental diet digestibility (Kononoff at al., 2002). The optimal fecal consistency for feedlot cattle is a fecal score of 3 according to Woolsoncroft et al. (2018).

Fecal pH can help estimate the extent of feed digestion as an indicator of total tract digestion of the diet. Previous literature suggests a further extent of starch digestion in the rumen may be attributed to a higher fecal pH, whereas a decrease in fecal pH may be attributed to an increase in hindgut fermentation (Wheeler and Noller, 1977; Yang and Beauchemin, 2006). No differences in fecal pH were observed between treatments on d 0 ($P = 0.26$; Table 3.6) or expected since all cattle were consuming the same diet prior to the start of experimental treatments. On d 14, the CON steers tended ($P = 0.07$) to have a higher fecal pH compared to the INT and HGH steers (Table 3.6). A linearly decrease in final fecal pH was observed as roughage level increased ($P = 0.02$; Table 3.6). The small increase in roughage could improve the digestion and fermentation of carbohydrates by stimulating ruminal contractions and the production of saliva both of which can aid in regulating hindgut pH by preventing excess carbohydrates from escaping ruminal fermentation. An increased final fecal pH in the CON diet ($P = 0.04$) may be attributed to

an increased flow of fermentable carbohydrates from the small intestine into the hindgut (Gressley et al., 2011).

Rumen Fluid Characteristics

No differences were observed for rumen pH or rumen pH change ($P \geq 0.11$; Table 3.7) during any period of the experiment. All rumen pH values for any period averaged between 5.43 and 7.94 (± 0.36; Table 3.7), which is close to the normal range reported for feedlot cattle ruminal pH of 5.6 to 6.2 (Schwartzkopf-Genswein, 2003). Seeing no difference in rumen pH results was not expected even though the oral – stomach tube technique utilized in this experiment, can cause pH to vary due to intra-ruminal localization and potential for saliva contamination (Enemark et al., 2002). To account for saliva contamination, which can raise rumen pH the first 50 mL of rumen fluid collected was dumped, prior to collecting the sample for analysis. All animals were sampled prior to feeding in the same timeframe during each collection limiting the effect of time on ruminal pH. Cattle consuming diets with 5% roughage inclusion tended to spend a greater amount of time under a ruminal pH of 5.6 compared to cattle consuming diets with 10% roughage inclusion, according to Wiese et al. (2017).

No effect of treatment was observed for ruminal $_{L}$ -lactate concentrations on d 0 ($P = 0.93$; Table 3.7), although there was a treatment effect on d 14 ($P = 0.0003$; Table 3.7) and a tendency for a treatment effect on d 28 in which steers' ruminal lactate concentrations tended to decrease linearly as roughage level increased ($P = 0.09$ and $P = 0.06$, respectively; Table 3.7). While the concentrations of rumen lactate reported in the current experiment are generally low, diets containing increased levels of easily

digestible carbohydrates can cause ruminal lactate concentrations to increase up to 80 mmol/l and cause rumen pH to fall to 5.0 (Møller et al., 1997; Owens et al., 1998).

Since sample collection was conducted over 100 d after arrival at WSBRC, and all cattle were consuming the same PTD diet prior to experimental treatments, so no differences in rumen lactate concentrations were expected. The risk for acidosis is lower late in the finishing period compared to the beginning of the feeding period (Leedle et al., 1995; Nagaraja and Titgemeyer, 2007). The INT and HGH steers saw a reduction in rumen lactate over the course of the trial due to the reduction in readily digestible carbohydrates in the treatment diets, while the CON steers levels remained elevated compared to the INT and HGH steers. Results of Ahrens (1967) and Bruno and Moore (1962) reported the rumen fluid of cattle consuming only roughage contained low levels of lactic acid. The rate of lactate production increases with increasing levels of concentrate in the diet (Nagaraja and Titgemeyer, 2007). Results of the current experiment were expected, because concentrate levels were increased in the CON treatment compared to the INT and HGH diets. Ruminal lactate concentrations for the CON steers were increased compared to the INT and HGH steers on d 14 and tended to be increased for CON steers on d 28. This is supported by Dunlop and Hammond (1965) who reported lactate utilizing microbial species are not able to maintain sufficient numbers in the rumen to utilize the increased amounts of lactic acid produced causing a depression in ruminal pH when the concentrate content of the diet increased.

Blood Metabolites

Blood Glucose

No treatment × day interaction was detected for serum glucose concentrations ($P = 0.95$; Table 3.8). There was a treatment effect ($P = 0.0001$; Table 3.8) and a day effect ($P < 0.0001$; Table 3.8). Glucose concentrations for any period averaged between 76.1 and 94.4 (± 7.89) mg/dL (Table 3.8). In general, glucose concentrations increased from d 0 to d 14, then decreased through d 58. The INT steers had the lowest treatment concentration of glucose (82.2 mg/dL) compared to the CON (93.3 mg/dL) and HGH (90.1 mg/dL; Table 3.8). These concentrations are all within expected normal ranges; previous studies have reported plasma glucose levels ranging from 65.2 to 101.1 mg/dL in finishing feedlot steers (Evans et al., 1975; Hancock et al., 1988). Blood glucose can be utilized to provide insight on starch metabolism and utilization in cattle. Cattle consuming high roughage diets have reduced quantities of alpha-linked glucose polysaccharides pass from the rumen into the small intestine (Bird et al., 1996); therefore, the reduced glucose values for steers on the INT diet is not likely of biological concern. As the concentration of starch in the diet increases, a greater amount of starch escapes ruminal digestion and is absorbed in the small intestine into the bloodstream increasing blood glucose concentrations (Church, 1988).

Blood Lactate

No treatment × day interaction ($P = 0.98$) or main effect of treatment ($P = 0.55$) were detected for serum lactate concentrations (Table 3.8). There was a day effect ($P < 0.0001$; Table 3.8). In general, lactate concentrations decreased from d 0 to d 14, remained steady from d 15 to d 28, then decreased on d 58. The CON steers had the

highest numerical concentration of lactate (0.49 g/L) compared to the INT (0.46 g/L) and HGH (0.45 g/L; Table 3.8). L-lactate is a byproduct of propionate metabolism in the rumen that can enter the bloodstream, and has been researched as a symptom of systemic acidosis (Church, 1988). Because additional lactate can be absorbed into the blood stream analyzing blood samples to assess lactate concentrations in the body is a reliable method to provide insight to lactic acid utilization in the rumen. Lactate concentrations for any period averaged between 0.19 and 0.86 (± 0.16) g/L (Table 3.8). Literature reports normal blood lactate concentrates between 0.5-2.0 mmol/L (0.09-0.36 g/L; Dunlop and Hammond, 1965).

Serum Urea Nitrogen

There was no treatment × day interaction ($P = 0.54$), or main effect of treatment ($P = 0.72$) detected for SUN concentrations throughout the trial, although there was a day effect ($P = 0.04$; Table 3.8). The day effect detailed increasing SUN levels from d 0 through d 28 (41.4 to 47.9 mg/dL), then decreasing SUN levels from d 28 to final (44.4 mg/dL; Table 3.8). The decrease in SUN levels at the end of the end of the experiment could be attributed to the beta-agonist fed during that period. A beta-agonist repartitions where energy within the animal is destined, away from fat deposition toward muscle deposition. The day effect shows the effect of SUN concentration over the time of diet adaptation illustrating changes in short term protein intake and nitrogen utilization. Serum urea nitrogen is utilized in ruminants and other production species as a marker of nitrogen intake and utilization (Preston et al., 1965; Nolan et al., 1970; Kohn et al., 2005).

Serum urea nitrogen is regarded as one of the most effective retrospective measurement of the short-term protein status in ruminants (Hammond, 1997; Herdt

2000). Normal SUN concentrations in healthy beef steers range from 7-20 mg/dL (Hammond, 1997). Concentrations of SUN in this experiment, averaged between 31.7 and 58.5 (± 6.46) mg/dL for all periods (Table 3.8). The levels observed in this experiment were above levels reported in the literature, indicating there may be excess nitrogen being produced within the rumen. While the level of CP and amount of ruminally degradable protein in a diet are known to influence SUN concentration, the differences in CP between the CON (13.10%) and the INT and HGH steers (14.10% and 14.20% CP, respectively) did not appear to be large enough to impact urea production among treatments (Table 3.8).

Non-esterified Fatty Acid

No treatment × day interaction was detected for serum NEFA concentrations (P = 0.93). There was a treatment effect (P = 0.002) and a day effect observed for NEFA concentrations (P = 0.0032; Table 3.8). Table 3.8 shows HGH steers had the highest concentration of NEFA (0.2034 mEq/L) compared to the INT (0.1622 mEq/L) and CON (0.1587 mEq/L; Table 6). In general, NEFA concentrations increased from d 0 to d 14, then decreased through d 58. Prepartum dairy cows, less than 2 wk to calving, had an increased risk for disease after calving, such as a displaced left abomasum when NEFA concentrations were ≥ 0.3 mEq/L, the animal (Ospina et al., 2010).

Although NEFA have been studied more extensively in dairy cattle, NEFA are often reported with beta-hydroxybutyrate as indicators of energy balance. Non-esterified fatty acid concentrations are one of the most common metabolites used to estimate the nutrient status of cattle and are utilized as an indicator of negative energy balance, most often used in dairy cattle undergoing transition (Bowden, 1971; Chapinal et al., 2011;

Ospina et al., 2010). When compared to other blood metabolites, NEFA are less sensitive to time of collection (Eicher et al., 1999). The trend for decreased concentrations on the final collection were also reported in blood glucose, blood lactate, and SUN concentrations.

CONCLUSION

The objective of this experiment was to evaluate the effects of increased roughage inclusion late in the finishing period on growth performance, carcass traits, and ruminal and fecal characteristics of feedlot steers. Results from this experiment indicate feeding increased roughage late in the finishing period did not impact final BW, overall ADG, HCW, or ruminal pH between dietary treatments. Carcasses of steers fed the HGH diet tended to have an increased REA, while there were no differences between KPH, dressing percentage, USDA Yield Grades, liver scores, or back fat between treatments. Steers consuming the CON diet had higher rumen lactate concentrations and numerically higher blood lactate concentrations throughout the experiment. Although steers on the HGH diet had an increased DMI, no differences in G:F or ADG were detected between treatments. Additionally, while no differences in fecal consistency were observed during the experiment, final fecal pH decreased linearly as roughage level increased. Removing the 2 pens from the final data collection resulting in in 13 pens (5 pens for CON, 4 pens for INT, and 4 pens for HGH) compared to the original 15 pens (5 pens per treatment), may have reduced the statistical power making statistical differences in performance and efficiency between treatments more difficult to detect if differences existed.

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Table 3.1. Pre-experiment diet compositions

	Treatments[2]	
Ingredients, % of DM[1]	RCV	PTD
Prairie hay	28.44	6.00
Dry-rolled corn	15.00	63.84
Sweet Bran[3]	51.26	20.00
Urea	-	0.16
Dry supplement[4]	5.20	5.00
Liquid supplement[5]	-	5.00
Nutrient composition, DM basis		
DM, %	68.44	77.15
CP[6], %	13.46	13.29
NDF[7], %	56.15	22.59
ADF[8], %	26.21	8.07
ADL[9], %	5.44	3.36
peNDF[10], %	65.80	79.26
TDN[6], %	1.91	3.36
Fat, %	1.32	1.72
NE_m[11], Mcal/kg	0.75	1.10
NE_g[12], Mcal/kg	0.64	0.48
Ca[13], %	0.75	0.48
P, %	1.19	0.84
K, %	0.35	0.23

[1]Receiving diet (RCV): common receiving diet for all cattle. Diet analyzed by Servi-Tech Laboratories, Dodge City, KS. Pre-trial diet (PTD); representative of a typical finishing diet for the facility.
[2]Dry matter
[3]Cargill Inc., Dalhart, TX
[4]Dry supplement: (% DM basis) 40.0% ground corn, 29.6% limestone, 20.0% wheat middlings, 7.0% urea, 1.0 % salt, 0.53% magnesium oxide, 0.51% zinc sulfate, 0.17% manganese oxide, 0.13% copper sulfate, 0.08% selenium premix (0.6%), 0.0037% cobalt carbonate, 0.32% vitamin A (30,000 IU/g), 0.10% vitamin E (500 IU/g), 0.009% vitamin D (30,000 IU/g). 0.20 % tylosin (Tylan-40, Elanco Animal Health, Greenfield IN) and 0.33% monensin (Rumensin- 90; Elanco Animal Health)
[5]Liquid supplement: (% DM basis) 45.86% corn steep, 36.17% cane molasses, 6% hydrolyzed vegetable oil, 5.46% 80VOP/20 oil, 5.2 % water, 1.23% urea (55% solution), and 0.10% xanthan gum.
[6]Crude protein
[7]Neutral detergent fiber
[8]Acid detergent fiber
[9]Acid detergent lignin
[10]Total digestible nutrients; calculated according to Weiss et al. (1992)
[11]Net energy maintenance; calculated according to NASEM (2016)
[12]Net energy gain; calculated according to NASEM (2016)
[13]Minerals were analyzed by Servi-Tech Laboratories, Dodge City, KS

Table 3.2. Experimental diet compositions

	Treatments[1]		
Ingredients, % DM[2]	CON	INT	HGH
Prairie hay	6.00	12.00	18.00
Dry-rolled corn	63.84	57.77	51.70
Sweet Bran[3]	20.00	20.00	20.00
Urea	0.16	0.23	0.30
Dry supplement[4]	5.00	5.00	5.00
Liquid supplement[5]	5.00	5.00	5.00
Nutrient composition, DM basis			
DM, %	77.79	77.29	77.27
CP[6], %	13.10	14.10	14.20
NDF[7], %	15.62	25.31	31.27
ADF[8], %	5.66	9.63	13.18
ADL[9], %	0.99	2.64	3.68
peNDF[10], %	16.10	25.00	19.10
TDN[6], %	83.15	78.31	71.34
Fat, %	3.61	4.82	2.36
NE_m[11], Mcal/kg	1.83	1.69	1.49
NE_g[12], Mcal/kg	1.20	1.08	0.90
Ca[13], %	0.59	0.64	0.43
P, %	0.49	0.49	0.49
K, %	0.86	0.93	0.90
Mg, %	0.22	0.25	0.23

[1]Treatments: The control (CON) diet consisted of 6.00% prairie hay, 63.84% dry-rolled corn, 20.00% Sweet Bran, and 0.16% urea on a DM basis. The intermediate roughage (INT) diet consisted of 12.00% prairie hay, 57.77% dry rolled corn, 20.00% Sweet Bran, and 0.23% urea on a DM basis. The high roughage (HGH) diet consisted of 18.00% prairie hay, 51.70% dry-rolled corn, 20.00% Sweet Bran, and 0.30% urea on a DM basis added as needed to meet CP requirement. All dietary treatments had 5.00% dry supplement and 5.00% liquid supplement.

[2]Dry matter

[4]Cargill Inc., Dalhart, TX

[5]Dry supplement: (% DM basis) 40.0% ground corn, 29.6% limestone, 20.0% wheat middlings, 7.0% urea, 1.0 % salt, 0.53% magnesium oxide, 0.51% zinc sulfate, 0.17% manganese oxide, 0.13% copper sulfate, 0.08% selenium premix (0.6%), 0.0037% cobalt carbonate, 0.32% vitamin A (30,000 IU/g), 0.10% vitamin E (500 IU/g), 0.009% vitamin D (30,000 IU/g). 0.20 % tylosin (Tylan-40, Elanco Animal Health, Greenfield IN) and 0.33% monensin (Rumensin- 90; Elanco Animal Health)

[6]Liquid supplement: (% DM basis) 45.86% corn steep, 36.17% cane molasses, 6% hydrolyzed vegetable oil, 5.46% 80VOP/20 oil, 5.2 % water, 1.23% urea (55% solution), and 0.10% xanthan gum

[5]Crude protein

[6]Neutral detergent fiber

[7]Acid detergent fiber

[8]Acid detergent lignin
[9]Physically effective fiber provided by the roughage and byproducts in the diet.
[10]Total digestible nutrients; calculated according to Weiss et al. (1992)
[11]Net energy maintenance; calculated according to NASEM (2016)
[12]Net energy gain; calculated according to NASEM (2016)
[13]Minerals were analyzed by Servi-Tech Laboratories, Dodge City, KS

Table 3.3. Effect of roughage inclusion late in the finishing period on the growth performance and feed efficiency of crossbred steers

Item	Treatments[1]			SEM[2]	*P*-value	Linear *P*-value
	CON	INT	HGH			
BW[3], kg						
d -27[4]	374	374	374	4.2	0.99	0.99
d 0[5]	497	504	500	14.6	0.86	0.82
d 14	512	516	511	14.4	0.90	0.94
d 28	521	522	520	14.3	0.99	0.95
Final[6]	551	551	548	8.9	0.89	0.66
ADG[7], kg						
d -27 to 0[8]	1.75	1.90	1.81	0.091	0.53	0.66
d 0 to 14	1.15	0.99	0.89	0.290	0.49	0.49
d 15 to 28	0.74	0.51	0.76	0.229	0.41	0.95
d 29 to final	1.36	1.57	1.44	0.324	0.59	0.68
d 0 to final	1.10	1.09	1.11	0.129	0.97	0.88
DMI[9], kg/d						
d -27 to 0[8]	10.02	10.26	10.13	0.302	0.68	0.68
d 0 to 14	9.88	9.87	9.83	0.393	0.99	0.89
d 15 to 28	9.23	9.31	9.60	0.261	0.28	0.13
d 29 to final	9.67[c]	10.31[b]	11.20[a]	0.320	0.001	0.0003
d 0 to final	9.58[c]	10.00[b]	10.34[a]	0.315	0.06	0.02
G:F[10]						
d -27 to 0[8]	0.183	0.195	0.188	0.0126	0.78	0.77
d 0 to 14	0.114	0.101	0.092	0.0107	0.36	0.16
d 15 to 28	0.097	0.075	0.092	0.0189	0.37	0.74
d 29 to final	0.131	0.140	0.121	0.0126	0.59	0.58
d 0 to final	0.117	0.113	0.108	0.0147	0.71	0.42

[1]Treatments: The control (CON) diet consisted of 6.00% prairie hay, 63.84% dry-rolled corn, 20.00% Sweet Bran, and 0.16% urea on a DM basis. The intermediate roughage (INT) diet consisted of 12.00% prairie hay, 57.77% dry rolled corn, 20.00% Sweet Bran, and 0.23% urea on a DM basis. The high roughage (HGH) diet consisted of 18.00% prairie hay, 51.70% dry-rolled corn, 20.00% Sweet Bran, and 0.30% urea on a DM basis added as needed to meet CP requirement. All dietary treatments had 5.00% dry supplement and 5.00% liquid supplement.

[2]n = 5 pens for all CON and all time points except final for INT and HGH treatments n = 4 pens.

[3]Body weight

[4]Day -27 refers to the reallocation prior to starting experimental treatments

[5]The lighter 2 blocks began experimental treatments 35 d following heavier block beginning treatment, referred to throughout the remainder of the manuscript as d 0.

[6]Final refers to d 58 of experimental treatments, respective of block

[7]Average daily gain

[8]Calculated based on treatment start dates. Lighter 2 blocks began treatments 35 d later than the heavier 2 blocks.
[9]Dry matter intake
[10]Gain to feed calculated by dividing the ADG for the pen by the average daily DMI for the pen for each respective period
[a,b,c]Within a row, least squares means lacking a common superscript differ ($P < 0.05$)

Table 3.4 Effect of roughage inclusion on particle separation and estimated physically effective fiber of experimental diets

	Treatments[1]		
Item	CON	INT	HGH
NDF[2], % DM[3]	18.1	20.6	27.3
Sieve screen size, mm	Retained/screen %		
19.0	4.3	13.4	40.7
8.0	13.6	11.6	5.4
4.0	72.2	66.4	46.7
Particles less than 4 mm	9.9	8.6	7.2
Particles greater than 4 mm	90.1	91.4	92.8
Estimated peNDF[4], % DM	16.3	19.1	25.0

[1]Treatments: The control (CON) diet consisted of 6.00% prairie hay, 63.84% dry-rolled corn, 20.00% Sweet Bran, and 0.16% urea on a DM basis. The intermediate roughage (INT) diet consisted of 12.00% prairie hay, 57.77% dry rolled corn, 20.00% Sweet Bran, and 0.23% urea on a DM basis. The high roughage (HGH) diet consisted of 18.00% prairie hay, 51.70% dry-rolled corn, 20.00% Sweet Bran, and 0.30% urea on a DM basis added as needed to meet CP requirement. All dietary treatments had 5.00% dry supplement and 5.00% liquid supplement.

[2]Neutral detergent fiber

[3]Dry matter

[3]Percent of physically effective NDF (peNDF) was estimated by multiplying the percentage of sample larger than 4 mm in particle size by the percent NDF (as a decimal) of the diet after separation

Table 3.5. Effect of roughage inclusion late in the finishing period on carcass characteristics of crossbred feedlot steers

	Treatment[1]					
Item	CON	INT	HGH	SEM[2]	*P*-value	Linear *P*-value
HCW[3], kg	389	389	384	7.5	0.35	0.16
Rib eye area, cm^2	38.2[c]	39.8[b]	40.9[a]	0.97	0.06	0.02
Fat thickness[4], cm	1.30	1.17	1.03	0.161	0.47	0.23
KPH[5], %	2.56	2.57	2.51	0.174	0.90	0.72
Dressing percentage	63.2	62.6	62.1	1.09	0.24	0.10
Calculated USDA YG[6]	2.70[a]	2.36[b]	1.99[c]	0.586	0.11	0.04
Marbling score[7]	506	479	500	18.0	0.53	0.81
Liver score[8], % of pen						
O	100	93.8	100	7.04	0.29	0.94
Contaminated	-	6.2	-	7.04	0.29	0.94

[1]Treatments: The control (CON) diet consisted of 6.00% prairie hay, 63.84% dry-rolled corn, 20.00% Sweet Bran, and 0.16% urea on a DM basis. The intermediate roughage (INT) diet consisted of 12.00% prairie hay, 57.77% dry rolled corn, 20.00% Sweet Bran, and 0.23% urea on a DM basis. The high roughage (HGH) diet consisted of 18.00% prairie hay, 51.70% dry-rolled corn, 20.00% Sweet Bran, and 0.30% urea on a DM basis added as needed to meet CP requirement. All dietary treatments had 5.00% dry supplement and 5.00% liquid supplement.
[2]n = 5 pens for CON, n = 4 pens for INT and HGH diets.
[3]Hot carcass weight
[4]Fat measurement taken between the 12th and 13th ribs
[5]Kidney, pelvic, and heart fat
[6]Yield Grade
[7]Small00 = 400; Modest00 = 500; Moderate00 = 600.
[8]Liver scores at harvest: O = normal, healthy liver, free of abscesses. A− = livers that displayed less than 2 abscesses which are generally less than 2.54 cm in diameter. Contaminated = contaminated with fecal material during harvest.
[a,b,c]Within a row, least squares means lacking a common superscript differ (P < 0.05)

Table 3.6. Effect of roughage inclusion late in the finishing period on fecal score and fecal pH of crossbred feedlot steers

Item	Treatment[1]			SEM[2]	*P*-value	Linear *P*-value
	CON	INT	HGH			
Fecal score[3]						
d 0[4]	3.54	3.67	3.39	0.204	0.22	0.36
d 14	3.19	3.32	3.30	0.181	0.86	0.67
d 28	3.03	3.13	2.80	0.193	0.13	0.17
Final[5]	2.97	2.78	2.96	0.299	0.59	0.96
Fecal score change[6]						
d 0 to 14	-0.278	-0.236	-0.002	0.5427	0.67	0.42
d 15 to 28	-0.033	-0.191	-0.391	0.4926	0.54	0.28
d 29 to final	-0.158	-0.375	0.188	0.2169	0.23	0.26
d 0 to final	-0.584	-0.910	-0.430	0.3576	0.26	0.57
Fecal pH						
d 0	6.43	6.16	5.97	0.277	0.16	0.06
d 14	7.04[a]	6.60[b]	6.67[b]	0.128	0.07	0.07
d 28	6.68	6.64	6.80	0.056	0.14	0.15
Final	6.88[a]	6.77[b]	6.54[c]	0.088	0.04	0.02
Fecal pH change[6]						
d 0 to 14	0.708	0.566	0.804	0.2977	0.62	0.70
d 15 to 28	-0.360[b]	0.138[a]	0.094[b]	0.1286	0.03	0.03
d 29 to final	0.224[a]	0.253[a]	-0.228[b]	0.0826	0.003	0.002
d 0 to final	0.426	0.668	0.415	0.2934	0.48	0.96

[1]Treatments: The control (CON) diet consisted of 6.00% prairie hay, 63.84% dry-rolled corn, 20.00% Sweet Bran, and 0.16% urea on a DM basis. The intermediate roughage (INT) diet consisted of 12.00% prairie hay, 57.77% dry rolled corn, 20.00% Sweet Bran, and 0.23% urea on a DM basis. The high roughage (HGH) diet consisted of 18.00% prairie hay, 51.70% dry-rolled corn, 20.00% Sweet Bran, and 0.30% urea on a DM basis added as needed to meet CP requirement. All dietary treatments had 5.00% dry supplement and 5.00% liquid supplement.

[2]n = 5 pens for all CON and all time points except final for INT and HGH treatments n = 4 pens.

[3]Fecal score adapted from Ireland-Perry and Stallings (1993) and Woolsoncroft et al. (2018), with a greater score indicating a looser fecal consistency on a scale of 1 to 5 with 1 representing a cow on dry hay and 5 being the consistency of water.

[4]The lighter 2 blocks began experimental treatments 35 d following heavier block beginning treatment, referred to throughout the remainder of the manuscript as d 0

[5]Final refers to d 58 of experimental treatments, respective of block

[6]The difference between collection periods; the later date was subtracted from the earlier date.

[a,b,c]Within a row, least squares means lacking a common superscript differ (P < 0.05)

Table 3.7. Effect of roughage inclusion late in the finishing period on ruminal characteristics of crossbred feedlot steers

Item	Treatment[1]			SEM[2]	*P*-value	Linear *P*-value
	CON	INT	HGH			
Rumen lactate, mg/dL						
d 0[3]	1.61	2.02	2.02	0.894	0.93	0.75
d 14	2.548[a]	0.945[b]	0.865[b]	0.2377	0.0004	0.0003
d 28	1.776[a]	0.307[b]	0.357[b]	1.1070	0.09	0.06
Rumen pH						
d 0	6.98	6.97	6.92	0.175	0.84	0.58
d 14	7.17	7.17	7.33	0.104	0.11	0.07
d 28	6.81	6.88	6.90	0.133	0.66	0.39
Rumen pH change[4]						
d 0 to 14	0.125	0.123	0.341	0.1428	0.14	0.09
d 15 to 28	-0.316	-0.240	-0.378	0.1454	0.41	0.55
d 0 to 28	-0.227	-0.161	-0.069	0.1854	0.60	0.32

[1]Treatments: The control (CON) diet consisted of 6.00% prairie hay, 63.84% dry-rolled corn, 20.00% Sweet Bran, and 0.16% urea on a DM basis. The intermediate roughage (INT) diet consisted of 12.00% prairie hay, 57.77% dry rolled corn, 20.00% Sweet Bran, and 0.23% urea on a DM basis. The high roughage (HGH) diet consisted of 18.00% prairie hay, 51.70% dry-rolled corn, 20.00% Sweet Bran, and 0.30% urea on a DM basis added as needed to meet CP requirement. All dietary treatments had 5.00% dry supplement and 5.00% liquid supplement.

[2]n = 5 pens per treatment

[3]The lighter 2 blocks began experimental treatments 35 d following heavier block beginning treatment, referred to throughout the remainder of the manuscript as d 0.

[4]The difference between collection periods; the later date was subtracted from the earlier date.

[a,b,c]Within a row, least squares means lacking a common superscript differ ($P < 0.05$)

Table 3.8. Effect of roughage inclusion late in the finishing period on serum metabolite concentrations of crossbred feedlot steers

	Treatments[1]					Day[3]					
Variable	CON	INT	HGH	SEM[2]	*P*-value	0[4]	14	28	Final[5]	SEM[2]	*P*-value
Glucose, mg/dL	93.3[a]	82.2[b]	90.1[a]	3.92	0.0001	91.5[a]	94.4[a]	91.4[a]	76.8[b]	4.11	<0.0001
Lactate, g/L	0.486	0.454	0.450	0.047	0.55	0.540[a]	0.507[a]	0.521[a]	0.287[b]	0.0501	<0.0001
SUN[6], mg/dL	44.7	43.3	44.7	1.51	0.72	41.5[b]	43.2[b]	47.9[a]	44.4[ab]	1.81	0.04
NEFA[7], mEq/L	0.159[b]	0.162[b]	0.203[a]	0.1283	0.002	0.149[c]	0.199[a]	0.190[ab]	0.160[bc]	0.0144	0.003

[1]Treatments: The control (CON) diet consisted of 6.00% prairie hay, 63.84% dry-rolled corn, 20.00% Sweet Bran, and 0.16% urea on a DM basis. The intermediate roughage (INT) diet consisted of 12.00% prairie hay, 57.77% dry rolled corn, 20.00% Sweet Bran, and 0.23% urea on a DM basis. The high roughage (HGH) diet consisted of 18.00% prairie hay, 51.70% dry-rolled corn, 20.00% Sweet Bran, and 0.30% urea on a DM basis added as needed to meet CP requirement. All dietary treatments had 5.00% dry supplement and 5.00% liquid supplement.

[2]n = 5 pens for all CON and all time points except final for INT and HGH treatments n = 4 pens

[3]Refers to days since start of experimental treatments

[4]The lighter 2 blocks began experimental treatments 35 d following heavier block beginning treatment, referred to throughout the remainder of the manuscript as d 0

[5]Cattle were harvested in 2 groups on each group's respective d 58

[6]Serum urea nitrogen

[7]Non esterified fatty acid

[a,b,c]Within a row, least squares means lacking a common superscript differ ($P < 0.05$)

REFERENCES

Ahrens, F. A. 1967. Histamine, lactic acid, and hypertonicity as factors in the development of rumenitis in cattle. Amer. J. Vet. Res. 28:1335-1342. ISSN: 0002-9645.

Allwardt, K., C. Ahlberg, A. Broocks, K. Bruno, A. Taylor, S. Place, C. Richards, C. Krehbiel, M. Calvo-Lorenzo, U. DeSilva, D. VanOverbeke, R. Mateescu, C. Goad, M. M. Rolf, 2017. Technical note: Validation of an automated system for monitoring and restricting water intake in group-housed beef steers'. J. Anim. Sci., 95: 4213–4219. doi:10.2527/jas.2017.1593.

Alsemgeest, S.P.M., Lalsbeek, H.C., Wensing, Th., Koeman, J.P., van Ederen, A.M., Gruys, E., 1994. Concentrations of serum amyloid-A (SAA) and haptoglobin (Hp) as parameters of inflammatory diseases in cattle. Vet. Quart. 16, 21-23. doi:10.1080/01652176.1994.9694410

Apaoblaza, A., S. D. Gerrard, S. K. Matarneh, J. C. Wicks, L. Kirkpatrick, E. M. England, T. L. Scheffler, S. K. Duckett, H. Shia, S. L. Silvac, A. L. Grant, D. E. Gerrard. 2020. Muscle from grass- and grain-fed cattle differs energetically. J. Meat Sci. 161:1-8. doi:10.1016/j.meatsci.2019.107996

Arave, C.W. and J. L. Albright. 1981. Cattle behavior. J. Dairy Sci. 64:1318-1329. doi:10.3168/jds.S0022-0302(81)82705-1

Aschenbach, J. R., G. B. Penner, F. Stumpff, and G. Gäbel. 2011. Ruminant nutrition symposium: role of fermentation acid absorption in the regulation of ruminal pH. J. Anim. Sci. 89:1092-1107. doi:10.2527/jas.2010-3301

Baldwin, R. L. 1965. Pathways of carbohydrate metabolism in the rumen. In Dungherty RW (Ed.) Physiology of Digestion in the Ruminant. Butterworths. London, UK. pp. 379-389.

Baumann, H. and J. Gauldie. 1994. The acute phase response. Immun. Today. 15:74-80. doi:10.1016/0167-5699(94)90137-6

Beauchemin, K. A., W. Z. Yang, and L. M. Rode. 2001. Effects of barley grain processing on the sit and extent of digestion of beef feedlot finishing diets. J. Anim. Sci. 79:1925-1936. doi:10.2527/2001.7971925x

Bines, J. A., and A. W. F. Davey 1970. Voluntary intake, digestion, rate of passage, amount of material in the alimentary tract and behaviour in cows receiving complete diets containing straw and concentrates in different proportions. Br. J. Nutr. doi:10.1079/BJN19700104

Bird, A. R., W. J. Croom Jr., Y. K. Fan, B. L. Black, B.W. McBride, and I. L. Taylor. 1996. Peptide regulation of intestinal glucose absorption. J. Anim. Sci. 74:2523-2540. doi:10.2527/1996.74102523x

Boosman, R., Niewold, T.A., Mutsaers, C.W.A.A.M., Gruys, E., 1989. Serum amyloid A concentration in cows given endotoxin as an acute-phase stimulant. Am. J. Vet. Res. 50, 1690-1694. PMID: 2508514

Bowden, D. 1971. Non-esterified fatty acids and ketone bodies in blood as indicators of nutritional status in ruminants: A review. Canadian Journal of Animal Science, 51(1),

1–13. Downloaded from www.nrcresearchpress.com by 74.195.229.50.

Brown, M. S., C. H. Ponce, and R. Pulikanti. 2006. Adaptation of beef cattle to high-concentrate diets: performance and ruminal metabolism. J. Anim. Sci. 84(E. Suppl.):E25-E33. doi:10.2527/2006.8413_supplE25x

Bruno, C. F. and W. E. C. Moore. 1962. Fate of lactic acid in rumen ingesta. J. Dairy Sci. 45:109. doi:10.3168/jds.S0022-0302(62)89336-9

Calderon-Cortes, J. F. and R. A. Zinn. 1996. Influence of dietary forage level and forage coarseness of grind on growth performance and digestive function in feedlot steers. J. Anim. Sci. 74:2310-2316. doi:doi.org/10.2527/1996.74102310x.

Cerrilla, O., M. Esther, and G. M. Martínez. 2003. Starch digestion and glucose metabolism in the ruminant: a review. Interciencia. ProQuest. 28(7): 380-386. Available in: http://www.redalyc.org/articulo.oa?id=33908203

Chapinal, N., D. M. Veira, D. M. Weary, and M. A. G. von Keyserlingk. 2007. Technical note: validation of a system for monitoring individual feeding and drinking behavior and intake in group-housed cattle. J. Dairy Sci. 90:5732-5736. doi:10.3168/jds.2007-0331.

Chapinal, N., M. Carson, T. F. Duffield, M. Capel, S. Godden, M. Overton, J. E. P. Santos, and S. J. LeBlanc. 2011. The association of serum metabolites with clinical disease during transition period. J. Dairy Sci. 94:4897-4903. doi:10.3168/jds.2010-4075.

Church, D. C. 1988. The ruminant animal digestive physiology and nutrition. Prentice-Hall, Inc. Englewood Cliffs. NJ.

Cochran, R. C., D. C. Adams, J. D. Wallace, and M. L. Galyean. 1986. Predicting

digestibility of different diets with internal markers: evaluation of four potential markers. J. Anim. Sci. 63:1476-1483. doi:10.2527/jas1986.6351476x

Cole, N. A., R. R. Johnson, and F. N. Owens. 1976. Influence of roughage level on the site and extent of digestion of whole shelled corn by beef steers. J. Anim. Sci. 43:483-489. doi:10.2527/jas1976.432483x

Corkum, M. J., L. A. Bate, T. Tennessen, and A. Lirette. 1994. Consequences of reduction of number of individual feeders on feeding behaviour and stress level of feedlot steers. Appl. Anim. Behav. 41:27-35. doi:10.1016/0168-1591(94)90049-3

Craig, H. B., T. N. Blumer and E. R. Barrick. 1959. Effect of several combinations of grass and grain in the ration of beef steers on the color characteristics of lean and fat. J. Anim. Sci. 18:241-248. doi:10.2527/jas1959.181241x

DeVries, T. J., M. A. G. von Keyserlingk, and D. M. Weary. 2004. Effect of feeding space on the inter-cow distance, aggression, and feeding behavior of free-stall housed lactating dairy cows. J. Dairy Sci. 87:1432-1438. doi:10.3168/jds.S0022-0302(04)73293-2

DeVries, T. J. and M. A. G. von Keyserlingk. 2009. Competition for feed affects the feeding behavior of growing dairy heifers. J. Dairy Sci. 92:3922-3929. doi:10.3168/jds.2008-1934

Dunlop, R. H., P. D. Hammond. 1965. D-Lactic acidosis of ruminants. Ann. N.Y. Acad. Sci. 119:1109-1132. doi:10.1111/j.1749-6632.1965.tb47466.x

Eckersall, P. D., S. Duthie, S. Safi, N. U. Horadagoda, S. Doyle, R. Parton, D. Bennett, and J. L. Fitzpatrick. 1999. An automated biochemical assay for haptoglobin:

prevention of interference from albumin. Comp Haematol Int 9:117-124. doi:10.1007/BF02600369

Eckersall, P. D., F. J. Young, A. M. Nolan, C. H. Knight, C. McComb, M. M. Waterston, C. J. Hogarth, E. M. Scott, and J. L. Fitzpatrick. 2006. Acute phase proteins in bovine milk in an experimental model of Staphylococcus aureus subclinical mastitis. J. Dairy Sci. 89: 1488–1501. doi:10.3168/jds.S0022-0302(06)72216-0.

Egan, A., and R. Kellaway. 1971. Evaluation of nitrogen metabolites as indices of nitrogen utilization in sheep given frozen and dry mature herbages. Br. J. Nutr, 26(3), 335–351. doi:10.1079/BJN19710042.

Enemark, J. M. D., R. J. Jorgensen, P. S. Enemark. 2002. Rumen acidosis with special emphasis on diagnostic aspects of subclinical rumen acidosis: a review. ISSN 1392-2130. Vet. Zootec. 20:16-29.

Evans, E., J. G. Buchanan-Smith, and G. K. Macleod. 1975. Postprandial patterns of plasma glucose, insulin and volatile fatty acids in ruminants fed low and high-roughage diets. J. Anim. Sci. 41:1474-1479. doi:10.2527/jas1975.4151474x

Faichney, G.J. 1975. The use of markers to partition digestion within the gastro-intestinal tract of ruminants. Conf. of Digestion and metabolism in the ruminant. Proceedings of the 4th International Symposium on Ruminant Physiology. Sydney, NSW.

France, J. and R. C. Siddons. 1993. Volatile fatty acid production. Pp. 107-121 in Quantitative Aspectd of Ruminant Digestion and Metabolism. J. M. Forbes and J. France, eds. Wallingford, Oxen, UK: CAB International.

Fredin, S. M, L. F. Ferraretto, M. S. Akins, P. C. Hoffman, and R. D. Shaver. 2014. Fecal starch as an indicator of total-tract starch digestibility by lactating dairy cows. J.

Dairy Sci. 97:1862-1871. doi:10.3168/jds.2013-7395

Friend, T. H. and C. E. Polan. 1974. Social rank, feeding behavior, and free stall utilization by dairy cattle. J. Dairy Sci. 57:1214-1220. doi:10.3168/jds.S0022-0302(74)85040-X

Galyean, M. L., and P. J. Defoor. 2003. Effects of roughage source and level on intake by feedlot cattle. J. Anim. Sci. 81(E. Suppl. 2):E8-E16. doi:10.2527/2003.8114_suppl_2E8x.

Galyean, M. L. and M. E. Hubbert. 2014. Review: traditional and alternative sources of fiber – Roughage values, effectiveness, and levels in starting and finishing diets. Prof. Anim. Sci. 30:571-584. doi:10.15232/pas.2014-01329.

Gentry, W. W., C. P. Weiss, C. M. Meredith, F. T. McCollum, N. A. Cole, and J. S. Jennings. 2016. Effects of roughage inclusion and particle size on performance and rumination behavior of finishing beef steers. J. Anim. Sci. 94:4759-4770. doi:10.2527/jas2016-0734

Gill, D. R., F. N. Owens, J. J. Martin, D. E. Williams, R. A. Zinn, and R. J. Hillier. 1981. Roughage level in feedlot rations. Okla. Agric. Exp. Sta. Misc. Publ. MP-108:141.

González, L. A., X. Manteca, S. Calsamiglia, K. S. Schwartzkopf-Genswein, and A. Ferret. 2012. Ruminal acidosis in feedlot cattle: Interplay between feed ingredients, rumen function and feeding behavior (a review). Anim. Feed Sci. Technol. 172:66–79. doi:10.1016/j.anifeedsci.2011.12.009.

Gonyou, H. W. and W. R. Stricklin. 1981. Eating behavior of beef cattle groups fed from a single stall or trough. Appl. Anim. Ethol. 7:123-133. doi:10.1016/0304-3762(81)90090-0

Grant, R. J. and J. L. Albright. 2000. Feeding Behaviour. Pages 365-382 in Farm Animal Metabolism and Nutrition. J. P. F. D'Mello, ed. CABI Publishing, Wallingford, Oxon, UK.

Green, T. C., J. G. Jago, K. A. Macdonald, and G. C. Waghorn. 2013. Relationships between residual feed intake, average daily gain and feeding behavior of growing dairy heifers. J. Dairy Sci. 96:3098-3107. doi:10.3168/jds.2012-6087

Gressley, T. F., M. B. Hall, and L. E. Armentano. 2011. Ruminant nutrition symposium: productivity, digestion, and health responses to hindgut acidosis in ruminants. J. Anim. Sci. 89:1120–1130. doi:10.2527/jas.2010-3460

Gruys, E., A. M. Ederen, S. P. M. Alsemgeest, H. C. Kalsbeek, and T. Wensing. 1993. Acute phase protein values in blood of cattle as indicators of animals with pathological processes. Arch. Lebensmittelhygiene 44, 107-111. doi:10.13140/2.1.4279.9042

Hafez, S., W. Junge, and E. Kalm. 1988. Scha¨tzung der verdaulichkeit mit einer indikator-methode bei milchku¨hen im vergleich zum hohenheimer-futterwert-test. Arch. Tierernahr. 38:929–945. doi:10.1080/17450398809430920.

Hall, M. 2007. Carbohydrate nutrition and manure scoring. Part II: Tools for monitoring rumen function in dairy cattle. In: Proc. Minnesota Dairy Health Conf. St. Paul, MN. p. 81–86.

Hammond, A. C. 1997. Update on BUN and MUN as a guide for protein supplementation in cattle. pp 45-54 in Proc, 7th Annu. Rumin. Nutr. Symp. Gainesville, FL.

Hancock, D. L., J. E. Williams, H. B. Hedrick, E. E Beaver, S. M. Hannah, S. J. Miller, M. R. Ellerseick, G. B. Garner, R. E. Morrow, and J. R. Gerrish. Effects of previous

forage systems on feedlot performance, body composition and plasma variables of finishing steers. J. Anim. Sci. 66:2272-2283. doi:10.2527/jas1988.6692272x

Harmon, D. L., R. A. Britton, R. L. Prior, and R. A. Stock. 1984. Net portal absorption of lactate and volatile fatty acids in steers experiencing glucose-induced acidosis or fed a 70% concentrate diet ad libitum. J. Anim. Sci. 60: 560-569. doi:10.2527/jas1985.602560x

Haskell, M.J., J. A. Rooke, R. Roehe, S. P. Turner, J. J. Hyslop, A. Waterhouse, and C. A. Duthie. 2019. Relationships between feeding behaviour, activity, dominance, and feed efficiency in finishing beef steers. Appl. Anim. Behav. Sci. 210:9-15. doi:10.1016/j.applanim.2018.10.012

Herdt, T. H. 2000. Variability characteristics and test selection in herd level nutritional and metabolic profile testing. Veterinary Clinics of North America: Food Animal Practice, 16(2), 387–403. doi:10.1016/S0749-0720(15)30111-0

Huntington, G. B., R. L. Prior, and R. A. Britton. 1980. Glucose and lactate absorption and metabolic interrelationships in lambs changed from low to high concentrate diets. J. of Nutr. 110:1904-1913. doi:10.1093/jn/110.9.1904.

Huntington, G. B., E. J. Zetina, J. M. Whitt, and W. Potts. 1996. Effects of dietary concentrate level on nutrient absorption, liver metabolism, and urea kinetics of beef steers fed isnitrogenous and isoenergetic diets. J. Anim. Sci. 74:908-916. doi:10.2527/1996.744908x

Huzzey, J. M., D. M. Weary, B. Y. F. Tiau, and M. A. G. von Keyserlingk. 2014. Short communication: automatic detection of social competition using an electronic feeding system. J. Dairy Sci. 97:2953-2958. doi:10.3168/jds.2013-7434.

Ireland-Perry, R. L., and C. C. Stallings. 1993. Fecal consistency as related to dietary composition in lactating Holstein cows. J. Dairy. Sci.76:1074-1082. doi:10.3168/jds.S0022-0302(93)77436-6.

Jagger, S., J. Wiseman, D. J. A. Cole, and J. Craigon. 1992. Evaluation of inert markers for the determination of ileal and faecal apparent digestibility values in the pig. Br. J. Nutr. 68:729–739. doi:10.1079/BJN19920129

Kaske, M., Hatiboglu, S., Engelhardt, W.V., 1992. The influence of density and size of particles on rumination and passage from the reticulo-rumen of sheep. Br. J. Nutr. 67, 235–244. doi:10.1079/BJN19920027.

Kohn, R., M. Dinneen, and E. Russek-Cohen. 2005. Using blood urea nitrogen to predict nitrogen excretion and efficiency of nitrogen utilization in cattle, sheep, goats, horses, pigs, and rats. J. of Anim. Sci., 83(4), 879–889. doi:10.2527/2005.834879x

Kononoff, P., J. Heinrichs, and G. Varga. 2002. Using manure evaluation to enhance dairy cattle nutrition. Penn. State Coop. Ext., Pennsylvania State Univ., University Park, PA.

Kononoff, P. J., A. J. Heinrichs, and D. R. Buckmaster. 2003. Modification of the Penn State forage and total mixed ration particle separator and the effects of moisture content on its measurements. J. Dairy Sci. 86:1858-1863. doi:10.3168/jds.S0022-0302(03)73773-4

Kotb, A. R., and T. D. Luckey. 1972. Markers in nutrition. Nutr. Abstr. Rev. 42(3):813-845. PMID: 4117042

Krehbiel, C. R., J. J. Cranston, and M. P. McCurdy. 2006. An upper limit for caloric density of finishing diets. J. Anim. Sci. 84(Suppl): E34–E49. doi:10.2527/2006.8413_supplE34x

Kushner, I. and D. L. Rzewnicki. 1994. The acute phase response: general aspects. Baillière's Clinical Rheumatology. 8:513-530. doi:10.1016/S0950-3579(05)80113-X.

Leedle, J. A. Z., M. L. Coe, and R. A. Frey. 1995. Evaluation of health and ruminal variables during adaptation to grain-based diets in beef cattle. Am. J. Vet. Res. 56(7):885-892. PMID: 7574156.

Lindsay, D. B. 1970. Carbohydrate metabolism in ruminants. Pp. 438-451. in Physiology of Digestion and Metabolism in the Ruminant: Proceedings of the Third International Symposium, August 1969. Cambridge, England, A. T. Phillipson ed. Newcastle upon Tyne, England: Oriel Press.

Lippke, H., 2002. Estimation of Forage Intake by Ruminants on Pasture. Crop. Sci., 42:869-872. doi:10.2135/cropsci2002.8690.

Llonch, P., M. Somarriba, C. A. Duthie, S. Troy, R. Roehe, J. Rooke, M. J. Haskell, and S. P. Turner. 2018. Temperament and dominance relate to feeding behaviour and activity in beef cattle: implications for performance and methane emissions. Animal 12: 2639-2648. doi:10.1017/S1751731118000617

Lodge-Ivey, S. L., J. Browne-Silva, and M. B. Horvath. 2009. Technical note: Bacterial diversity and fermentation end products in rumen fluid samples collected via oral lavage or rumen cannula. J. Anim. Sci. 87:2333-2337. doi:10.2527/jas.2008-1472

Lorenz, I. 2015. Subacute Ruminal Acidosis - Digestive System. Merck Veterinary Manual. Available from: https://www.merckvetmanual.com/digestive-

system/diseases-of-the-ruminant-forestomach/subacute-ruminal-acidosis

Madara, J. L. 1991. Functional morphology of epithelium of the small intestine: In S. G. Schultz (Ed.) Handbook of physiology. Section 6. the gastrointestinal system. Vol. IV. Intestinal absorption and secretion. p83. American physiological society, Bethesda, MD.

Marhaug, G. and A. B. Dowton. 1994. Serum amyloid A: An acute phase apolipoprotein and precursor of AA amyloid. Baillieres Clin Rheumatol, 1994; 8, 553-73. doi:10.1016/S0950-3579(05)80115-3

Marsh, W. H., B. Fingerhut, and H. Miller. 1965. Automated and manual direct methods for the determination of blood urea. Clin. Chem. 11:624-627. doi:10.1093/clinchem/11.6.624.

McBride, G. 1968. Behavioral measurement of social stress. In: E. S. E. Hafez (Editor) Adaptation of Domestic Animals. Lea and Febiger, Philadelphia, PA, pp. 360-366.

McCann, J. 2018. New perspectives on adapting cattle to finishing diets without compromising rumen health. Dept. Anim. Sci. Univ. Illinois at Urbana-Champaign. Available at: https://animal.ifas.ufl.edu/apps/dairymedia/rns/2018/Mccann.pdf

McPhee, C. P., G. McBride, and J. W. James. 1964. Social behavior of domestic animals. III. Steers in small yards. Animal Science, 6(1), 9-15. doi:10.1017/S0003356100037892.

Mertens, D. R. 1987. Predicting intake and digestibility using mathematical models of ruminal function. J. Anim. Sci. 64:1548–1558. doi:10.2527/jas1987.6451548x.

Mertens, D. R. 1997. Creating a system for meeting the fiber requirements of dairy cows. J. Dairy Sci. 80:1463-1481. doi:10.3168/jds.S0022-0302(97)76075-2

Metz, J. H. M. 1975. Time patterns of feeding and rumination in domestic cattle. Communications Agriculture University 75-12, Wageningen, The Netherlands. Available at: https://library.wur.nl/WebQuery/wurpubs/423037

Meyer, N. F., and T. C. Bryant. 2017. Diagnosis and management of rumen acidosis and bloat in feedlots. Vet Clin Food Anim 33:481–498. doi:10.1016/j.cvfa.2017.06.005

Møller, P. D., L. Diernæs, J. Sehested, J. Hyldgaard-Jensen, and E. Skadhauge. 1997. Absorption and Fate of l- and d-Lactic Acid in Ruminants. Comp Biochem. Physiol. A Physiol, 118:387-388 doi:10.1016/S0300-9629(96)00325-8

Nagaraja, T. G., and E. C. Titgemeyer. 2007. Ruminal Acidosis in Beef Cattle: The Current Microbiological and Nutritional Outlook. J. Dairy Sci. 90:E17-E38. doi:10.3168/jds.2006-478

National Academies of Sciences, Engineering and Medicine (NASEM). 2016. Nutrient Requirements of Beef Cattle: Eighth Revised Edition. Washington, DC: The National Academies Press. doi:10.17226/19014

Nielsen, B. 1999. On the interpretation of feeding behaviour measures and the use of feeding rate as an indicator of social constraint. Appl. Anim. Behav. Sci. 63:79-91. doi:10.1016/S0168-1591(99)00003-9

Nkrumah, J. D., D. H. Crews, J. A. Basarab, M. A. Price, E. K. Okine, Z. Wang, C. Li, and S. S. Moore. 2007. Genetic and phenotypic relationships of feeding behavior and temperament with performance, feed efficiency, ultrasound and carcass merit of beef cattle. J. Anim. Sci. 85:2382-2390. doi:10.1016/S0168-1591(99)00003-9

Nolan, J. V., M. R. Cocimano, and R. A. Leng. 1970. Prediction of parameters of urea metabolism in sheep from the concentration of urea in plasma. Animal production in

Australia: Proceedings of the Australian Society of Animal Production. 8:22-28.

Okine, E.K., Mathison, G.W., Kaske, M., Kennelly, J.J., Christopherson, R.J., 1998. Current understanding of the role of the reticulum and reticulo-omasal orifice in the control of digeta passage from the ruminoreticulum of sheep and cattle. Can. J. Anim. Sci. 78, 15–21. doi:10.4141/A97-021

Olofsson, J. 1999. Competition for total mixed diets fed for ad libitum intake using one or four cows per feeding station. J. Dairy Sci. 82:69-79. doi:10.3168/jds.S0022-0302(99)75210-0

Ospina, P. A., D. V. Nydam, T. Stokol, and T. R. Overton. 2010. Evaluation of nonesterified fatty acids and Beta-hydroxybutyrate in transition dairy cattle in the northeastern United States: critical thresholds for prediction of clinical diseases. J. Dairy Sci. 93:546-554. doi:10.3168/jds.2009-2277.

Owens, F. N. and A. L. Goetsch. 1988. Ruminal fermentation. Pp. 145-171 in The Ruminant Animal: Digestive Physiology and Nutrition, D. C. Church, ed. Englewood Cliffs, NJ: Prentice Hall.

Owens, F. N. and C.F. Hanson. 1992. External and internal markers for appraising site and extent of digestion in ruminants, J. Dairy Sci. 75:2605-2617. doi:10.3168/jds.S0022-0302(92)78023-0

Owens, F. N., D. S. Secrist, W. J. Hill, and D. R. Gill. 1998. Acidosis in cattle: a review. J. Anim. Sci. 76:275-286. doi:10.2527/1998.761275x

Penner, G. B., M. Taniguchi, L. L. Guan, K. A. Beauchemin, and M. Oba. 2009. Effect of dietary forage to concentrate ratio on volatile fatty acid absorption and the expression of genes related to volatile fatty acid absorption and metabolism of ruminal tissue. J.

Dairy Sci. 92:276-2781. doi:10.3168/jds.2008-1716

Plaizier, J. C., D. O. Krause, G. N. Gozho, and B. W. McBride. 2008. Subacute ruminal acidosis in dairy cows: The physiological causes, incidence and consequences. Vet. J. 176:21–31. doi:10.1016/j.tvjl.2007.12.016.

Piveteau, P. 1999. Metabolism of lactate and sugars by dairy propionibacteria: a review. Le Lait 79:23-41. doi:10.1051/lait:199912

Preston, R., D. Schnakenberg, and W. Pfander. 1965. Protein utilization in ruminants. 1. Blood urea nitrogen as affected by protein intake. J. of Nutr., 86:281–288. doi:10.1093/jn/86.3.281

Pritchard, R. H. and K. W. Bruns. 2003. Controlling variation in feed intake through bunk management. J. Anim. Sci. 81(E. Suppl. 2):E133-E188. doi:10.2527/2003.8114_suppl_2E133x

Proudfoot, K. L., D. M. Veira, D. M. Weary, and M. A. G. von Keyserlingk. 2009. Competition at the feed bunk changes the feeding, standing and social behavior of transition dairy cows. J. Dairy Sci. 92:3116-3123. doi:10.3168/jds.2008-1718

R Core Team. 2018. R: a language and environment for statistical computing. R foundation for statistical computing. Vienna, Austria. URL: http://www.r-project.org/.

Raun, N. S. and W. Burroughs. 1962. Suction strainer technique in obtaining rumen fluid samples from intact lambs. J. Anim. Sci. 21:454-457. doi:10.2527/jas1962.213454x

Reid, R., and N. Hinks. Studies on the carbohydrate metabolism of sheep. XVII. 1962. Feed requirements and voluntary feed intake in late pregnancy, with particular reference to prevention of hypoglycemia and hyperketonemia. Australian Journal of

Agricultural Research, 13(6):1092–1111. doi:10.1071/AR9621092.

Reynolds, C. K., P. C. Aikman, B. Lupoli, D. J. Humphries, and D. E. Beever. 2003. Splanchnic metabolism of dairy cows during the transition from late-gestation through early lactation. J. Dairy Sci. 86:1201-1217. doi:10.3168/jds.S0022-0302(03)73704-7.

Ruuska, S., W. Hämäläinen, A. Sairanen, E. Juuntinen, L. Tuomisto, M. Järvinen and J. Mononen. 2014. Can stealing cows distort the results of feeding trials? An experiment for quantification and prevention of stealing of feed by dairy cows from roughage intake control feeders. Appl. Anim. Behav. Sci. 159:1-8. doi:10.1016/j.applanim.2014.08.001.

Salinas-Chavira, J., E. Alvarez, M. F. Montano, and R.A. Zinn. 2013. Influence of forage NDF level, source and pelletizing on growth performance, dietary energetics, and characteristics of digestive function for feedlot cattle. Anim. Feed Sci. Technol. 183:106–115. doi:10.1016/j.anifeedsci.2013.05.004

Samuelson, K. L., M. E. Hubbert, M. L. Galyean, and C. A. Löest. 2016. Nutritional recommendations of feedlot consulting nutritionists: the 2015 new mexico state and texas tech university survey. J. Anim. Sci. 94:2648-2663. doi:10.2527/jas2016-0282.

Schwartzkopf-Genswein, K. S., S. S. Atwood, and T. A. McAllister. 2002. Relationship between bunk attendance, intake and performance of steers and heifers on varying feeding regimens. Appl. Anim. Behav. Sci. 76:179-188. doi:10.1016/S0168-1591(02)00009-6

Schwartzkopf-Genswein, K. S., K. A. Beauchemin, D. J. Gibb, D. H. Crews, D. D. Hickman, M. Streeter, and T. T. McAllister. 2003. Effect of bunk management on

feeding behaviour, ruminal acidosis and performance of feedlot cattle: a review. J. Anim. Sci. 81, E149-E158. doi:10.2527/2003.8114_suppl_2E149x.

Schwartzkopf-Genswein, K. S., D. D. Hickman, M. A. Shah, C.R. Krehbiel, B. M. A. Genswein, R. Silasi, D. G. Gibb, D. H. Crews, and T. A. McAllister. 2011. Relationship between feeding behavior and performance of feedlot steers fed a barley-based diets. J. Anim. Sci. 89:1180-1192. doi:10.2527/jas.2010-3007

Shaver, R. D. 2002. Rumen acidosis in dairy cattle: bunk management considerations. Pages 75–81 in Proc.12th Int. Symp. on Lameness in Ruminants. J. K. Shearer, ed. Orlando, FL

Short, F. J., P. Gorton, J. Wiseman, and K. N. Boorman. 1996. Determination of titanium dioxide added as an inert marker in chicken digestibility studies. Anim. Feed Sci. Technol. 59:215–221. doi:10.1016/0377-8401(95)00916-7

Stricklin, W. R. and H. W. Gonyou. 1981. Dominance and eating behavior of beef cattle fed from a single stall. Appl. Anim. Ethol. 7:135-140. doi:10.1016/0304-3762(81)90091-2

Suber, R. L., J. F. Hentges, J. C. Gudat, ang G. T. Edds. 1979. Blood and ruminal fluid profiles in carbohydrate-foundered cattle. Am. J. Vet. Res. 40:1005-1008. PMID: 41464.

Südekum, K. H., W. Ziggers, N. Roos, H. Sick, S. Tamminga, and M. Stangassinger. 1995. Estimating the passage rate of digesta in steers and wethers using the ratio of 13C and 12C and titanium(IV)-oxide. Isotopes Environ. Health Stud. 31:219-227. doi:10.1080/10256019508234020.

Sutton, J. D. 1979. Carbohydrate fermentation in the rumen – variations on a theme. Proceedings of the Nutrition Society. 38:275-281. doi:10.1079/PNS19790049

Swanson, K. C., Z. E. Carlson, M. C. Ruch, T. C. Gilbery, S. R. Underdahl, F. E. Keomanivong, M. L. Bauer, and A. Islas. 2017. Influence of forage source and forage inclusion level on growth performance, feeding behavior, and carcass characteristics in finishing steers. J. Anim. Sci. 95:1325-1334. doi:10.2527/jas2016.1157

Takahaski, E., Y. Uzuka, S. Tanabe, M. Satoh, and H. Furuoka. 2007. Serum amyloid A and haptoglobin levels in bovine amyloidosis. J. Vet. Med. Sci. 69(3):321-232. doi:10.1292/jvms.69.321.

Titgemeyer, E. C., C. K. Armendariz, D. J. Bindel, R. H. Greenwood, and C. A. Löest. 2001. Evaluation of titanium dioxide as a digestibility marker for cattle. J. Anim. Sci. 79:1059-1063. doi:10.2527/2001.7941059x

Tourlomoussis, P., P. D. Eckersall, M. M. Waterson, and S. Buncic. 2004. A comparison of acute phase protein measurements and meat inspection findings in cattle. Foodborne Pathogens and Disease. doi:10.1089/fpd.2004.1.281

Turgeon, D. A., Jr., D. R. Brink and R. A. Britton. 1983. Corn particle size mixtures, roughage level and starch utilization in finishing steer diets. J. Anim. Sci. 57:739-749. doi:10.2527/jas1983.573739x

Wagner, J. J., S. L. Archibeque, and D. M. Feuz. 2014. The modern feedlot for finishing cattle. Ann. Rev. Anim. Biosci. 2:535-54. doi:10.1146/annurev-animal-022513-114239.

Wang, Z., J. D. Nkrumah, C. Li, J. A. Basarab, L. A. Goonewardene, E. K. Okine, D. H. Crews Sr., and S. S. Moore. 2006. Test duration for growth, feed intake, and feed

efficiency in beef cattle using the growsafe system. J. Anim. Sci. 84:2289-2298. doi:10.2527/jas.2005-715

Weiss, W. P., Conrad, H. R. and St. Pierre, N. R. 1992. A theoretically-based model for predicting total digestible nutrient values of forages and concentrates. Anim. Feed Sci. Technol. 39: 95-110. doi:10.1016/0377-8401(92)90034-4

Werling, D., F. Sutter, M. Arnold, G. Kun, P. C. J. Tooten, E. Gruys, M. Kreuzer, and W. Langhans. 1996. Characterization of the acute phase response of heifers to a prolonged low dose infusion of lipopolysaccharide. Res. Vet. Sci. 61:252-257. doi:10.1016/S0034-5288(96)90073-9.

Wheeler, W. E., and C. H. Noller. 1976. Limestone buffers in complete mixed rations for dairy cattle. J. Dairy Sci. 59:1788–1793. doi:10.3168/jds.S0022-0302(76)84438-4

Wheeler, W. E., and C. H. Noller. 1977. Gastrointestinal tract pH and starch in feces of ruminants. J. Anim. Sci. 44:131-135. doi:10.2527/jas1977.441131x

Wiese, B. I., J. Campbell, S. Hendrick, and G. B. Penner. 2017. Ruminal pH, short-chain fatty acid concentrations, and serum acute phase protein concentrations during finishing for steers with and without rumen and liver pathology. Can. J. Anim. Sci. 97:581–589. doi:10.1139/cjas-2016-0212

Wilson, B. K., D. L. Step, C. L. Maxwell, J. J. Wagner, C. J. Richards, C. R. Krehbiel. 2015. Evaluation of multiple ancillary therapies used in combination with an antimicrobial in newly received high-risk calves treated for bovine respiratory disease. J. Anim. Sci. 93:3661-3674. doi:10.2527/jas.2015-9023

Wise, W. B., R. W. Harvey, B. R. Haskins and E. R. Barrick. 1968. Finishing beef cattle on all concentrate rations. J. Anim. Sci. 27:1449. doi:10.2527/jas1968.2751449x

Woolsoncroft, M. A., M. E. Youngers, L. J. McPhillips, C. G. Lockard, C. L. Haviland, E. S. DeSocio, W. R. Ryan, C. J. Richards, and B. K. Wilson. 2018. Effects of exercise and roughage source on the health and performance of receiving beef calves. P. Anim. Sci. 34:183-191. doi:10.15232/pas.2017-01673.

Yang, W. Z., K. A. Beauchemin, and L. M. Rode. 2002. Effects of particle size of alfalfa-based dairy cow diets on site and extent of digestion. J. Dairy Sci. 85:1958–1968. doi:10.3168/jds.S0022-0302(02)74272-0

Yang, W. Z., and K. A. Beauchemin. 2006. Increasing the physically effective fiber content of dairy cow diets may lower efficiency of feed use. J. Dairy. Sci. 89:2694–2704. doi:10.3168/jds.S0022-0302(06)72345-1

Zebeli, Q., J. R. Aschenbah, M. Tafaj, J. Boguhn, B. N. Ametaj, and W. Drochner. 2012. Invited review: role of physically effective fiber and estimation of dietary fiber adequacy in high-producing dairy cattle. J. Dairy Sci. 95:1041-1056. doi:10.3168/jds.2011-4421

Zinn, R. A. 1986. Influence of forage level on response of feedlot steers to salinomycin supplementation. J. Anim. Sci. 63:2005-2012. doi:10.2527/jas1986.6362005x

Zinn, R. A., A. Plascencia, and R. Barajas. 1994. Interaction of forage level and monensin in diets for feedlot cattle on growth performance and digestive function. J. Anim. Sci. 72:2209-2215. doi:10.2527/1994.7292209x

APPENDICES

Appendix 1. R Code

```
## Feed Bunk Preference R code

##Location of data files and package loading
setwd("C:/Users/knpierc/Google Drive/Pierce, Kaitlyn/RawData")
library(tidyverse)

## Accumulate the data files
path <- "Raw Data Files/"

## Sets the data directory
data_dir <- list.files(path, pattern = ".DAT")

data <- NULL

for(file in data_dir) {
    this.data <- read_csv(paste(path, file, sep=""), col_names = FALSE,
                          col_types = cols(.default = col_character()))
    this.date <- substr(paste(file), 3, 8)
    this.date <- paste("20", this.date, sep="")
    this.date <- as.Date(this.date, '%Y%m%d')
    this.data$date <- this.date
    data <- rbind(data, this.data)
}

rm(this.data, this.date, data_dir, file, path)

## Labeling the data file columns to clean and analyze data
names(data) <- c("eid","tag","bunk","starttime","endtime","duration",
"beg.wt","end.wt","diet","wt.diff","blank","intake","blank2","blank3",
"blank4","blank5","date")

## Removing the extra columns and cleaning up the data
data <- data %>%
    select(-blank, -blank2, -blank3, -blank4, -blank5) %>%
    select(date, everything())

data <- data %>%
    filter(!tag %in% c("123456", "106"))

## Sets the time zones, dates of the trial, and starts to organize the
feedings in the data files into formats R can read
```

```
data <- data %>%
    mutate(starttime = ifelse(nchar(starttime) == 7, paste("0",
starttime, sep=""), starttime)) %>%
    mutate(endtime = ifelse(nchar(endtime) == 7, paste("0", endtime,
sep=""), endtime)) %>%
    mutate(starttime = paste(date, starttime)) %>%
    mutate(starttime = as.POSIXct(starttime, '%Y-%m-%d %h:%m:%s')) %>%
    mutate(endtime = as.POSIXct(paste(date,endtime),'%Y-%m-%d
%h:%m:%s')) %>%
    mutate(duration = endtime - starttime,
           beg.wt = as.numeric(beg.wt), end.wt = as.numeric(end.wt))%>%
    mutate(wt.diff = beg.wt - end.wt) %>%

mutate(bunk = as.numeric(bunk)) %>%
    arrange(bunk, starttime) %>%
    group_by(bunk) %>%
    mutate(lag.bunk.wt.diff = lag(end.wt) - beg.wt) %>%
    ungroup() %>%
    mutate(feed.amount = (pmin(wt.diff, lag.bunk.wt.diff))*-1) %>%
    mutate(tag = ifelse(feed.amount > 5, "feed", tag)) %>%
    mutate(feed.amount = ifelse(feed.amount > 5, feed.amount, NA)) %>%
    filter(tag != "0") %>%
    mutate(time.of.day =
as.numeric(starttime - trunc(starttime,"days"))) %>%
    filter(!(tag == "feed" & time.of.day > 1200)) %>%
    filter(date < as.Date("2019-05-31"))

## Set the definitions of intake and visits
data <- data %>%
    mutate(intake = ifelse(wt.diff < 0, 0, wt.diff)) %>%
    mutate(visit = ifelse(duration >= 5, 1, 0))

## Determine which feeding of the day each visit is in
data <- data %>%
    group_by(bunk, date) %>%
    mutate(feed.event.counter = ifelse(tag == "feed", 1, 0)) %>%
    mutate(feeding = cumsum(feed.event.counter)) %>%
    ungroup() %>%
    mutate(feeding = ifelse(feeding == 0, 3, feeding)) %>%
    select(-feed.event.counter)

## Assign a week number to the data to be used for later analysis
data <- data %>%
    filter(date >= as.Date("2019-02-18")) %>%
    mutate(week = as.numeric(date - as.Date("2019-02-18")) / 7) %>%
    mutate(week = floor(week))

## Update bunk numbering to the new system ##
```

```
# System updated halfway into trial and changed the bunk numbering so
this will correct for the change and allow all the data to be analyzed
correctly
cutoff.time <- as.POSIXct("2019-04-01 11:26:45 GMT")

data <- data %>%
    mutate(bunk = case_when(
        starttime <= cutoff.time & bunk == 1 ~ 1,
        starttime <= cutoff.time & bunk == 2 ~ 2,
        starttime <= cutoff.time & bunk == 3 ~ 3,
        starttime <= cutoff.time & bunk == 4 ~ 4,
        starttime <= cutoff.time & bunk == 5 ~ 5,
        starttime <= cutoff.time & bunk == 6 ~ 6,
        starttime <= cutoff.time & bunk == 9 ~ 7,
        starttime <= cutoff.time & bunk == 10 ~ 8,
        starttime <= cutoff.time & bunk == 11 ~ 9,
        starttime <= cutoff.time & bunk == 12 ~ 10,
        starttime <= cutoff.time & bunk == 13 ~ 11,
        starttime <= cutoff.time & bunk == 14 ~ 12,
        starttime <= cutoff.time & bunk == 15 ~ 13,
        starttime <= cutoff.time & bunk == 16 ~ 14,
        starttime <= cutoff.time & bunk == 17 ~ 15,
        starttime <= cutoff.time & bunk == 18 ~ 16,
        starttime <= cutoff.time & bunk == 19 ~ 17,
        starttime <= cutoff.time & bunk == 20 ~ 18,
        starttime <= cutoff.time & bunk == 23 ~ 19,
        starttime <= cutoff.time & bunk == 24 ~ 20,
        starttime <= cutoff.time & bunk == 25 ~ 21,
        starttime <= cutoff.time & bunk == 26 ~ 22,
        starttime <= cutoff.time & bunk == 27 ~ 23,
        starttime <= cutoff.time & bunk == 28 ~ 24,
        TRUE ~ bunk
    ))
rm(cutoff.time)

# Labeled the pens in the trial by labeling the bunks within the pen
with the same pen #
data <- data %>%
    mutate(pen = case_when(
        bunk %in% c(1:6) ~ "1" ,
        bunk %in% c(7:12) ~ "2" ,
        bunk %in% c(13:18) ~ "3" ,
        bunk %in% c(19:24) ~ "4"
    ))

# Set the dates of each period for analysis
## this creates 2 days in week 13 that are in test, and 5 in
restriction
data <- data %>%
```

```
    mutate(period = case_when(
   date %in% c(as.Date("2019-02-12"):as.Date("2019-02-17")) ~
"adaptation",
   date %in% c(as.Date("2019-02-18"):as.Date("2019-03-17")) ~
"transition",
   date %in% c(as.Date("2019-03-18"):as.Date("2019-05-21")) ~ "test",
   date %in% c(as.Date("2019-05-22"):as.Date("2019-05-30")) ~
"restriction"
    ))
## weeks summary
weeks <- data %>%
    select(date, week, period) %>%
    distinct() %>%
    arrange(date)

## week corrections and creates a 2 d skip at the end of the test
period, then a 7 d restriction period. Bunk programming inaccurate
during the 2 d anyway
data <- data %>%
    filter(date!= as.Date("2019-05-20")) %>%
    filter(date!= as.Date("2019-05-21")) %>%
    filter(date!= as.Date("2019-05-29")) %>%
    filter(date!= as.Date("2019-05-30")) %>%
    mutate(week = ifelse(period == "restriction", 13, week))

# Sort out the feeding data
feed.data <- data %>% filter(tag == "feed")

# How many feedings occur each day
feeding.summary <- feed.data %>%
    group_by(bunk, date) %>%
    summarize(sum = sum(feed.amount),
              count = n()) %>%
    ungroup()

# Plotting the summaries for visualization
ggplot(feeding.summary, aes(date, count)) + geom_line() +
facet_wrap(~bunk)
ggplot(feeding.summary, aes(date, sum)) + geom_line() +
facet_wrap(~bunk)

#Filtering out erroneous data points
bunk.days.to.delete <- feeding.summary %>%
    filter(count > 4 | sum > 150) %>%
    mutate(bunk.date = paste(bunk, date))

############################
##  remove days that something bad happened
############################
```

```
data <- data %>%
    mutate(bunk.date = paste(bunk, date)) %>%
    filter(!bunk.date %in% bunk.days.to.delete$bunk.date)

feed.data <- feed.data %>%
    mutate(bunk.date = paste(bunk, date)) %>%
    filter(!bunk.date %in% bunk.days.to.delete$bunk.date)

## also filter out feed events and "non visits"
data <- data %>%
    filter(visit == 1) %>%
    filter(tag != "feed" )

### Ploting when feeding events occured
ggplot(feed.data, aes(time.of.day, bunk)) + geom_point(alpha = 0.3) +
    xlim(0, 1440)

### Show how much feed was fed in each feeding
  # Added labels to graph for publication and presentations#
feedings <- feed.data %>%
    group_by(bunk, feeding) %>%
    summarize(feed.amount = sum(feed.amount)) %>%
ggplot(aes(bunk, feed.amount, fill = as.factor(feeding))) + geom_col()
+ labs(x= 'Feedbunk', y='Total amount of feed, kg', fill='Feeding')
feedings + coord_cartesian(xlim = c(0,25), ylim = c(1000, 10000))

#### Getting back to intake, clean the data to clarify feeding events
ggplot(data %>% filter(pen == "1"), aes(x=starttime, y= wt.diff, color=
as.factor(bunk))) + geom_line()

ggplot(data %>% filter(pen == "1"), aes(x=starttime, y=intake, color =
as.factor(bunk))) + geom_line()

ggplot(feed.data %>% filter(pen == "1"), aes(x=starttime,
y=feed.amount, color = as.factor(bunk))) + geom_line()

ggplot(data, aes(wt.diff)) + stat_ecdf()

# Plot of amount of feed put into the feed bunk, scaled for publication
and presentation
ggplot(feed.data, aes(feed.amount)) + stat_ecdf() + labs(x='Feed, kg',
y='Percentage of feed in the feedbunk') + scale_y_continuous(labels =
scales::percent) + scale_x_continuous(limits = c(0, 100))

# Total amount of feed intake per day.
ggplot(data, aes(intake)) + stat_ecdf() +
  labs(x='Feed, kg', y='Percentage of animals') +
  scale_y_continuous(labels = scales::percent)
```

```
# Determining meal size
quantile(data$intake)
# Max meal size = 25.9 kg

# Setting meal size by filtering out intakes over or under 99.5% of the
total feedings
max.meal.size <- quantile(data$intake, 0.995)
data <- data %>% filter(intake <= max.meal.size)
quantile(data$intake)
# After filtering -> Max meal size = 3.7 kg

# Meal duration. scaled for presentataions and publication
ggplot(data, aes(duration)) + stat_ecdf() +
  labs(x='Meal Duration, sec', y='Percentage of animals') +
scale_y_continuous(labels = scales::percent) +
scale_x_continuous(limits = c(0,2000))
quantile(data$duration)

# Graphs to visualize amount of intake per feeding
ggplot(data %>% filter(pen == 1 & tag == "117") %>% arrange(tag, date,
feeding), aes(date, intake, fill = feeding)) + geom_bar(stat =
"identity") + facet_wrap(~tag)
ggplot(data %>% filter(pen == 2), aes(date, intake, color = feeding)) +
geom_bar(stat = "identity") + facet_wrap(~tag)
ggplot(data %>% filter(pen == 3), aes(date, intake, color = feeding)) +
geom_bar(stat = "identity") + facet_wrap(~tag)
ggplot(data %>% filter(pen == 4), aes(date, intake, fill =
as.factor(feeding))) + geom_bar(stat = "identity") + facet_wrap(~tag)

# Graphs to visualize intake variation per feeding
## Random Animal ID selected for presentations
ggplot(data %>% filter(pen == 4 & tag == 180), aes(date,intake, fill=
as.factor(feeding))) + geom_bar(stat = "identity")
ggplot(data %>% filter(pen == 3 & tag == 115), aes(date,intake, fill=
as.factor(feeding))) + geom_bar(stat = "identity") + facet_wrap(~tag)
ggplot(data %>% filter(pen == 2 & tag == 203), aes(date, intake, fill =
as.factor(feeding))) + geom_bar(stat = "identity") + facet_wrap(~tag)
ggplot(data %>% filter(pen == 1 & tag == 238), aes(date, intake, fill =
as.factor(feeding))) + geom_bar(stat = "identity") + facet_wrap(~tag)

## Daily intake summary
summary.day <- data %>%
    group_by(tag, date) %>%
    summarize(intake = sum(intake),
              visits = n(), duration.total = sum(duration)) %>%
    ungroup()

## Weekly intake summary
summary.week <- data %>%
```

```
    group_by(tag, week) %>%
    summarize(intake = sum(intake),
              visits = n(), duration.total = sum(duration)) %>%
    ungroup()

## Period intake summary
summary.period <- data %>%
    group_by(tag, period) %>%
    summarize(intake = sum(intake),
              visits = n(), duration.total = sum(duration)) %>%
    ungroup()

## Bunk intake summary during transition period
summary.bunk.transition <- data %>%
    filter(period == "transition") %>%
    group_by(tag, period, pen, bunk) %>%
    summarize(intake = sum(intake),
              visits = n(), duration.total = sum(duration)) %>%
    ungroup() %>%
    mutate(duration.mean = duration.total / visits,
           intake.mean = intake / 6)

# Bunk intake summary during Bunk Preference Test period
summary.bunk.test <- data %>%
    filter(period == "test") %>%
    group_by(tag, period, pen, bunk) %>%
    summarize(intake = sum(intake),
              visits = n(), duration.total = sum(duration)) %>%
    ungroup() %>%
    mutate(duration.mean = duration.total / visits,
           intake.mean = intake / 6)

# Determined summary of each bunk per week of the Bunk Preference Test
period
summary.bunk.week <- data %>%
    filter(period == "test" ) %>%
    group_by(tag, pen, bunk, week) %>%
    summarize(intake = sum(intake),
              visits = n(), duration.total = sum(duration)) %>%
    ungroup() %>%
    mutate(duration.mean = duration.total / visits,
           intake.mean = intake / 6)

# Graph of pen 1 total intake divided up by feed bunk attended
ggplot(summary.bunk.week %>% filter(pen == "1"), aes(tag, intake),
color = bunk) + geom_col(aes(fill = as.character(bunk)))
## Graph of only a couple animals in a pen to see differences more
clearly##
# Graph for presentation and publication
```

```
bunks <- ggplot(summary.bunk.week %>% filter(pen == "1" & tag ==
c("117", "158", "201", "212", "231", "238")), aes(tag, intake), color =
bunk)+
geom_col(aes(fill = as.character(bunk)))+ xlab("Tag number")+
ylab("Total intake, kg")
bunks + scale_fill_discrete(name = "Bunk number")

## Feeding summary
summary.feeding <- data %>%
    group_by(tag, feeding, pen) %>%
      summarize(intake = sum(intake), visits = n(),
      duration.total = sum(duration)) %>%
    ungroup()
# Graph of total intake per feeding
ggplot(summary.feeding %>% filter(pen == "1"), aes(tag, intake), color
= feeding) + geom_col(aes(fill = as.character(feeding)))

 ## Preferred Bunk for intake summary
fav.bunk.intake <- summary.bunk.test %>%
    select(tag, bunk, intake) %>%
    arrange(tag, desc(intake)) %>%
    group_by(tag) %>%
    slice(1) %>%
    ungroup() %>%
    rename(fav.bunk.for.intake = bunk, fav.bunk.intake = intake) %>%
    left_join(summary.period) %>%
    filter(period == "test" ) %>%
    mutate(fav.bunk.intake.percentage = fav.bunk.intake / intake)

write.csv(fav.bunk.intake, "fav.bunk.intake.csv")

fav.bunk.intake.week.single <- summary.bunk.week %>%
    select(tag, bunk, intake, week) %>%
    arrange(tag, week, desc(intake)) %>%
    group_by(tag, week) %>%
    slice(1) %>%
    arrange(tag, week) %>%
    ungroup() %>%
    rename(fav.bunk.for.intake = bunk, fav.bunk.intake = intake) %>%
    left_join(summary.week) %>%
    mutate(fav.bunk.intake.percentage = fav.bunk.intake / intake) %>%
    arrange(tag, week)

fav.bunk.intake.week <- summary.bunk.week %>%
    select(tag, bunk, intake, week) %>%
    arrange(tag, week, desc(intake)) %>%
    group_by(tag, week) %>%
    slice(1:2) %>%
    arrange(tag, week) %>%
```

```
    ungroup() %>%
    rename(fav.bunk.for.intake = bunk, fav.bunk.intake = intake) %>%
    left_join(summary.week) %>%
    mutate(fav.bunk.intake.percentage = fav.bunk.intake / intake)

write.csv(fav.bunk.intake.week, "fav.bunk.intake.week.csv")

unique.tags <- unique(data$tag) %>% sort()
unique.tags.A <- head(unique.tags, 62)
unique.tags.B <- tail(unique.tags, 62)

# Plot of each animal's perferred bunk for each week of the trial
# Used this to determine which feed bunk to restrict for the 7 d
Restriction period
ggplot(fav.bunk.intake.week.single %>% filter(fav.bunk.for.intake %in%
c(1:6)), aes(tag, week, color = as.factor(fav.bunk.for.intake))) +
geom_col(width = 0.3, position = "fill" , alpha = 0.7) + coord_flip() +
geom_text(aes(label=fav.bunk.for.intake), size = 3, hjust=.1, vjust=.1)

# Plot of Preferred bunk percentage vs total intake
ggplot(fav.bunk.intake, aes(intake, fav.bunk.intake.percentage)) +
geom_point() + stat_smooth(method = "lm", col = "orange") + xlab("Total
intake, kg") + ylab("Percentage of intake from preferred bunk") +
scale_y_continuous(labels = scales::percent)

# Plot of Preferred bunk percentage vs total intake
#scaled to 60% for publication and presentation
ggplot(fav.bunk.intake, aes(intake, fav.bunk.intake.percentage)) +
geom_point() + stat_smooth method = "lm", col = "orange") + xlab("Total
intake, kg") + ylab("Percentage of intake from preferred bunk") +
scale_y_continuous(labels = scales::percent, limits = c(0,.6))

# Plot of percentage of intake from preferred bunk vs the percentage of
animals with labels for presentation and publication
ggplot(fav.bunk.intake, aes(fav.bunk.intake.percentage)) + stat_ecdf()
+ ylab("Percentage of animals") + xlab("Percentage of intake from
preferred bunk") + geom_vline(xintercept = 1/6, color = "orange") +
xlim(0,1) + scale_x_continuous(labels = scales::percent, limits =
c(0,1)) +
scale_y_continuous(labels = scales::percent)+ theme(axis.line.x =
element_line(color="black", size = 1), axis.line.y =
element_line(color="black", size = 1))

# Quantile of intake from perferred bunk vs preferred bunk intake
percentage
quantile(fav.bunk.intake$fav.bunk.intake.percentage)

# Quantile of intake from perferred bunk vs preferred bunk intake
percentage. 80% of the previous quantile
```

```r
quantile(fav.bunk.intake$fav.bunk.intake.percentage, 0.8)

## Summary of Preferred bunk for visits
fav.bunk.visits <- summary.bunk.test %>%
    select(tag, period, bunk, visits) %>%
    arrange(tag, desc(visits)) %>%
    group_by(tag, period) %>%
    slice(1) %>%
    ungroup() %>%
    rename(fav.bunk.for.visits = bunk, fav.bunk.visits = visits) %>%
    left_join(summary.period) %>%
    mutate(fav.bunk.visit.percentage = fav.bunk.visits / visits)

# Plot of percentage of visits to preferred bunk vs the total number of
visits to the feed bunk
ggplot(fav.bunk.visits, aes(visits, fav.bunk.visit.percentage)) +
geom_point() + ylab("Percentage of visits to animal's preferred bunk")
+ xlab("Total number of visits") + scale_y_continuous(labels =
scales::percent

# Plot of percentage of visits to preferred bunk vs the total number of
visits to the feed bunk. Scaled to 50% for presentation and publication
ggplot(fav.bunk.visits, aes(visits, fav.bunk.visit.percentage)) +
geom_point() + ylab("Percentage of visits to animal's preferred bunk")
+ xlab("Total number of visits") + scale_y_continuous(labels =
scales::percent, limits = c(0,.5))

# Plot of percentage of visits to preferred bunk vs the percentage of
total visits with labels for presentation and publication
ggplot(fav.bunk.visits, aes(fav.bunk.visit.percentage)) + stat_ecdf() +
ylab("Percentage of total visits") + xlab("Percentage of visits from
the animal's preferred bunk") + geom_vline(xintercept = 1/6, color =
"orange") + scale_x_continuous(labels = scales::percent, limits = c(0,
.7)) +  scale_y_continuous(labels = scales::percent) +
theme(axis.line.x = element_line(color="black", size = 1), axis.line.y
= element_line(color="black", size = 1))

# Quantile of visits to perferred bunk vs percentage of visits to
preferred bunk
quantile(fav.bunk.visits$fav.bunk.visit.percentage)

### model intake or performance
summary(lm(intake ~ fav.bunk.intake.percentage, fav.bunk.intake))
summary(lm(visits ~ fav.bunk.intake.percentage, fav.bunk.intake))
summary(lm(adg ~ fav.bunk.intake.percentage, fav.bunk.intake))
summary(lm(gf ~ fav.bunk.intake.percentage, fav.bunk.intake))

fav.bunk.intake.matrix <- fav.bunk.intake %>%
    select(-tag, -period, -fav.bunk.for.intake) %>%
```

```
    mutate(visits = as.numeric(visits),
    duration.total = as.numeric(duration.total)) %>%
    as.matrix()
cor(fav.bunk.intake.matrix, use="complete.obs", method="kendall")

#########################################################################
##### ADG & G:F
## Datafile for BW, ADG and G:F read into R
data.wt.long <- readxl::read_excel("BW and ADG data.xlsx", sheet =
"RRData") %>%
    rename(tag = New) %>%
    mutate(tag = as.character(tag)) %>%
    gather(date, wt, 2:8) %>%
    mutate(date = as.Date(as.numeric(date), origin = "1900-01-01"))

# Plot of BW from begining to end of experiment, as expected there was
a linear increase in BW
ggplot(data.wt.long, aes(x = date, y = wt, group=tag)) + geom_line()

# Calculating the ADG of each steer from the beginning of the
Transition to the end of experiment
data.wt.wide <- data.wt.long %>% spread(date, 3) %>%
    mutate(gain = `2019-05-14`- `2019-03-23`,
           dof = as.Date("2019-05-14") - as.Date("2019-03-23"),
           adg = gain/as.numeric(dof)
    )

# Calculates the G:F for each steer
summary.tag <- fav.bunk.intake %>%
    left_join(data.wt.wide) %>%
    mutate(`g:f` = adg/(intake/60))

#Summaries of the linear models for each input vs percentage of intake
from preferred bunk
summary(lm(adg ~ fav.bunk.intake.percentage + `2019-03-23`,
summary.tag))
summary(lm(`g:f` ~ fav.bunk.intake.percentage + `2019-03-23`,
summary.tag))
summary(lm(intake ~ fav.bunk.intake.percentage + `2019-03-23`,
summary.tag))

## G:F plot against bunk preference
library(readxl)
G_to_F <- read_excel("G to F.xlsx")
attach(G_to_F)
data.feed <- data.frame(G_to_F, fav.bunk.intake)
      mutate(Gain = as.numeric(Gain))

# Plot of percentage of intake from preferred bunk vs G:F
```

```
ggplot(data.feed, aes(Gain, fav.bunk.intake.percentage)) + geom_point()
+
 xlab("G:F, lbs") + ylab("Percentage intake from preferred bunk") +
scale_y_continuous(labels = scales::percent, limits = c(0,.6)) +
scale_x_discrete(breaks=c(NA,"0.18"))

feed <- ggplot(data.feed, aes(Gain, fav.bunk.intake.percentage)) +
geom_point() + stat_smooth(method = "lm", formula = y ~ x, col =
"orange") +
xlab("G:F, lbs") + ylab("Percentage intake from preferred bunk")

#The previous G:F graph for publication with percentages and labels
feed + theme(axis.line.x = element_line(color="black", size = 1),
axis.line.y
= element_line(color="black", size = 1)) + scale_y_continuous(labels =
scales::percent, limits = c(0,.6)) +
scale_x_discrete(breaks=c(NA,"0.18"))
```

VITA

Kaitlyn Nichole Pierce

Candidate for the Degree of

Master of Science

Thesis: DETERMINING THE EXISTENCE OF BUNK PREFERENCE IN AN AUTOMATED INDIVIDUAL INTAKE SYSTEM AND THE EFFECTS OF INCREASED ROUGHAGE LATE IN THE FINISHING PERIOD ON FEEDLOT STEER PERFORMANCE, INTAKE, AND EFFICIENCY

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