UTLIZING FEEDING AND BEHAVIOR TECHNOLOGIES IN CONFINEMENT CATTLE

A Thesis

by

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ABSTRACT

The objectives of the first study were to evaluate the effects of direct-fed microbials (DFM) with or without monensin plus tylosin on the performance, feeding behavior patterns and feed efficiency of steers transitioned to a high-concentrate diet. Crossbred steers were randomly assigned to 1 of 4 treatments (n = 32) in a 2 x 2 factorial design, with Factor 1 being diets with DFM (25 g/d; Natur's Way) or without DFM (**CON**), and Factor 2 being diets with monensin (40 g/ton) and tylosin (10 g/ton; **MON**) or without MON (**CON**). During the grower/transition period, MON-fed steers had 9.5% higher ($P < 0.05$) ADG, and improved F:G (7.8 vs 8.94; $P = 0.06$) and RFI (-0.28 vs 0.27 kg/d; $P < 0.01$) vs those not supplemented MON. DFM-fed steers had lower ($P < 0.01$) ADG than non DFM-fed steers and tended ($P < 0.09$) to have a higher RFI. Daily variances of bunk-visit and meal event frequencies were reduced ($P < 0.01$) in MON-fed steers vs those fed diets without MON during the grower/transition period.

There were MON x DFM interactions ($P < 0.10$) for ADG and F:G during the finisher period. Numerically, steers had a 4.7% lower F:G when the MON diet without DFM was fed, whereas, F:G was higher in steers fed the MON diet containing DFM. During the finisher period, steers fed MON diets had lower (P < 0.01) DMI and lower RFI ($P < 0.01$; -0.23 vs 0.23 kg/d). Conversely, DFM-fed steers had higher RFI ($P < 0.01$) compared to respective controls. The steers fed the MON diets consumed 6.7% less DMI, spent 9% more ($P < 0.05$) time consuming meals, and thus had 14% slower ($P < 0.01$) meal eating rates than steers fed diets without monensin.

The objectives of the second study were to evaluate and validate the sensitivities, specificities and accuracies of an ultra-wideband radio frequency identification system (**RFID**) system to measure the frequency and duration of bunk visit (**BV**) events and brush usage (**BU**) events. For the first trial, 4 algorithms were developed to quantify the frequency and duration of BV events by recording the timestamps for the start and end of each BV event. A virtual line was established that ran parallel to the edge of the feed bunk, defined at the 0-cm line. Additional virtual lines were established that ran parallel with the 0-cm virtual line at 0, 5, 10, and 15 cm from the edge of the feed bunk to define the end of a BV event. The algorithms were compared to determine the most accurate algorithm for recording BV events. The 0-10 cm in-and-out algorithm had the highest r^2 values of 0.81 and 0.91 for frequency and duration of BV events, respectively, with the overall accuracy of BV presence and absence being 85.9%. For the second trial, 4 algorithms were developed to quantify frequency and duration of BU events by recording the timestamps for the start and end of each BU event. The 4 algorithms evaluated had x-y dimensions of 90 x 90, 120 x 120, 150 x 150 and 180 x 180 cm surrounding the brush. The 150 x 150 cm algorithm had the highest r^2 values of 0.73 and 0.79 of frequency and duration of BU events, respectively, with the overall accuracy of BU presence and absence being 76.1%. The ultra-wideband RFID geolocation system was able to accurately measure BV events; More research is warranted to determine if the accuracy of the system for BU usage can be improved.

DEDICATION

To Mom and Dad,

For always encouraging me,

Sit tall in the saddle, hold your head up high

Keep your eyes fixed where the trail meets the sky

And live like you ain't afraid to die

And don't be scared, just enjoy your ride

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Data from Chapter II was composited from a trial conducted from 2018-2019 by PI Gordon Carstens, with cattle provided by the AgriLife McGregor Research Station in McGregor, Texas. The analysis depicted in Chapter III was collected in collaboration with AllTraq of Oklahoma City, Oklahoma.

All work conducted for this thesis was completed by the student independently.

NOMENCLATURE

AAE	average absolute error
ADF	acid detergent fiber
ADG	average daily gain
AFD	average feed disappearance
BRD	bovine respiratory disease
BU	brush usage
BV	bunk visit
BW	body weight
$BW^{0.75}$	metabolic body weight
CCC	concordance correlation coefficient
d	day
DDG	dried distillers’ grain
DFM	direct-fed microbials
DM	dry matter
DMI	dry matter intake
F:G	feed:gain
h	hour
HD	head down
min	minute
MSEP	mean square error of prediction
NEg	net energy for gain

NEm	net energy for maintenance
NFI	non-feeding interval
R^2	correlation value
RFI	residual feed intake
RFID	radio frequency identification
RMSE	root mean square error
s	second
SD	standard deviation
SE	standard error
TDN	total digestible nutrients
TTB	time to bunk

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CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

Bovine respiratory disease (BRD) is the most common disease affecting beef cattle. The accuracy of visual observation of clinical signs for detection of BRD in feedlot cattle by pen riders has been reported to be only 27% (Timisit et al., 2016). As cattle are prey animals, the reliance on subjective observations of illness signs is unreliable, since cattle will attempt to mask the outward clinical signs of disease or injury. Thus, the utility of visual observations to detect illness is limited.

Ultra-wideband radio frequency identification (RFID) tags have been previously utilized to monitor feeding behavior traits to allow for the identification of more efficient and productive animals (Chapinal et al. 2007; Mendes et al., 2011). Validation of these new systems is vital to effectively implementing them into the feedlot industry, but as most feedlots monitor feed intake based upon a pen average, rather than on an individualized animal basis, there is potential for these systems to provide an economical benefit to the producer.

Additionally, as BRD is one of the leading causes of death in feeder cattle at 16.2%, quickly identifying these morbid animals is fundamental for a positive net return to feedlot managers (USDA, 2011). By implementing environmental enrichment techniques, not only does the welfare of the animal improve, but there is also potential for using those behavior patterns to more quickly recognize the onset of illness due to differences in these behavior patterns (Toaff-Rosenstein and Tucker, 2018).

Lastly, another potential strategy to maximize animal production to feed the ever growing population is to integrate new feeding technologies such as feed additives to improve feed efficiency. An emphasis on disease prevention rather than treatment has emerged, thus research into naturally occurring feed additives has become more common in recent years. By monitoring individual-animal behavior and evaluating the effects of new feed additives, the beef industry will continue to become more efficient without reducing production.

Predicting feeding behavior patterns in feedlot cattle

Feeding behaviors have been evaluated in order to better understand mechanisms associated with inter-variation in feed efficiency among cattle (Lancaster et al., 2009). Several RFID-based feed-intake systems have been developed involving feed alleys (DeVries et al., 2003), feed bunks with a barrier gate (Chapinal et al., 2007), and the unrestrictive system C-lock bunks (Mendes et al., 2011), which allow for mass collection of data without excess labor. Feeding efficiency in cattle has been identified as the correlation between intake and output, with more efficient cattle consuming less feed but exhibiting more overall growth (Haskell et al., 2018). Residual feed intake (RFI) is the difference between the amount of feed an animal is expected to consume based on its nutritional requirements and its actual intake as compared to others in its group with similar rates of gain (Archer et al., 1999 and Koch et al., 1963). Low RFI animals are therefore more efficient and desirable, as they consume less than expected while maintaining performance. Cattle with a lower RFI value have been shown to have a shorter bunk duration (Basarab et al., 2007; Durunna et al., 2011; Lancaster et al., 2009;

Nkrumah et al., 2007) and fewer feeding events (Duranna et al., 2011; Golden et al., 2008; Kelly et al., 2010; Lancaster et al., 2009; Nkrumah et al., 2007). Beyond feeding behavior, cattle that walk more per day inside the pen have been shown to have higher RFI value (Llonch et al., 2018). When looking to determine the feed efficiency of cattle, automatic feed bunks are utilized, along with an RFID tag placed in the ear, to record the amount of feed that disappears when an animal consumes a meal. Other behaviors can be recorded with these technologies and analyzed to determine the overall efficiency of an individual animal. The GrowSafe® system (Airdrie, Alberta, Canada) is a specific electronic feeding system that allows cattle to be housed and fed in groups without the use of a barrier or gate. This system is paired with an RFID tag that registers and collects data when an animal enters the bunk and begins a feeding event.

Other RFID technologies include electronic accelerometer RFID tags and water intake systems, which monitor feeding behavior, rumination, and water intake behaviors (Chapinal et al., 2007; Wolfger et al., 2015). These technologies are vital in determining the feeding behaviors and overall efficiencies of cattle on an individual basis being housed in group pens. A new RFID tag is currently being researched to determine its accuracy in evaluating feeding behavior, water intake, and exploitation of luxury resources in the animal's environment. These methods are being studied to potentially assess cattle health and allow for quicker recognition of compromised animals. Furthermore, using feeding behaviors to identify cattle infected with bovine respiratory disease has been researched (Quimby et al., 2001), as visual identification of these animals is difficult and morbid cattle may be past the point of responding to antimicrobial treatments once exhibiting clinical symptoms.

History of RFID systems

Across the studies listed, validation of RFID systems has been crucial in determining the precision of these technologies in predicting feeding behaviors. Over the years, research has varied in evaluating the accuracy of these systems. Specifically, GrowSafe® has been shown in Schwartzkopf-Genswein et al. (1999) to have a statistical difference between observed video data and recordings from the GrowSafe® system. This was attributed to two separate inconsistencies on the GrowSafe® system with either a failure to record an animal that approached the bunk or recording an animal when there was no animal at the bunk (Schwartzkopf-Genswein et al., 1999). Although no feeding behavior data was recorded beyond frequency and duration of bunk visits, if there had been data collection, it would have to have been discarded due to unaccounted inaccuracies within the system. This study recognized the value of the newer GrowSafe® system as compared to its more restrictive counterparts, such as the Calan gate system. The GrowSafe® system allows animals to be housed in groups and given unrestricted access to feed. The main limitation to the system is that only one animal may approach each individual bunk at a time. Load cells measure feed loss for each bunk visit and that information is stored within the GrowSafe® system. Due to the inconsistencies, advice was given to future researchers about the placement of the RFID tags and metal rods used in pens, as these may have been the cause of the inconsistencies between the observed data and the GrowSafe® recordings.

In contrast, more recent studies (Mendes et al., 2011; Sowell et al., 1998) have validated the GrowSafe® system and its usefulness in recording feeding behavior data for animals housed in group pens. Once feeding behavior data was obtained, these traits were regressed to evaluate the accuracy of the GrowSafe® system (Mendes et al., 2011). In these studies, the GrowSafe® system was shown to be a valid data recording system. As validation of the data collecting system is vital to predicting feed efficiency, accuracy needed to be evaluated first. Chapinal et al. (2007) also looked into validating a group housed feeding and water intake system. Like GrowSafe®, the Insentec® monitoring system (Insentec®, Marknesse, the Netherlands) records feed intake data as well as water intake. Unlike its competitor, Insentec® raises and lowers a barrier each time an animal comes up to a bunk or water trough to prevent more than one animal from consuming feed/water. As in Mendes et al., (2011), electronic data captured was regressed against the visual observations to establish the validity of the system to record an animal present when the animal was either at the feed bunk or water trough. The recorded feeding behavior was shown to be comparable to the visual observations (Chapinal et al., 2007). Drinking behavior was also assessed, with similar results discovered. Duration, frequency, and intake for both feed and water were determined to be accurately recorded by the electronic system (Chapinal et al., 2007).

Additionally, in Quimby et al. (2001), a cumulative sums chart (CUSUM, SAS Institute, Inc, 1995) was used to determine target values and control limits in a study involving the GrowSafe® system and higher risk calves arriving at a feedlot. Due to a decrease in appetite as an animal becomes ill, a lower control limit was used to help identify morbid animals. However, pen riding was still enforced and any discrepancies between the data collected and visual observation, decisions to remove an animal for treatment were based on visual observations (Quimby et al., 2001). Therefore, the CUSUM analysis was considered a diagnostic test over a true diagnosis of an animal's health status. Using the feeding behavior data collected by the GrowSafe® system and the RFID tags placed in the calf's ears, the results of this study implied that morbid cattle could be identified electronically 3.7-4.5 days earlier than traditional pen riding methods (Quimby et al., 2001). Other research involving cattle (Basarab et al., 1996) agrees with these findings and also implies that feeding and watering behavior should be monitored and can predict morbidity of an animal sooner than a pen rider. So, morbid animals who are identified sooner can receive treatment more quickly, and thus have the potential to respond better to antimicrobial therapy.

Other RFID technologies have emerged that record feeding intake data not by presence in a feed bunk, but through monitoring ear movement (Wolfger et al., 2015). An RFID tag equipped with an accelerometer is placed in a calf's ear, and differences in movements trigger the tag to record and collect perceived feeding behaviors. This technology was validated for feeding and rumination time in dairy cattle (Bikker et al., 2014) and sought to be proven in beef cattle. The SensOor® tag (Agis Automatisering BV, Harmelen, The Netherlands) does not measure feed intake through individual feed bunks like its counterparts, GrowSafe® and Insentec®, but rather examines cattle behaviors without the need for an adaptation period. Thus, by monitoring the animals ear movements, rumination and feeding behaviors were hoped to be accurately assessed.

Wolfger et al. (2015) found that the SensOor® tag could potentially be a useful method of recording feeding behavior, but further research would be needed in order to validate its accuracy in determining rumination in beef cattle. One drawback to this tool was the accelerometer's failure to differentiate feeding behavior, specifically intake, from rumination, and thus the correlation between observed rumination and recorded rumination was lower than the feeding behavior correlation. As ear movement was the only measure used to differentiate the two behaviors, altering the algorithm of the accelerometer may increase the accuracy of this tool.

Future of RFID systems

Utilizing RFID based technologies within the beef cattle industry should become more prominent as they can provide feeding behavior data on an individualized basis. The feedlot industry in particular measures intake on a pen basis, rather than by animal. Further integrating these technologies within that sector of the industry would have lasting implications. For instance, as stated above, visual identification of cattle infected with BRD often comes after the calf is able to respond to treatment. Currently, to combat the risk of BRD, high risk cattle are treated with an metaphylactic antibiotic upon entering a feedlot. By using RFID tags to individualize each animal, feeding behaviors can be monitored, and changes in that behavior could be used as an identifying tool for cattle who are in the early stages of morbidity to better target antimicrobial treatment. Additionally, by constantly recording feeding behavior traits, individual animal efficiency can be determined prior to slaughter. Animals with a lower RFI can be re-sorted together to make a more homogenous pen, as can cattle who are deemed less efficient. Thus, feeding programs would better suit the individual animal, rather than a pen average.   A few disadvantages are apparent, such as load cell bunks limiting the number of animals that can consume feed at the same time and the expensive costs associated with implanting these systems into a feedlot. Also, in order to implement these bunks, feedlots would need to alter the structure of their pens to allow for the implementation of these technologies, which does have a tremendous cost. An alternative option to load cell bunks is currently being researched. CattleTraq® (AllTraq, Oklahoma City, Oklahoma) eliminates the need for load cell bunks and instead utilizes an RFID tag and receivers placed in the pen and existing bunks. Cattle movement, bunk duration and frequency data are collected and processed within their system. Validation of this new technology is still being researched, but this system has the opportunity to integrate itself into the feedlot industry without an enormous preliminary cost. Once a successful integration of any of the systems discussed has taken place, the value and knowledge these systems can provide far outweigh the initial costs. Validation of these systems is key, and they should not be used to replace visual observation of the animal by a pen rider or bunk reader, but rather utilized as a tool to more accurately and efficiently make decisions regarding cattle health and performance.

Predicting brush usage using RFID tags in feedlot steers

Within a feedlot setting, cattle are confined to only perform core behaviors such as eating, drinking, and sleeping without stimulation from environmental factors (Park et al., 2019; Mandel et al., 2013). Luxury behaviors are classified as behaviors that have low resistance, and thus will be discontinued in times of illness or distress to the animal.

Within the dairy industry, installing either automatic or stationary brushes are becoming more common (Georg et al., 2007). While the reasoning for inputting a brush in a pen is mostly economical as the brushes aid in cow cleanliness and thus potentially increasing milk yield (Schukken and Young, 2009), others are implementing them to enrich an animal's environment (Wilson et al., 2002). Enriching an animal's environment requires modifying a confinement-based environment to expand the functions of the animals housed in restricted pens (Newberry, 1995). As using a brush is considered a luxury behavior, evaluating brush usage in cattle could potentially more quickly predict the onset of disease, especially BRD, the most common cattle disease in the U. S. (Toaff-Rosenstein and Tucker, 2018; Hilton, 2014). Currently, brush usage is either recorded in person by a trained individual or via video recordings decoded by trained individuals (Toaff-Rosenstein and Tucker, 2018). As this process is tedious and time consuming, monitoring this trait using RFID technologies is being studied to evaluate the accuracy of not only the system utilized, but also if brush usage can be consistently utilized as a predictor of the onset of disease (Toaff-Rosentstein et al., 2017). Therefore, locating and validating a system that is able to automate the process of tracking animal brush usage could potentially have large economic effects on the beef cattle feedlot industry.

Brush usage in dairy cattle

Since the mid-1980s, brushes have become more common in the dairy industry as they provide not only stimulus for the animal, but also aid in keeping dairy cows clean and increase milk yield by 3.5% during the cows second lactation (Schukken and Young, 2009). Grooming behavior is natural, and utilizing a brush mimics this behavior and allows cattle to reach areas they are unable to do so on their own (Ewing et al., 1999). When cattle are incapable of reaching certain body parts, they will utilize their environment (fence posts, branches, fence lines) in order to perform those behaviors (Brownlee, 1950; Simonsen, 1979; Fraser and Broom, 1997; Ewing et al., 1999). Therefore, damage to these structures may occur over time if animals are left without an item to scratch themselves upon. Dairy cattle in particular have shown an increase in grooming post-milking or being restrained for a short amount of time, and if an animal is deprived of that behavior, then undesirable behaviors may develop (Bolinger at al., 1997; Ewing et al., 1999). Wood-Gush and Beilharz (1983) also proposed that a lack of stimulation in an animal’s environment can lead to monotony and thus disagreeable behaviors as animals attempt to amuse themselves within their dull environment.

Therefore, the dairy industry has been steadily implementing brushes in free-stalls to combat boredom-induced behaviors (Georg et al., 2007). As cows are able to shift their attention to a new environmental factor, less damage may occur to each other and their surroundings. While cows do utilize the brush for a limited amount of time each day, cows have displayed territorial behavior over this resource, indicating a consistent desire to use the brush despite adaptation periods to the structure (Val-Laillet et al., 2008). Lameness may also be minimized due to a reduction in buller-steer behavior (the destructive action of one animal in a group constantly being ridden by others in the pen), which not only has welfare implications on the animal, but also economic benefits to the producer, as pens that offer no grazing potential often see higher incidences of lameness (Haskell et al, 2006).

By introducing a brush into a confined environment, frustration and destructive behaviors decrease and welfare is enhanced by the cows, as their need for grooming behavior has a source that can provide for those needs (Pelley et al., 2005; Kohari et al., 2007). DeVries et al., (2007) witnessed a drastic increase of time spent scratching when utilizing a brush, compared to the control period in which cows only had access to walls, a feed bunk , and a water trough, further indicating increased bouts of scratching occur once a brush is added to a confinement environment. Rather than destructing their environment or their pen mates, cows selected to utilize the brushes, and thus while providing a stimulus, also decreased the need for maintenance within their pens.

Some research has been conducted to monitor brush usage during periods of stress for cows. In a study conducted with 40 Holstein heifers, during periods of high temperature, brush use decreased, as the cows were undergoing an environmental stressor (Mandel et al., 2013). Additionally, following artificial insemination, which requires a cow to be restrained, brush usage was cut in half over the following three days (Mendel et al., 2013). Therefore, brush usage may potentially be a tool that can allow producers to predict the onset of disease, as brush usage has previously shown to decrease in dairy cows undergoing stresses.

Behavior patterns in feedlot cattle

Bovine respiratory disease is the primary cause of morbidity and mortality in newly received calves in U.S. feedlots (Hilton, 2014). Currently, the only method of detection utilized is visual observation from a pen rider of clinical signs such as coughing, nasal discharge, and lethargy, although the diagnostic precision of these behaviors is often low (Duff and Gaylean, 2007; Wittum et al., 1996; Thompson et al., 2006; Schneider et al., 2009; White and Renter, 2009). These symptoms are also often displayed too far in the progression of the disease for treatment to be effective. Therefore, researchers are evaluating other methods to more quickly detect the onset of disease, such as feeding, grooming and luxury behaviors (Toaff-Rosenstein et al., 2018; Toaff-Rosenstein et al., 2016; Pillen et al., 2016; Belaid et al., 2019).

Activity measurements, such as steps taken in a day, of newly received cattle has shown that there is a reduction in activity up to six days prior to diagnosis of BRD (Pillen et al., 2016), and that this trend of reduction in activity is consistent prior to the onset of disease (Belaid et al., 2019; Tomczak et al., 2019). Hanzlicek et al. (2010) also witnessed a decrease in step count in cattle fitted with pedometers and induced with *Mannheimua haemolytica*, thus further illustrating how activity could be utilized as a pre-diagnostic tool. Additionally, monitoring feeding behavior patterns and dry matter intake in cattle either induced with BRD or identified with the disease may also provide an indication of the onset of illness, as cattle with BRD eat less for 2 to 10 days prior to visual signs and spend less time at the feed bunk (Toaff-Rosenstein et al., 2016; Toaff-Rosenstein et al., 2018; Belaid et al., 2019).

When looking at drinking behavior patterns, newly received calves that later contracted BRD were found to have a higher drinking frequency and duration 4 to 5 days post-arrival, but this drastically decreased when the cattle were diagnosed with the disease 11 to 27 days post-arrival, indicating that monitoring drinking behavior aided in more quickly identifying sick calves (Buhman et al., 2000). Contrastingly, Sowell et al.

(1999) saw no differences in drinking behavior between healthy and morbid feedlot steers. Therefore, the need for a more consistent distinguishing factor to detect the onset of disease is necessary to more accurately identify morbid animals.

Brush usage and RFID potential in feedlot cattle

Compared to dairy farms, cattle within a feedlot setting rarely have access to environmental enrichment factors such as a brush. Due to this constant lack of stimulation within a confined environment, feedlot animals may engage in destructive behaviors, as mentioned previously with dairy cows (Park et al., 2019). Unlike dairies, however, installing brushes is not currently commonplace. However, as mentioned above, monitoring feeding and other behavior changes in newly received feedlot calves is currently being researched to better predict the onset of disease prior to visual detection (Eberhart, et al., 2017; Quimby et al., 2001; Wolfger et al., 2015). Implementing a brush in a feedlot setting may not only provide a stimulus for the animal, but also indicate when they are becoming ill (Toaff-Rosenstein et al., 2016). Contrastingly, Toaff-Rosenstein and Tucker (2018) witnessed no differences in brush usage in beef heifers that contracted BRD versus the healthy calves. Interestingly, brush usage increased over time for all animals, indicating that an acclimation period is necessary to more effectively monitor brush usage behavior. However, although the cattle in the Toaff-Rosenstein et al. (2016) study were acclimated to the brush for 7 days prior to beginning the trial, the brushes only remained in the pens for a period of 20 minutes, therefore, this object may have provided a consistent novel experience to each animal since it was removed for the majority of a day.

Monitoring brush usage behavior patterns must be conducted on an individualized animal basis which is a limitation as brush usage is currently predominately evaluated by visual observations via video recordings. This method is time-consuming and requires extensive resources that are not available in most large-scale feedlot settings. Toaff-Rosenstein et al. (2017) aimed to identify if brush usage could be accurately monitored using 2 RFID tags per animal and 4 receivers in each pen. Video surveillance was still recorded to assess the accuracy of the system. Sensitivity and specificity were generally low and highly variable (0.54-1.0 and 0.59-0.98, respectively), indicating that the system was registering an animal as using the brush when the beef heifer was only standing near the brush or lying underneath the structure (Toaff-Rosenstein et al. 2017). As this area of research is relatively novel, further expansion into determining if an RFID system could potentially be utilized as a substitute for video recordings and allow for real-time monitoring of brush usage behaviors is necessary. Additionally, this method could in turn be applied as a tool for more quickly identifying morbid cattle prior to visual observation, especially in newly-received feedlot calves. As the CattleTraq® system also utilizes RFID tags and receivers placed in both the pens and within the bunks to monitor cattle movement, this system may provide a more accurate monitoring method for brush usage in feedlot cattle. Tags are designed so that only one is needed to be placed within an animal’s ear, unlike the system utilized by Toaff-Rosenstein et al. (2017), which minimizes both stress to the animal and processing time. Validation of this system is vital to replacing video recordings and providing real-time monitoring of brush usage by cattle. However, this system should not be used as a diagnostic method, but rather a tool to use in conjunction with visual observation of the animal by a pen rider or bunk reader to assess animal health.

Direct-fed microbials and monensin in feedlot cattle

Public concerns regarding antimicrobial resistance relating to antibiotic use in the food animal feed industry has increased in recent years. An emphasis on disease prevention rather than treatment has emerged, as consumers are progressively troubled about unwanted pathogens in meat products. Therefore, demand for products with no risk of contamination or crossover is increasing. Direct-fed microbials (DFM) are defined by the FDA as “a source of live, naturally occurring microorganisms” (Yoon and Stern, 1995) and feed manufacturers must label any animal feed products containing probiotics as such. Probiotics have been defined by Fuller (1989) as “a live microbial feed supplement, which beneficially affects the host animal by improving its intestinal microbial balance.” While this definition encompasses the majority of bacterial microbes, it does not represent the objective of improving microbe environment in the rumen, which led to the mandated label change by the FDA. As these products are naturally occurring, public perception is more favorable. Monensin is currently applied in the beef feedlot industry to increase feed efficiency and decrease dry matter intake in cattle adapting to high-grain diets (Burrin et al., 1988; Stock et al., 1995), while tylosin is utilized to reduce incidences of liver abscesses (Brown et al., 1975). In order to exceed current production levels to meet the demands of an ever-growing global population, feed ingredients that increase animal efficiency and rate of gain must be researched further to assess the practicality of implementing new products in beef cattle production systems.

Direct-fed microbials in dairy cattle

Research has been explored in the dairy industry, to varying degrees. In preruminant dairy calves, rather than evaluating growth and efficiency in calves, establishing healthy intestinal microorganisms has been studied. In young and/or stressed calves, enteropathogens in the intestine can lead to diarrhea due to the rapid inclusion of solid feed in the early stages of life. Therefore, quick adaptation of a healthy microbial population in the developing rumen and intestine is imperative to animal health. Stress to neonates has been shown to increase diarrhea, which is also associated with a decrease in *Lactobacillus* bacteria in the gastrointestinal tract (Tannock, 1983). Sandine (1979) also reported that lactobacilli populations are higher in healthy calves and lower in calves experiencing scours. Therefore, feeding young/stressed calves *Lactobacillus* may reduce diarrhea outbreaks by causing an increase of *Lactobacillus* shedding (Gilliland et al., 1980; Jenny et al., 1991; Abu-Tarboush et al., 1996) and a decrease of coliforms shedding (Bruce et al., 1979). Even in studies where no advantages were seen to feeding calves DFM products, there was also no detriment to animal health (Morril et al., 1977; Jenny et al., 1991).

Additionally, adaptation to conventional feedlot diets depends on the growth and development of ruminal epithelium and overall capacity of the rumen. In Nakanishi et al. (1993), young Holstein calves were fed a supplement containing *L. acidophilus*. When rumination was measured on d 30, calves consuming this yogurt supplement were shown to ruminate more than those in the control group, suggesting including DFM in calf diets may encourage rumen development.

Although studies evaluating animal performance in young calves fed DFM are mixed, the current hypothesis is that any advantages seen in an animal's microbial population and growth will result in a healthier animal who has the capacity to perform better, due to the lower incidences of scours (Beeman, 1985). Measuring severity of diarrhea is important to further evaluate the potential benefits of including DFM products in young/stressed animals' diets.

Direct-fed microbials in beef cattle

Direct-fed microbials (DFM) impacts have been previously researched in order to assess effects on animal health and growth efficiency. Krehbiel et al. (2003) showed that including DFM in diets fed to feedlot cattle resulted in a 2.5 to 5% increase in average daily gain (ADG) and around a 2% increase in feed efficiency. However, in Elam et al. (2003), no effects on finishing steers feedlot performance or carcass composition was shown. Several studies have also demonstrated how DFM affects rumen fermentation by stabilizing rumen pH and altering VFA production (Beauchemin et al., 2003; Ghorbani et al., 2002; Nocek and Kautz, 2006). Ruminal acidosis is the most common nutritional disease for feedlot cattle, therefore, the use of DFM to combat this ailment has productivity, health, and welfare implications. Ruminal acidosis occurs when lactic acid is produced at a greater rate than can be evacuated from the rumen, resulting in pH depression below 5.4 (Aschenbach et al., 2011). Supplementing diets with lactate-utilizing bacteria DFM may neutralize lactic acid in the rumen and increase ruminal pH, thus reducing incidence of acidosis and increasing the productivity of the animal (Yang et al., 2004).

Conversely, the effects of DFM on stressed calves has been evaluated for potential advantages, as chronic stress can alter ruminal microbial populations to the detriment of the animal (Williams and Mahoney, 1984). Cattle deemed “high risk” are lighter weight cattle that are exposed to a number of stressful situations including a long transport period, comingling with different animals, and experience to new rations and environments (Duff and Gaylean, 2007). Due to this high level of stress placed on the animal, health concerns arise due to inflammatory responses that lead to a comprised immune system within the animal (Cooke, 2017). By introducing bacterial DFM to stabilize and repopulate the ruminal environment, rumen adaptation to environmental stressors may increase and thus reduce performance and death loss. During the 1980’s, several trials involving the inclusion of DFM in rations fed through the receiving period for an average of 30 d resulted in an average increase of 13.2% for ADG, 2.5% increase in intake and a 6.3% improvement in feed conversion compared to the control treatments (Crawford et al., 1980; Hutcheson et al., 1980; Kiesling and Lofgreen, 1981; Davis, 1982; Kiesling et al., 1982; Hicks et al., 1986). Interestingly, the greatest performance effects witnessed typically occurred within the first 14 d of the receiving period (Crawford et al, 1980; Hutcherson et al., 1980). Morbidity was not statistically reduced by the inclusion of DFM, but there was still a 27.7% morbidity reduction in cattle fed bacterial DFM. While DFM has been shown to positively affect the performance and overall health of cattle, results are still variable across studies. Although no performance benefits were expressed in Dew and Thomas (1981) and Kiesling and Lofgreen (1981), no detriment to health was shown either. In a more recent study conducted upon newly received cattle, no performance or health advantage was exhibited, however calves fed DFM during their first antimicrobial treatment were less likely to need a second dose 3 d post initial treatment versus the calves who were not fed DFM (Krehbiel et al., 2001).

Monensin in feedlot steers

Monensin is classified as an ionophore that is provided to cattle orally as a monensin sodium supplement (Haney and Hoehn, 1967). As monensin inhibits Gram-positive bacteria, an effect on rumen metabolism occurs by increasing energy and nitrogen metabolism, as well as reducing bloat and incidence of acidosis by lowering lactic acid production (Schelling, 1984). Additionally, monensin alters the proportion of volatile fatty acid production (VFA) in the rumen to favor more propionate production versus butyrate and acetate production (Richardson et al., 1976; Prang et al., 1978). This in turn leads the animal being provided more energy from the feedstuff as the glucose supply increases (Lomax et al., 1979; Baird et al., 1980). However, previous research of the effects of monensin on performance and feeding efficiency are varied, with some studies showing an improvement in feed efficiency (Steen et al., 1978; Horton et al, 1981), and others showing minimal advantages to supplementing feedlot steers with the ionophore (Horton, 1984; Yang et al., 2010).

Stock et al. (1995) evaluated the effects of feeding a monensin/tylosin combination at two dietary concentrations within a feedlot setting and found that DMI was reduced, but that ADG and F:G were improved compared to steers who were not fed the diets containing the supplement. Interestingly, degree of improvement in feed efficiency and decrease in DMI were not affected by inclusion rate of monensin/tylosin (Stock et al., 1995). When looking at day-to-day variation in DMI within individual cattle, those supplemented with monensin had a reduction in DMI variance during the grain adaptation period (Stock et al., 1995). However, across the entire 110 day trial, average DMI across the individually fed steers was not different between the monensin supplemented cattle versus the control calves, indicating monensin and monensin/tylosin reduces the variation across animals within a pen (Stock et al., 1995). These results are in agreeance with Burrin et al (1988) who also observed a decrease in DMI variation in individually fed steers who were adapting to a high grain diet. Reduction in variance of feed consumption has shown to potentially result in improved gain and feed efficiency (Gaylean, et al, 1992), as well as lowering lactate concentrations within the rumen (Nagaraja et al., 1982). Increased day-to-day variation and decreased DMI is also an indication of subacute acidosis (Fulton et al., 1979), and as monensin stabilizes the variation of these traits and lowers lactate levels, a reduction in acidotic cattle may result. Therefore, gain and efficiency was improved in these healthy calves (Stock et al., 1990). As almost all feedlot steers are fed on a group pen basis, with feed calls based on pen averages, monensin/tylosin may be reducing individual variance of intake to create a more reliable pen DMI average.

Although performance and growth results are variable in cattle fed both DFM and monensin, there seems to be no detriment to cattle health when fed diets containing either supplement. As public concern increases over the addition of medicated feeds, the demand for more natural livestock feed ingredients is growing. With contrasting results for both supplements, further elucidating the impact on growth, feeding behavior, and carcass traits is necessary to determine the efficacy of both DFM and monensin, specifically in comparison to the other.

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CHAPTER II

EFFECTS OF DIRECT-FED MICROBIALS WITH AND WITHOUT MONENSIN PLUS TYLOSIN ON GROWTH, FEEDING BEHAVIOR, FEED EFFICIENCY AND CARCASS CHARACTERISTICS IN CATTLE

Introduction

As societal concerns over about the use of antibiotics in livestock production increases, there is a need to develop alternative feed additives that increase feed efficiency and animal productivity. Previous research has shown that direct-fed microbials (DFM) have increased ADG and improve feeding efficiency in cattle (Elam at al., 2003). However, research is mixed on the impact of including DFM in beef cattle diets, as Kiesling and Lofgreen (1981) reported no improvements in feeding efficiency or other performance traits in cattle supplemented with DFM. Additionally, effects on stressed calves fed DFM has been evaluated to elucidate the impact on cattle health and feed efficiency (Crawford et al., 1980).

Previous research has shown that cattle supplemented with monensin have exhibited a decrease in DMI and an improvement in feed efficiency in cattle transitioning from a high roughage to a high grain diet (Burrin et al., 1988; Steen et al., 1978). However, research on the positive effects of monensin has varied, with Horton (1984) and Yang et al. (2010) both concluding that feed efficiency was not improved in cattle supplemented with monensin when fed high concentrate diets. Stock et al. (1995) and Gaylean et al. (1992) both found that monensin may reduce day-to-day variation in feeding behavior patterns, which may favorably affect feed efficiency and performance.

Due to the mixed research results and growing public concern with antimicrobial resistance, finding alternative feed additives to antibiotics that also increase feed efficiency and performance is necessary to sustain an ever-growing population. Additionally, due to the prevalence of monensin use in finishing feedlot cattle diets, the goal of this study was to determine the effects of DFM in combination with monensin on performance, feed efficiency, feeding behavior patterns and carcass quality in feedlot steers.

Materials and methods

Animals and experimental design

All animal care and use procedures were in accordance with the guidelines for use of Animals in Agricultural Teaching and Research as approved by the Texas A&M University Institutional Animal Care and Use Committee (AACUC #2018-034A).

One hundred and twenty-eight crossbred steers sourced from the Texas A&M AgriLife McGregor Research Center were used for this study. Upon weaning, the steers were administered a 7-way vaccine for clostridial agents and *Mannheimia haemolytica* (One Shot Ultra, Zoetis), adapted to a roughage-based grower diet that did not include DFM or MON feed additives and trained to eat from electronic feed bunks (GrowSafe Systems) for 14 d. Thereafter, the steers were fitted with a passive EID tag (Allflex, USA Inc., Dallas, TX), stratified by body weight (BW) and exit velocity, and randomly assigned to 1 of 4 treatments (n = 32) in a 2 x 2 factorial experimental design, with Factor 1 being diets with DFM (25 g/d; Natur's Way) or without DFM (CON), and

Factor 2 being diets with monensin (40 g/ton) and tylosin (10 g/ton; MON) or without MON (CON). During the study, steers were housed in 1 of 4 pens (50 x 11 m), with each pen equipped with 4 electronic feed bunks (GrowSafe Systems) to facilitate collection of feed intake and feeding behavior data on an individual-animal basis. The pen assignments were rotated at 14-d intervals, which coincided with collection of BW data, to minimize the random effect of pen. Additionally, the feed bunks were cleaned at 14-d intervals. The steers were fed a grower diet for 14 d, 1 of 2 transition diets for 16 d and a finisher diet for 96 d (**Table 2.1**). Steers were fed once daily to provide ad libitum access to feed. The 4 dietary treatments were maintained throughout the grower, transition and finisher periods, which consisted of diets containing (1) mineral-vitamin premix without monensin plus Tylan (MON) and dried distillers grain (DDG) carrier without DFM, (2) mineral-vitamin premix with MON and DDG carrier without DFM, (3) mineral-vitamin premix without MON and DDG carrier with DFM and (4) mineral-vitamin premix with MON and DDG carrier with DFM. To deliver the treatment diets, 2 base diets were batched each day consisting of the diet with the mineral-vitamin premix without MON, and the diet with the mineral-vitamin premix with MON. The base diet without MON was delivered first, and thereafter the DDG carrier with DFM added to the mixer wagon and mixed prior to delivery. To prevent dietary-treatment contamination, the mixer wagon was cleaned before the MON-only diet was batched. Likewise, once the MON-only diet was delivered, the DDG carrier with DFM was added to the mixer wagon and mixed prior to delivery.

Diet samples were collected at 14-d intervals, composited by weight, and diet dry matter percentage measured by drying samples in a forced air oven for 48-h at 105 °C. Samples were sent to Cumberland Valley Analytical Services Inc. (Maugansville, MD) for analysis of ash (535 C; AOAC 2000; method 942.05), ADF (AOAC, 2000; method 973.18), NDF with heat-stable ∞-amylase and sodium sulfite (Van Soest et al., 1991), and CP (N x 6.25; AOAC 2000; method 990.03, Leco FP528 Nitrogen Analyzer, Lec, St. Joseph, MI). Following the 96-d finisher period, the steers were moved to group pens and maintained on the same dietary treatments until they attained approximately 1 cm backfat thickness.

Carcass evaluation

The steers were harvested at the Cargill Processing Plant in Amarillo, Texas. Upon harvest, carcass data including backfat thickness, ribeye area, intramuscular fat, dressing percent, hot carcass weight were collected to determine yield and quality grades. Additionally, liver abscess scores were recorded.

Data collection and statistical analysis

The GrowSafe® system consisted of feed bunks equipped with load bars to measure feed disappearance, and an antenna to record animal presence by detection of the animal's RFID tag during feeding events. Assigned feed disappearance rates were computed daily for each feed bunk to assess data quality, and data excluded by pen for each day that the assigned feed disappearance **(AFD**) of an individual feed bunk in a pen was less than 90% or the average AFD for a pen was less than 95%. During the grower/transition period, data for 3, 2, 5 and 7 d were excluded for the MON plus DFM, MON only, DFM only and control treatments, respectively, due to data-quality issues. During the finisher period, data for 11, 13, 19 and 19 d were excluded for MON plus DFM, MON only, DFM only and control treatments, respectively, due to data-quality issues. Estimates for missing feed intake data were derived from linear regression of the feed intake on the day of trial as described in Hebart et al. (2004).

Feeding behavior traits evaluated in this study were based on the frequency and duration of bunk visit (**BV**) events. The frequency of BV events was defined as the number of BV events recorded during a 24-h period, regardless of whether feed was consumed, and BV duration as the sum of the lengths of BV events recorded during a 24-h period. The intervals between BV events were defined as the non-feeding intervals (**NFI**), with maximal NFI defined by the longest NFI within each day. Head down (**HD**) duration was computed as the sum of the number of times the RFID ear tag for an animal was detected each day multiplied by the scan rate of the GrowSafe system. Time to bunk (**TTB**) was defined as latency between feed delivery and an animal's first BV event each day. Meal events represent clusters of BV events that are differentiated from the next meal by an NFI that is longer than the NFI within a meal (Yeates et al., 2001). The longest NFI considered to be a part of a meal is defined as the meal criterion, which was computed with a 2-pool Gaussian-Weibull probability density function using the Meal Criterion Calculation Software (MCC; ver. 1.7.6836.33854;http://nutritionmodels.tamu.edu). The meal criterion for each animal was used to transform BV-event data into meal traits (frequency and duration of meal events, and mean meal length and size). Eating rates during BV and meal events were computed as DMI divided by BV and meal duration, respectively. Additionally, to further assess the intensity of feeding behavior patterns, the following ratios of feeding behavior traits were evaluated: BV frequency per meal event, HD duration per meal event, and HD duration per BV event. Day-to-day variation of DMI, and the frequency and duration of BV and meal events, HD duration, maximal NFI, TTB, and meal length were computed for each animal as the root mean squared error (**RMSE**) of the residuals from the linear regression of each of the feeding behavior trait on day of trial using the Standard Least Squares procedure of JMP (SAS Inst. Inc., Cary, NC).

Body weights were measured at 14-d intervals while the steers were in pens equipped with electronic feed bunks, and at 28-d intervals while housed in group pens. A final BW was recorded the morning the steers were shipped to the processing plant. Within the grower/transition and finisher periods, growth data was calculated using linear regression of serial BW on day of study, with regression coefficients used to compute ADG, and initial and final BW. Moisture analysis from bi-weekly samples were used to adjust feed intake measurements to determine daily dry matter intake (**DMI**). Within grower/transition and finisher periods, RFI was computed as the residual from the linear regression of DMI on ADG and mid-test $BW^{0.75}$ (Koch et al., 1963), and F:G computed as DMI divided by ADG.

A generalized mixed model of SAS that included MON and DFM treatments as fixed effects, and the MON x DFM interaction was used to examine treatment effects on all response variables (Feed intake, feeding behavior traits, daily variances of DMI and feeding behavior traits, performance, carcass traits). The PDIFF option of SAS was used to compare subclass means when the DFM x MON interaction was significant at $P < 0.05$. For carcass data, Pearson Chi-square tests were used to determine if dietary treatment affected the proportion of liver abscesses, and the proportion of carcasses grading choice or higher.

Results

The effects of DFM with and without monensin plus tylosin on performance, feed efficiency and feeding behavior patterns are presented separately for the grower/transition and finisher periods in **Tables 2.2** and **2.3**. As the MON x DFM interaction was not significant for most of the response variables, the main effect least-squares means are presented in **Tables 2.2** and **2.3**. For those response variables with significant MON x DFM interactions, the subclass means are presented in figures. During the trial, 1 steer died during the first week of the adaptation period, and 2 steers were removed with the study due to poor performance.

Grower/transition period

As expected, the initial BW was not affected by DFM or MON treatments. During the grower/transition period, the steers fed the MON diets had a 9.5% higher ($P < 0.05$) ADG and similar DMI compared to steers fed diets without MON (**Table 2.2**). Thus, steers fed the MON diets tended ($P = 0.06$) to have an improved F:G (7.8 vs. 9.4 ± 2.4) and had lower ($P < 0.01$) RFI compared to steers fed diets without MON. Steers fed diets with DFM grew slower ($P < 0.01$) and had similar DMI compared to steers fed diets without DFM. The F:G was not affected by the DFM treatment, although the steers fed diets with DFM tended ($P < 0.09$) to have a higher RFI compared to steers fed diets without DFM.

The MON treatment did not affect frequency or duration of BV events, or eating rate during BV events during the grower/transition period (**Table 2.2**). The MON x DFM interaction was significant ($P < 0.001$) for maximal non-feeding interval (**Figure 2.1**), as steers fed diets containing MON had higher ($P < 0.05$) maximal non-feeding interval when DFM was included, but not when DFM were excluded from the diet. Additionally, there was a MON x DFM interaction ($P < 0.05$) for meal criterion (**Figure 2.2**). Steers fed diets containing MON had lower ($P < 0.05$) meal criterion when DFM was also included, but not when DFM was excluded. The effect of MON on reducing meal criterion in DFM-based diets resulted in steers fed MON diets tending to consume fewer ($P = 0.11$) meal events than steers fed diets without MON. The MON treatment did not affect meal duration, mean meal length and size, or eating rate of meal events (**Table 2.2**). Likewise, MON treatment did not affect HD duration or either of the 3 ratio-based feeding behavior traits. Steers fed MON diets approached the feed bunk 29 min faster following feed delivery compared to steers fed diets without MON.

Steers fed diets containing DFM had fewer ($P < 0.001$) BV events and higher ($P < 0.001$) maximal non-feeding intervals (MON x DFM interaction; $P < 0.001$) than steers fed diets without DFM. The DFM treatment did not affect HD duration, frequency and duration of meal events or length and size of meal events or meal eating rate. In contrast to the effect of MON, steers fed diets containing DFM had slower ($P < 0.05$)

TTB compared to steers fed diets without DFM. Steers fed diets with DFM had fewer ($P < 0.01$) BV events per meal than steers fed diets without DFM, however, the other 2 ratio-based feeding behavior traits were not affected by the DFM treatment.

The day-to-day variance of DMI was not affected by MON treatment. However, steers fed diets with MON had lower ($P < 0.01$) daily variances for frequency of BV and meal events, and maximal non-feeding intervals than steers fed diets without MON. The significant MON x DFM interaction for BV frequency RSME (**Figure 2.3**) was due to the fact that the magnitude of the reduction in daily variance of BV frequency caused by the MON treatment was greater when DFM was included vs excluded from diets. Additionally, there was a tendency ($P = 0.11$) for daily variation in meal duration to be less in steers fed diets with vs without MON. Likewise, the daily variation for TTB was lower ($P < 0.001$) for steers fed diets containing MON compared to those fed diets without MON. The MON x DFM interaction for TTB RMSE (**Figure 2.4**) was due to the fact that the reduction in daily variance in TTB caused by the MON treatment was greater when DFM was included (-51%) than excluded (-41%) from diets.

Steers fed the DFM diets had greater ($P < 0.5$) daily variance in DMI compared with steers fed diets without DFM (**Figure 2.5**). However, the DFM treatment had minimal effects on day-to-day variances of feeding behavior traits, with the exception that daily variation in TTB was greater ($P < 0.0001$) for steers fed diets with vs without DFM (MON x DFM interaction; $P < 0.01$).

Finisher period

At the start of the finisher period, the initial BW were heavier ($P < 0.05$) in steers fed MON diets compared to steers fed diets without MON, as they had higher ADG during the grower/transition period. As a consequence, steers fed the MON diet gained less ($P < 0.01$) during the finisher period compared to steers fed diets without MON, although the MON x DFM interaction tended to be significant for ADG (**Figure 2.6**). Numerically, ADG were not affected by the MON treatment when diets without DFM were fed, whereas, ADG were numerically reduced when diets containing DFM were fed. Steers fed MON diets had 7% lower ($P < 0.01$) DMI compared to steers fed diets without MON. The MON treatment did not affect F:G during the finisher period, although there was a tendency for the MON x DFM interaction to be significant (**Figure 2.7**). Numerically, F:G were lower in MON-fed steers when diets without DFM were fed, whereas, F:G were higher in MON-fed steers when diets containing DFM were fed. Despite the significant MON x DFM interaction for F:G, steers fed diets containing MON had lower ($P < 0.01$) RFI compared to steers fed diets without MON. The DFM treatment did not affect initial BW or ADG during the finisher period. However, steers fed DFM diets consumed 4% more ($P < 0.05$) DMI and had higher ($P < 0.05$) RFI than steers fed diets without DFM.

The MON treatment did not affect frequency of BV events or maximal non-feeding interval during the finisher period (**Table 2.3**). However, steers fed MON diets had 9% longer ($P < 0.05$) BV duration compared to steers fed diets without MON. As steers fed MON diets also consumed 7% less DMI, the BV eating rate was 17% slower

($P < 0.01$) in steers fed diets with MON compared to those fed diets without MON. This trend continued as meal duration was longer ($P < 0.05$) and meal eating rate slower ($P < 0.01$) for steers fed MON diets than those fed diets without MON. Additionally, there was a tendency ($P = 0.06$) for average meal length to be longer for steers fed diet with MON vs without MON. The MON treatment did not the intensity of feeding behavior patterns as defined by HD duration, TTB or the 3 ratio-based feeding behavior traits. Compared to the grower/transition period, the MON treatment had less influence on daily variances of DMI and feeding behavior patterns. In fact, the daily variances of HD and BV duration were greater ($P < 0.05$) in steers fed MON diets compared to steers fed diets without MON, although there were tendencies ($P \leq 0.10$) for daily variances of BV frequency and duration and maximal non-feeding interval to be less in steers fed diets MON compared to without MON.

The DFM treatment did not affect feeding behavior patterns during the finisher period, although there was a tendency ($P = 0.07$) for steers fed DFM diets to have a greater HD duration per BV duration than steers fed diets without DFM. Likewise, the DFM treatment had minimal effects on daily variances of feeding behavior patterns. Steers fed diets with DFM had greater daily variation in maximum non-feeding interval and tended to have greater ($P = 0.09$) daily variation in BV duration throughout the finisher period compared to steers fed diets without DFM.

The effects of the dietary treatments on carcass characteristics and liver traits are displayed in **Tables 2.4** and **2.5**. Carcass quality and yield grade were not affected by MON and (or) DFM treatments, although there was a tendency ($P = 0.08$) for steers fed

MON diets to have a larger rib-eye area than steers fed diets without MON. There was a tendency (*P* = 0.07) for steers fed diets with DFM to have a higher proportion of condemned livers compared to steers fed diets without DFM.

Discussion

Grower/transition period

Monensin and tylosin are widely utilized within the beef cattle feedlot industry to improve feed efficiency and reduce incidence of liver abscesses (Brown et al., 1975; Haney and Hoehn, 1967; Richardson et al., 1976). Due to growing societal concerns about the use of antimicrobials in animal agriculture, finding alternative feed additives that pose no risk of antimicrobial resistance is critical to further improve feed efficiency in the beef industry. During this study, steers fed the MON diet had 9.5% ADG during the grower/transition period. Potter et al. (1985 and 1986) also found that steers supplemented with monensin on a high roughage diet grew 8.62% to 15.3% faster than the cattle not supplemented with monensin. The lower increases in ADG during the present study may be attributed to the steers transitioning to a high grain diet during this period, rather than maintaining a high roughage diet throughout the period.

Feeding behavior traits were minimally influenced during the grower and transition period, with monensin supplemented steers approaching the bunk more quickly and having a shorter maximum non-feeding interval compared to steers fed diets without monensin.

Monensin may minimize digestive distress by reducing day-to-day variances in feeding behavior traits as acidotic animals have shown to have more variable feed intake behaviors (Fulton et al., 1979), and monensin-fed steers displayed more stable feeding behavior patterns during the grower and transition period. Monensin has also been shown to create a more favorable rumen environment, thus stabilizing ruminal pH and decreasing lactic acid production (Nagaraja et al., 1979), and leading to fewer incidences of ruminal acidosis during transition to a high grain diet. This may have contributed to the improvements in ADG and the tendency for better feed conversion, as Gaylean et al., (1992) identified that a reduction in intake variation lead to more efficient animals. Within this study, variation in meal frequency was also lowered by the inclusion of monensin and potentially contributed to the increase in ADG compared to non-monensin supplemented steers during the grower and transition period.

Finisher period

The growth rate was not improved in steers fed the MON diets during the finisher phase, similar to previous studies that also found minimal effects on ADG in feedlot steers supplemented with monensin and consuming high grain diets (Horton, 1984; Yang et al., 2010). However, DMI was significantly decreased during the finisher period, in agreeance with Raun et al. (1976) and Potter et al. (1976) who also found a decrease in DMI in cattle fed high concentrate diets and supplemented with monensin. Despite the lower ADG during the finisher period, DMI was also reduced, which led to no differences in feed conversion. However, the steers fed diets had a lower RFI compared to steers that were not supplemented with monensin. There was also a tendency for a MON x DFM interaction for feed efficiency, with monensin-fed steers having a numerically improved feed efficiency, but only when DFM was excluded, which is in contrast to Swanson et al. (2018) who observed steers supplemented with both monensin and DFM to be the most efficient when compared to only monensin-fed and control steers.

Meal eating rate was reduced and bunk visit duration was increased during the finisher period in steers supplemented with monensin compared to those that were not, agreeing with Baile et al. (1979) who also observed a reduction in meal eating rate and an increase in meal duration in three monensin-fed steers consuming a high concentrate diet. Contrastingly, these findings disagree with Mullins et al. (2011), who witnessed no differences in meal duration in dairy cows supplemented with monensin compared to control animals. Erickson et al. (2003) found that meal length was reduced in cattle supplemented with monensin, in contrast with what was observed in the present study. However, by increasing meal duration and reducing meal eating rate, especially when consuming high concentrate diets, steers are less likely to experience subacute acidosis or other digestive disorders and thus remain more efficient as ruminal pH will remain more consistent throughout the longer meal event (Fulton et al., 1979).

Day-to-day variation in bunk visit duration and head down duration was increased during the finisher period, in contrast to the results shown during the grower and transition period. No other daily variance traits were influenced by the inclusion of monensin. However, there is an implication that monensin may increase variation in those feeding behavior traits in finishing beef steers, which may have also contributed to the reduction in daily gain during the finisher period.

Direct-fed microbial

The DFM fed during the duration of this trial did not favorably affect the performance or feed efficiency of the steers, which is in contrast to Elam et al. (2003), who saw an increase in ADG and feed efficiency in feedlot steers. Krehbiel et al. (2003) also observed an increase in feed efficiency in cattle supplemented with DFM compared to controls, although those results were not duplicated in this study. However, the results presented in this study agree with Kiesling and Lofgreen (1981), who saw no positive improvements in feed efficiency or growth traits in cattle supplemented with DFM. Previous research has shown an improvement in stressed calves (Crawford et al., 1980), but the cattle used in this study were sourced from the same location in which they were housed in for the entirety of the trial, thus minimizing stress and therefore potential effects associated with supplementing DFM.

One of the primary goals of this study was to determine if day-to-day feeding behavior variation was reduced for cattle fed the DFM treatment diets, but unlike prior studies (Yang et al., 1995), this study implied that ruminal pH fluctuated more so in cattle supplemented with DFM as their disparity in day-to-day DMI during the grower and transition period were increased when compared to the calves not supplemented with DFM. As inconsistent feed intake behaviors are characteristic of subacute acidosis (Fulton et al., 1979), and cattle were undergoing a transition from a high roughage to a high grain diet, this inconsistency may have contributed to the decrease in ADG during this period, despite the similar feed conversion ratio between DFM and non-DFM supplemented steers. Beauchemin et al. (2001) and Schwartzkopf-Genswein et al. (2003) also indicated that variation in feeding behavior patterns, especially as cattle are transitioning to diets with highly fermentable starches may lead to metabolic disease, and thus a reduction in growth and feed efficiency.

These differences did not continue in the final 96 d of the trial, indicating that the rumen may have adapted to the DFM treatment. Conversely, in agreeance with Elam et al. (2003), no carcass trait differences were shown in cattle supplemented DFM versus those who were not. Additionally, although health was not a primary focus within this study, there seemed to be no detriment to cattle who were supplemented with DFM when compared to cattle that were not. Due to the contrasting responses in beef cattle to DFM, further research needs to be conducted, possibly in higher risk cattle, to further elucidate the response of DFM on feedlot steer health, performance, and feed efficiency.

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Table 2.1. Ingredient and chemical composition of the diet fed during the trial.

Item	Grower	Transition 1	Transition 2	Finisher
Feed ingredients (As-fed basis)				
Dry-rolled corn, %	29.5	44.0	53.0	60.0
Distillers dried grains, %	25.5	20.5	20.5	20.5
Ground milo stalks, %	35.0	25.0	16.0	9.0
Molasses, %	6.0	6.0	6.0	6.0
Vitamin-mineral premix†, %	2.0	2.0	2.0	2.0
DDG carrier††, %	2.0	2.0	2.0	2.0
Nutrient composition (DM basis)				
Dry Matter, %	85.0	--	--	87.1
Crude Protein, %	13.2	--	--	13.5
ADF, %	19.8	--	--	9.6
NEm, Mcal/kg	0.80	--	--	0.89
NEg, Mcal/kg	0.47	--	--	0.56
TDN, %	70.7	--	--	77.7
Fat, %	4.30	--	--	4.85

†The same vitamin-mineral premix with or without monensin plus Tylan was included in all diets.

††The same dried distiller grains carrier with or without DFM was included in all diets.

Table 2.2: The main effects of direct-fed microbials (DFM) and/or monensin (Mon) supplementation on performance, feed efficiency, and feeding behavior patterns during the grower/transition period.

	Monensin		DFM			*P*-values		
Item	+Mon	-Mon	+DFM	-DFM	SE	Mon	DFM	Mon x DFM
Performance traits								
Initial BW, kg	305	301	305	300	11	0.31	0.16	0.56
Final BW, kg	346	338	342	342	12	0.08	0.96	0.58
ADG, kg/d	1.38	1.26	1.23	1.42	0.20	0.03	0.01	0.96
DMI, kg/d	10.2	10.2	10.1	10.3	0.6	0.75	0.36	0.62
F:G	7.79	9.35	8.77	8.37	2.40	0.06	0.63	0.24
RFI, kg/d	-0.28	0.27	0.13	-0.14	0.10	<0.01	0.09	0.66
Bunk visit traits (BV)								
BV frequency, events/d	64.4	66.6	60.2	70.8	2.1	0.49	0.01	0.96
BV duration, min/d	90.3	88.8	91.3	87.8	2.7	0.69	0.35	0.57
Max non-feeding interval, min	560	605	604	560	9	<0.01	<0.01	<0.01
BV eating rate, g/min	119	120	116	122	4	0.74	0.25	0.62
Meal traits								
Meal criterion, min	6.77	7.33	7.34	6.76	0.60	0.49	0.47	0.03
Meal frequency, events/d	9.66	10.64	10.43	9.88	0.40	0.11	0.36	0.83
Meal duration, min/d	163	164	160	166	4	0.80	0.30	0.26
Meal length, min/event	19.3	19.4	19.1	19.5	1.2	0.94	0.79	0.24
Meal size, kg	1.13	1.08	1.09	1.12	0.10	0.44	0.75	0.72
Meal eating rate, g/min	64.6	64.0	65.6	63.0	1.6	0.82	0.26	0.55
Intensity traits								
Head down (HD) duration, min/d	54.2	55.1	55.6	53.7	2.0	0.77	0.52	0.63
Time to bunk, min/d	50.3	79.5	72.1	57.7	4.2	0.01	0.02	0.16
HD duration per BV duration	0.59	0.61	0.60	0.60	0.00	0.15	0.98	0.92
HD duration per meal duration	0.34	0.34	0.36	0.33	0.00	0.84	0.13	0.50
BV events per meal event	7.00	6.89	6.36	7.53	0.30	0.82	0.01	0.53
Day-to-day variationᵗ								
DMI, kg/d	1.75	1.82	1.88	1.69	0.10	0.38	0.02	0.10
BV frequency, events/d	16.0	19.6	18.2	17.4	0.6	0.01	0.30	0.02
BV duration, min/d	24.0	23.4	24.3	23.1	0.7	0.57	0.22	0.86
Max non-feeding interval, min	149	167	162	153	4	0.01	0.14	0.19
Meal frequency, events/d	2.57	3.13	2.87	2.82	0.20	0.01	0.81	0.74
Meal duration, min/d	35.4	38.4	37.3	36.6	1.3	0.11	0.73	0.20
Meal length, min/event	5.83	6.27	6.07	6.04	0.40	0.46	0.97	0.33
HD duration, min/d	14.7	14.3	14.9	14.1	0.5	0.57	0.31	0.96
Time to bunk, min	60.0	112	101	71.0	3.0	<0.01	<0.01	<0.01

ᵗ Day-to-day variation as RMSE of linear regression on days on feed.

Table 2.3: The main effects of direct-fed microbials (DFM) and/or monensin (Mon) supplementation on performance, feed efficiency, and feeding behavior patterns during the finisher period.

	Monensin		DFM			*P*-values		
Item	+Mon	-Mon	+DFM	-DFM	SE	Mon	DFM	Mon x DFM
Performance Traits								
Initial BW, kg	341	333	335	339	3	0.05	0.36	0.36
Final BW, kg	495	497	496	496	4	0.76	0.99	0.56
ADG, kg/d	1.60	1.71	1.67	1.63	0.03	0.01	0.31	0.06
DMI, kg/d	9.89	10.60	10.40	10.00	0.13	0.01	0.04	0.58
F:G	6.23	6.30	6.32	6.21	0.09	0.64	0.44	0.09
RFI, kg/d	-0.23	0.23	0.15	-0.15	0.10	0.01	0.04	0.53
Bunk visit traits (BV)								
BV frequency, events/d	54.0	53.6	54.6	53.0	1.3	0.83	0.37	0.60
BV duration, min/d	74.2	67.9	70.3	71.8	2.2	0.04	0.62	0.28
Max non-feeding interval, min	648	638	647	639	11	0.55	0.57	0.48
BV eating rate, g/min	138	167	157	148	5	0.01	0.20	0.57
Meal traits								
Meal criterion, min	8.80	8.12	8.24	8.68	0.49	0.34	0.53	0.09
Meal frequency, events/d	8.23	8.68	8.53	8.39	0.28	0.26	0.73	0.81
Meal duration, min/d	143	133	138	138	3	0.03	0.99	0.19
Meal length, min/event	20.0	17.6	18.6	19.0	0.9	0.06	0.76	0.26
Meal size, kg	1.27	1.30	1.30	1.28	0.04	0.61	0.71	0.58
Meal eating rate, g/min	71.3	82.6	78.7	75.2	2.0	0.01	0.21	0.69
Intensity traits								
Head down (HD) duration, min/d	44.1	40.4	40.8	43.6	1.6	0.10	0.22	0.35
Time to bunk, min/d	48.8	51.8	49.1	51.4	3.2	0.51	0.61	0.96
HD duration per BV duration	0.59	0.59	0.58	0.60	0.01	0.99	0.07	0.89
HD duration per meal duration	0.31	0.31	0.30	0.32	0.01	0.68	0.13	0.77
BV events per meal event	7.23	6.82	7.11	6.94	0.24	0.23	0.64	0.84
Day-to-day variation (RMSE)[t]								
DMI, kg/d	2.10	2.14	2.13	2.12	0.04	0.47	0.80	0.16
BV frequency, events/d	13.4	14.2	13.4	14.1	0.3	0.10	0.14	0.32
BV duration, min/d	19.1	17.6	18.9	17.7	0.5	0.04	0.09	0.94
Max non-feeding interval, min	170	176	178	169	2	0.08	0.01	0.91
Meal frequency, events/d	2.31	2.39	2.37	2.33	0.09	0.50	0.77	0.58
Meal duration, min/d	30.8	30.3	30.4	30.7	0.8	0.70	0.84	0.81
Meal length, min/event	6.39	5.62	6.03	5.98	0.31	0.08	0.90	0.58
HD duration, min/d	11.7	10.5	11.3	11.0	0.4	0.03	0.55	0.99
Time to bunk, min/	59.7	60.9	60.0	60.6	2.2	0.69	0.83	0.36

[t] Day-to-day variation as RMSE of linear regression on days on feed.

Table 2.4: The main effects of direct-fed microbials (DFM) and/or monensin supplementation on beef cattle carcass traits.

	Monensin		DFM			*P*-values		
Item	+Mon	-Mon	+DFM	-DFM	SE	Mon	DFM	Mon x DFM
Carcass Traits								
Hot carcass weight, kg	357	352	357	352	7	0.26	0.32	0.28
Fat thickness, cm	1.17	1.17	1.14	1.17	0.02	0.92	0.60	0.41
Ribeye area, cm^2	86.5	83.9	85.8	84.5	0.1	0.08	0.41	0.07
Yield grade	2.75	2.82	2.76	2.81	0.10	0.47	0.64	0.88
Marbling score	475	471	476	470	10	0.79	0.63	0.90

Table 2.5: The sub-class effects of direct-fed microbials (DFM) and monensin (Mon) supplementation on beef cattle quality grades and liver traits.

	Dietary Treatments					*P*-Values	
	+Mon	+Mon	-Mon	-Mon			
Item	+DFM	-DFM	+DFM	-DFM	SE	Mon	DFM
Quality Grade							
≥ Premium choice, %	28.6	28.1	25.8	32.3	--	0.50	0.47
≥ Choice, %	82.1	93.8	96.8	90.3	--	0.31	0.47
Liver Traits ††							
Edible, %	92.9	93.8	74.2	93.5	--	0.13	0.18
Abscesses (A- & A), %	0	6.25	16.1	3.23	--	0.15	0.41
Condemned, %	7.14	0	9.68	3.23	--	0.42	0.07

†Edible = normal; A- = 1-2 small abscesses, A = 2-4 small active abscesses; Condemned = processing contamination, flukes or telangiectasia.

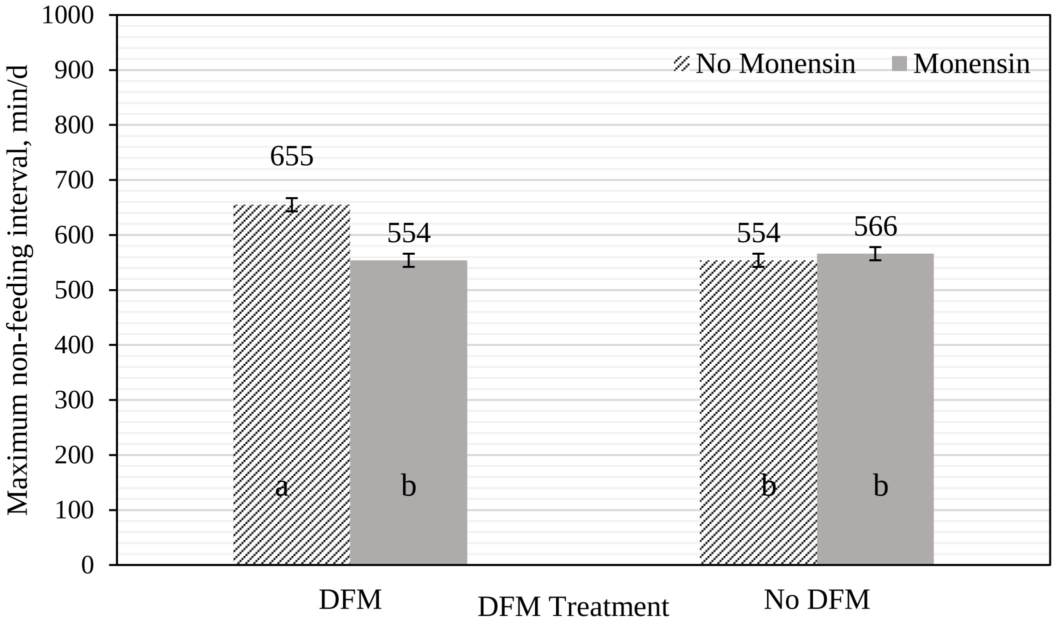

Figure 2.1 Subclass means for maximum non-feeding interval for the DFM × MON interaction in the grower/transition period. The DFM × MON interaction was significant at $P < 0.01$. Subclass means with different letters differ ($P < 0.05$).

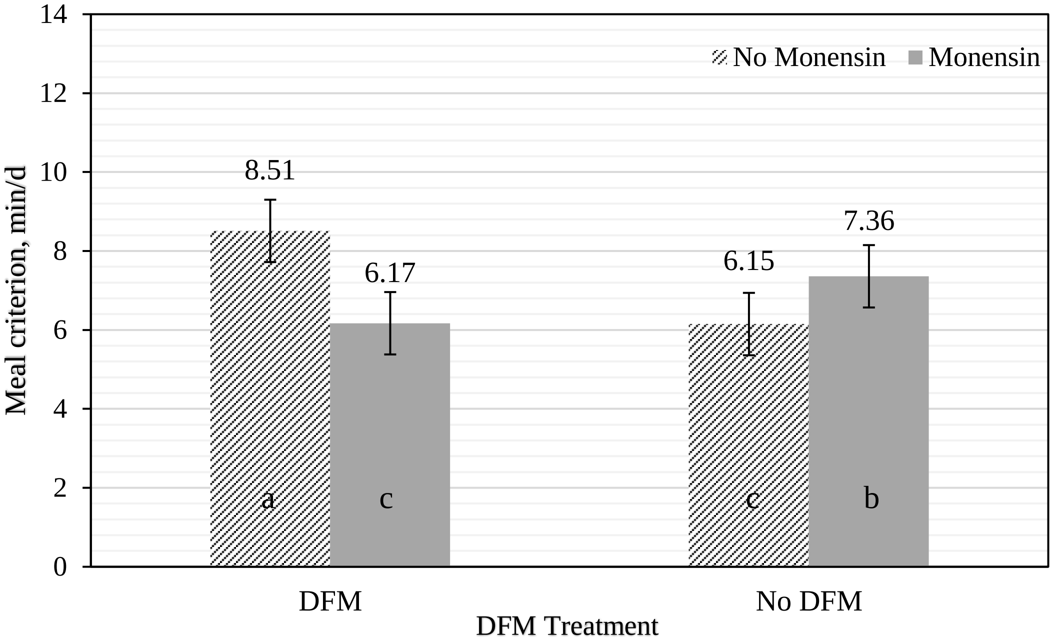

Figure 2.2. Subclass means for meal criterion for the DFM × MON interaction in the grower/transition period. The DFM × MON was significant at $P = 0.03$. Subclass means with different letters differ ($P < 0.05$).

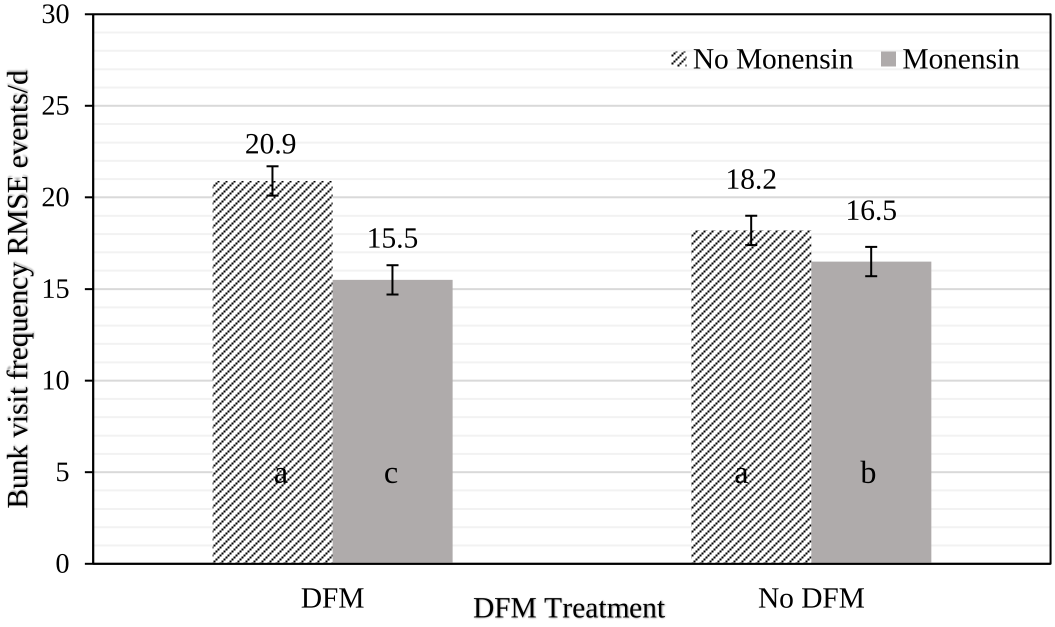

Figure 2.3. Subclass means for day-to-day variation (RMSE) in bunk visit frequency for the DFM × MON interaction during the grower/transition period. The MON × DFM interaction was significant at P = 0.02. Subclass means with different letters denote differences (*P* < 0.05).

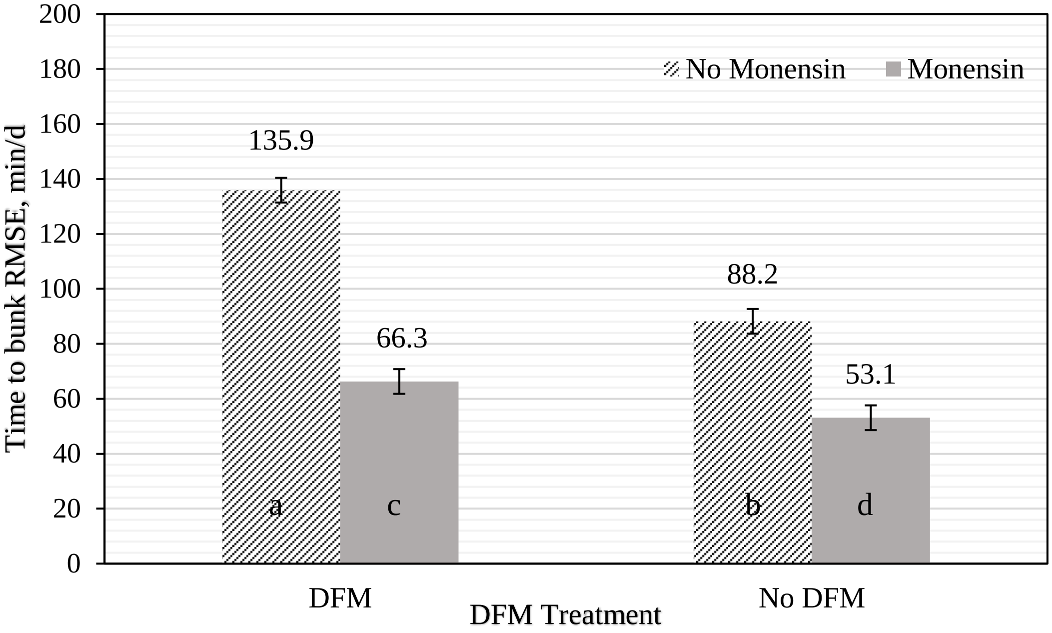

Figure 2.4. Subclass means for day-to-day variation (RMSE) in time to bunk for the DFM × MON interaction during the grower/transition period. The DFM × MON interaction was significant at P < 0.01. Subclass means with different letters differ ($P < 0.05$).

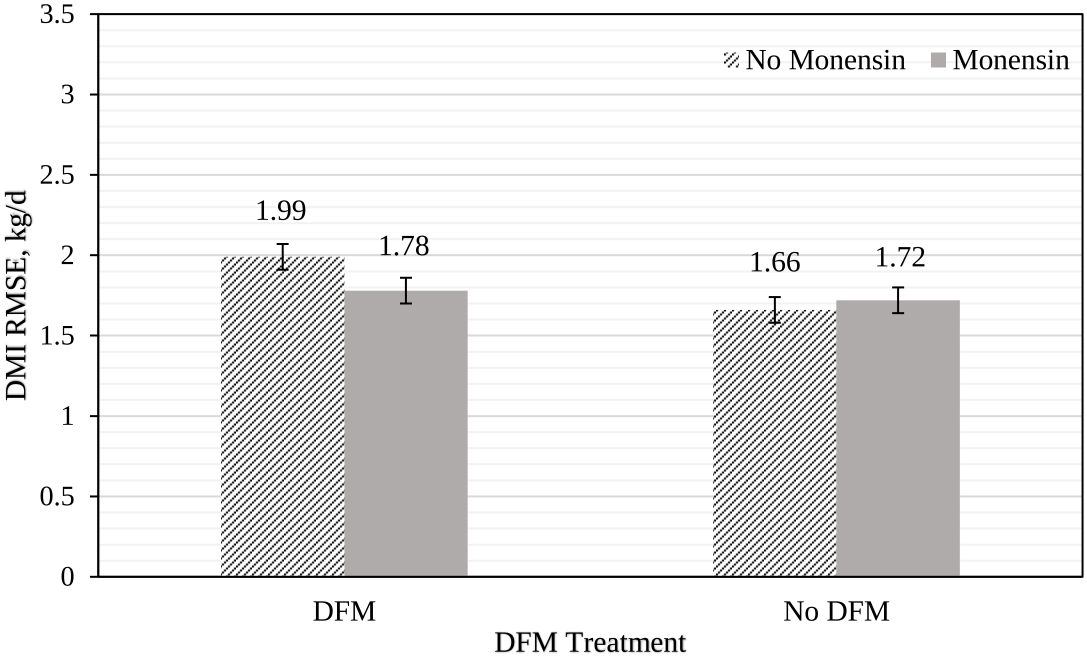

Figure 2.5. Subclass means for day-to-day variation (RMSE) in DMI for the DFM × MON interaction during the grower/transition period. Subclass means tended to be different at P = 0.10.

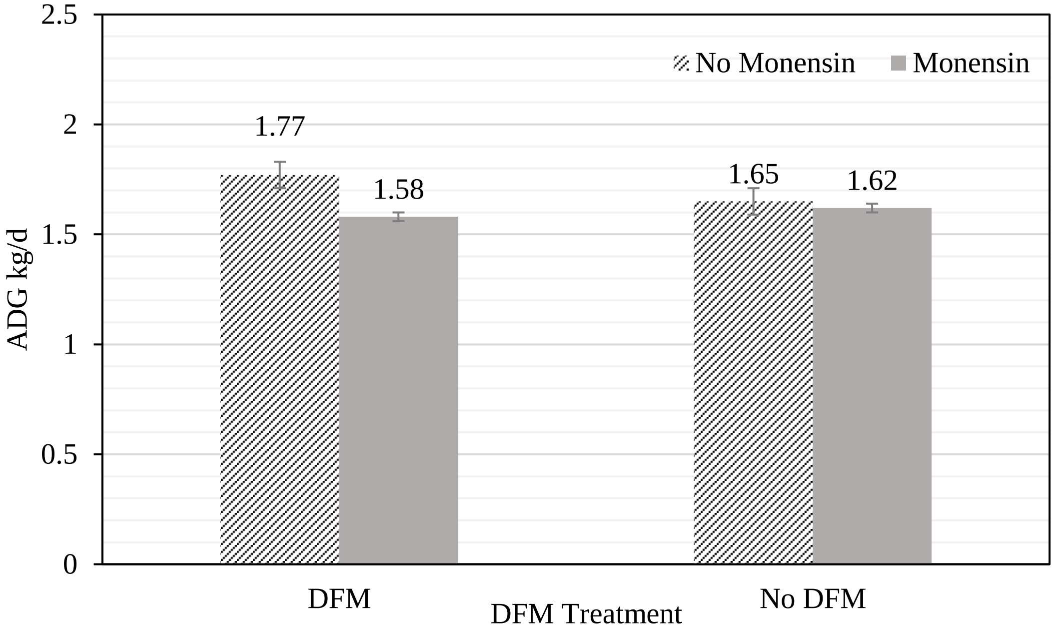

Figure 2.6. Subclass means for ADG for the DFM × MON interaction during the finisher period. Subclass means tended to be different at P = 0.06.

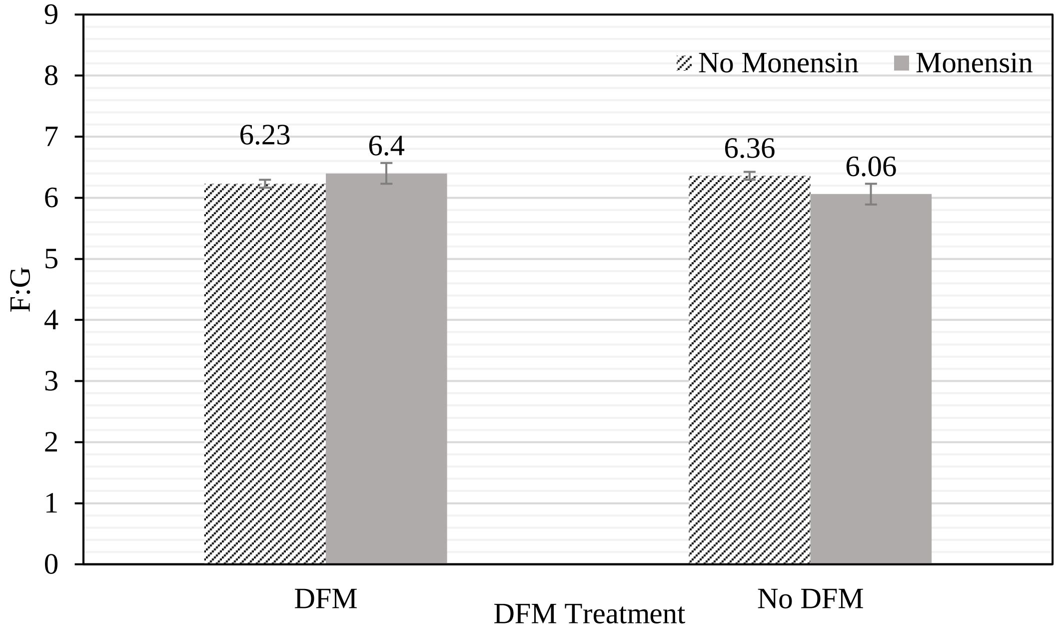

Figure 2.7. Subclass means for F:G for the DFM × MON interaction during the finisher period. Subclass means tended to be different at P = 0.09.

CHAPTER III

VALIDATION OF AN ULTRA-WIDEBAND RFID GEOLOCATION SYSTEM TO MONITOR FEEDING AND LUXURY BEHAVIOR PATTERNS IN FEEDLOT CATTLE

Introduction

Bovine respiratory disease (**BRD**) is the most common disease affecting beef cattle. Accurate preclinical detection of BRD is crucial for effective intervention of this disease. Current BRD-detection methods rely on subjective observations of clinical signs by pen riders that are not always reliable as cattle are prey animals with inherent instincts to mask signs of illness. The diagnostic sensitivity of BRD based on pen riders has been reported to be only 27% (Timsit et al., 2016), indicating that BRD cases often go undetected, or are detected later in the disease process when successful intervention is less likely.

Advancements in sensor and computing technologies has led to the development of various sensor-based technology systems that can continuously monitor in feeding and activity behavior patterns in the absence of human presence. These objective and non-invasive monitoring systems have the potential to detect the onset of disease earlier in the disease process, which would likely improve the success rate of antimicrobial therapy. Behavior traits can be classified as either core (high-resilience) or luxury (low-resilience). Feeding and drinking behaviors are categorized as core behavior traits required for survival, while luxury behavior traits, such as allogrooming or brush usage are not deemed to be critical for survival. Using statistical-process control (**SPC**) procedures, Quimby et al. (2001) monitored deviations in feeding duration of high-risk feeder calves and reported detecting BRD cases 3 to 4 d prior to detection by pen riders. Mandel et al. (2017) monitored changes in luxury behavior traits in dairy cows that were diagnosed with metritis. They found that frequency and duration of brush usage was substantially reduced both prior to and following the onset of metritis in dairy cows. Therefore, monitoring behavior pattern changes in cattle may lead to detection of disease prior to visual identification by pen riders.

Several systems that monitor feeding behavior patterns have been evaluated, including the GrowSafe®, Insentec®, and SensOor® system (Mendes et al., 2011; Chapinal et al., 2007; Wolfger et al., 2015). Each of these systems is designed to monitor individual animal intake and feeding behavior patterns, however, none of these systems have yet to be adapted to monitor brush usage behavior. As luxury behavior traits are not required for the sustainment of life, day-to-day variation in those traits is believed to occur prior to reduction in feeding behavior traits in cattle experiencing the onset of BRD. Therefore, monitoring both core and luxury behavior traits could improve the accuracy of preclinical detection of BRD in beef cattle. The CattleTraq® (AllTraq, Oklahoma City, OK) system varies in design from the technologies mentioned above because receivers are placed within the bunks and around the perimeter of the fence line to continuously communicate with ultra-wideband radio frequency identification (RFID) tags.

Validating this system is a necessary step prior to the assessment of the value of implementing this technology within a feedlot setting to not only monitor feeding behavior patterns, but also individual-animal brush use. Therefore, our objectives were to develop and evaluate various algorithms to convert geolocation data from the CattleTraq® RFID system into bunk-visit (BV) and brush-usage (BU) events.

Materials and methods

All animal care and use procedures were in accordance with the guidelines for use of Animals in Agricultural Teaching and Research as approved by the Texas A&M University Institutional Animal Care and Use Committee (IACUC # 2017-0257; IACUC # 2018-153).

Animal management and experimental design

Trial 1: Holstein steers (n = 12) sourced from a ranch in Stephenville, TX with an average initial BW of 160 ± 12 kg were used in this trial. The steers were randomly assigned to 1 of 2 pens (9 x 26 m) located at the Texas A&M University Beef Cattle Systems Research Center (College Station, TX), and adapted to a diet consisting of 33% cracked corn, 33% grass hay, 32% dried distillers' grain, and a 2% vitamin-mineral premix to meet requirements for growing cattle gaining 1 kg/d. Throughout the 10-d data-collection period, steers were fed twice daily, with feed delivery adjusted daily to achieve approximately 10% orts. The steers were fitted with ultra-wideband RFID (AllTraq®, Oklahoma City, OK) ear tags and foam stickers of unique shape and color to facilitate individual-animal identification during the collection of visual observation data via video recordings. A video surveillance camera (GV-EFD2101, GeoVision, Taiwan) was mounted 2.9 m above and 0.9 m in front of the center of the bunk for each pen to record individual animal feeding behavior activity (**Figure 3.1**). Internal clocks on the video cameras and the CattleTraq® data acquisition system was synchronized at the beginning of the trial to start recording at the same times each day.

Trial 2: Crossbred feedlot steers (n = 17) sourced from McGregor Research Center in McGregor, TX with an IBW of 493 ± 25 kg were used in this trial. The steers were randomly assigned to 1 of 2 pens (9 x 26 m) located at the Texas A&M University Beef Cattle Systems Research Center and fed a high-concentrate finisher diet containing 60% cracked corn, 28% dried distiller's grains, 10% grass hay and 2% mineral-vitamin premix to meet the requirements of finishing feedlot steers. These steers had previously been fed this diet during another study prior to the start of the current trial. Throughout the 7-d data-collection period, steers were fed twice daily, with feed delivery adjusted daily to achieve approximately 10% orts. The steers were fitted with ultra-wideband RFID ear tags and foam stickers of unique shape and color to facilitate individual-animal identification during the collection of visual observation data via video recordings.

Each pen was equipped with an L-shaped brush device (BarnWorld, Parker, CO) that was secured to the fence perimeter (**Figure 3.2**). The brushes in both pens were positioned in close proximity to each other to allow for a single surveillance camera (GV-EFD2101, GeoVision, Taiwan) to capture brush usage by animals in both pens simultaneously. The brushes were positioned 4 m from the water trough and 16 m from the feed bunk to minimize the influences of drinking and feeding activity on brush use. The brushes were positioned approximately 120 cm from the ground to allow for the steers to pass under the brush to groom their topline. The surveillance camera was located 2 m above the water trough oriented to the brushes to facilitate observed frequency and duration of brush-use events (**Figure 3.2**). The steers were adapted to the brushes for 2 d prior to the 7-d data collection period, and all steers were observed to have used the brush prior to the start of the trial. Internal clocks on the video cameras and the CattleTraq® data acquisition system was synchronized at the beginning of the trial to start recording at the same times each day.

The CattleTraq® system

The electronic (CattleTraq®) system used for this study consisted of computing hardware and software to provide real-time geolocation data for each animal within the pen. The hardware consisted of an ultra-wideband RFID transmitter attached to the animal via an ear tag, and multiple ultra-wideband RFID receivers positioned on the perimeter of the pens and fixed to the front face of the feed bunks (**Figure 3.3**). Geolocation of the tags was recorded at 1-s intervals and relayed back to a central server. Each feed bunk was fitted with 6 ultra-wideband RFID receivers that were spaced 0.91 m apart. In addition to the ultra-wideband RFID receivers positioned on the perimeter of the pens, an additional receiver was positioned above the water trough to facilitate capture of geolocation data for brush-use events. The geolocation data evaluated in this study was used to calculate the BV and brush-use events according to the multiple algorithms that are described below.

Data collection of observed behavior traits

Two trained observers independently viewed the time-lapse video and recorded the start and end times for each BV event using Behavioral Observation Research Interactive Software (BORIS; Friard and Gamba. 2018). The timestamps for a start of a BV event were based upon when the poll of the head of an animal crossed the edge of the feed bunk. Likewise, timestamps to end BV events were based upon when the poll of the head of an animal crossed the feed bunk edge into the pen area. For trial 1, video was captured for 8 h per d during a 10 d trial, starting at 0700 to 1100, and 1500 and to 1900 to correspond with the cattle being fed at 0800 and 1600 each day. Data from 5 of the 10-d period was available due to electrical/weather issues throughout the trial.

Likewise, for the second trial, two trained observers independently viewed the time-lapse video and recorded the start and end times for each BU event using Behavioral Observation Research Interactive Software (BORIS; Friard and Gamba. 2018). The timestamps for the start of BU events were recorded when the animal began use of the brush with their head, neck, shoulders, topline, side, or rump and timestamps to end BU events ended when the animal ceased contact with the brush. Total observer data was collected for 5 h per day from 1200 to 1700 during the 7-d collection period.

Electronic detection of behavior traits

An algorithm was developed to quantify the frequency and duration of BV events by recording the timestamps for the start and end of each BV event, based on when the geolocation coordinate for a tag was detected as entering and exiting the feed bunk. A virtual line was established that ran parallel to and at the edge of the feed bunk, which was defined as the 0-cm virtual line (**Figure 3.4**). Timestamps were recorded when the geolocation coordinate for a tag was first detected to have crossed the 0-cm virtual line to initiate a BV event and again, thereafter when the tag was detected to have crossed the 0-cm virtual line to end a BV event. As animals will often move their heads in and out of an open-feed bunk during a single observed BV event, multiple algorithms were evaluated to determine the optimal geolocational coordinate to end BV events. For this purpose, 3 additional virtual lines were established that ran parallel with the 0-cm virtual line, but that were 5, 10 or 15 cm from the edge of the feed bunk (0-cm virtual line). Four algorithms were evaluated for which the timestamp to initiate a BV event occurred when the tag was detected to have crossed the 0-cm virtual line and ended when the tag was detected to have crossed the 0-, 5-, 10- or 15-cm virtual lines; defined as the 0-0, 0-5, 0-10 and 0-15 cm algorithms. For each algorithm, the number of BV events detected per h and the sum of the durations of the BV events in min per h were recorded, and then compared to the frequency and duration of BV events that were observed. During the 5-d data-collection period, a total of 480 animal h of observed video were decoded and compared to the corresponding electronic data.

For the second trial, an algorithm was developed to quantify the frequency and duration of BU events by recording the timestamps for the start and end of each BU event, based on when the geolocation coordinate for a tag was detected within a virtual square boundary that surrounded the brush. As the brush was projected perpendicular to the fence line 90 cm into the pen, the width (x axis) of the virtual boundary started at 90 cm. As cattle often groom their rump when using a brush, multiple algorithms were evaluated to determine the optimal geolocation coordinates of the virtual boundary used to define BU events. For this purpose, 4 virtual boundaries were established that had the following x-y dimensions: 90 x 90, 120 x 120, 150 x 150 and 180 x 180 cm with the brush as the central point **(Figure 3.5).** These 4 algorithms were evaluated to determine the start and end of a BU event, which occurred when the tag was detected to have crossed in and out of the virtual boundary. For each BU algorithm, the number of BU events detected per h and the sum of the durations of the BU events in min per h were recorded and compared to the frequency and duration of BU events that were observed. During the 7-d data-collection period, a total of 595 animal h of observed video were decoded and compared to the corresponding electronic data.

Data received from the CattleTraq® system for each study was analyzed using R Studio (R Studio, Boston, MA) and converted into Excel (Microsoft Office Corp. Redmond, WA) files for further evaluation. Observation data transcribed through the BORIS monitoring system was compiled into Excel files to compare to the data collected by the ultra-wideband geolocation system.

Statistical analysis

Animal was the experimental unit for both trials. Observed and electronic measurements of BV and BU behavior traits were compared using a PROC MIXED model (JMP, SAS Institute Inc., Cary, NC) that included algorithm treatment as the fixed effects. For trial 1,the algorithms evaluated were 0-0, 0-5, 0-10 and 0-15 cm classifications to determine the geolocation virtual line to define timestamps for the start and end of BV events. For trial 2, the algorithms were 90-90, 120-120, 150-150 and 180-180 cm for the boundary positions for BU events.

Observed feeding behavior or brush use data were regressed on corresponding electronic data to obtain an estimate of precision (r^2). In addition, mean square error of prediction (MSEP), average absolute error of prediction (AAE), and concordance correlation coefficient (CCC) were computed using JMP® (SAS Institute Inc. Cary, NC) to assess the precision and accuracy of the geolocation system to predict feeding-behavior and brush-use traits. As described by DeVries et al. (2003), the sensitivity (likelihood that an animal present at the feed bunk or brush is detected present by the system), and the specificity (likelihood that an animal absent from the feed bunk or brush is detected absent by the system) were evaluated by determining feed bunk or brush presence and absence of observed and electronic BV or BU duration for each second of the video recording periods. Overall accuracy, sensitivity, and specificity were determined for each trial using SPSS (SPSS Inc. IBM. Chicago, IL).

Results

Bunk visit frequency and duration

The observed and electronic BV frequency and duration results are presented in **Table 3.1.** The average number of observed BV events recorded during the 10-d data collection period was 15.1 events per h. The electronic frequency of BV events was affected ($P < 0.05$) by the algorithm used define BV events. As the geolocation coordinate used to end BV events was increased from 0 to 15 cm, the frequency of electronic BV events decreased from 22.7 to 7.7 events per h. This inverse relationship between electronic BV frequency and distance from the edge of the feed bunk to end BV events occurred because cattle typically move their heads in and out of the feed bunk while remaining stationary during a single BV event. The electronic BV frequencies based on the 0-0 cm algorithm were higher ($P < 0.05$), and those based on the 0-10 and 0-15 cm algorithms lower ($P < 0.05$) than observed BV frequencies. The electronic BV frequencies based on the 0-5 cm algorithm did not differ from observed BV frequencies. The 0-0 and 0-10 cm algorithms used to define BV frequencies were more accurate and precise in predicting observed values compared to the 0-0 and 0-15 cm algorithms, based on greater r^2 (0.81), lower MSEP (7.1 and 9.1) and AAE (4.2 and 5.4) and higher CCC (0.90).

The average observed duration of BV events during the 10-d data collection period was 12.0 min per h. As for BV frequency, the electronic BV duration was affected ($P < 0.05$) by the algorithm used define BV events. As the geolocation coordinate used to end BV events was increased from 0 to 15 cm, the duration of electronic BV events increased from 9.1 to 11.9 min per h. The electronic BV duration based on the 0-0 and 0-5 cm algorithms were less ($P < 0.05$) than observed BV duration, whereas, the electronic BV durations based on the 0-10 and 0-15 cm algorithms did not differ from observed BV duration. Interestingly, none of the electronic BV durations were longer than the observed duration. For BV duration, the 0-10 and 0-15 cm algorithms were more accurate and precise in predicting observed values based on greater r^2 (0.91 and 0.89, respectively), lower MSEP (4.32 and 4.11) and AAE (1.90 and

1.74), and higher CCC (0.95 and 0.94). The observed and electronic data based on the 0-10 cm algorithm for frequency and duration of BV events is presented in **Figure 3.6**.

The sensitivity, specificity and accuracy of the CattleTraq® system to detect the presence of animals at the feed bunk for each BV algorithm is presented in **Table 3.2.** The sensitivity of the electronic system to detect animal attendance at the feed bunk was highest for the 0-0 cm algorithm and lowest for the 0-5 cm algorithm. The specificity of the electronic system for detection of animal attendance at the feed bunk was high for all BV algorithms and ranged from 92 to 95%. The 0-0 cm algorithm (88%) had the highest and the 0-5 cm algorithm the lowest accuracies (84%), with the 0-10 and 0-15 cm algorithms being intermediate in accuracy.

Brush use frequency and duration

The validation results for frequency and duration of BU events are presented in **Table 3.3**. The average number of observed BU events recorded during the 7-d data collection period was 0.98 events per h. When comparing the CattleTraq® system to the observed data for frequency of BU events, the 120-120, 150-150, and 180-180 cm algorithms did not differ from observed BU frequency, whereas, the electronic BU frequency generated by the 90-90 cm algorithm was less ($P < 0.05$) than observed BU frequency. As the virtual boundary used to define BU events was increased from 90 to 180 cm, the frequency of electronic BU events increased from 0.69 to 1.09 events per h. The 150-150 cm algorithm used to define BU frequencies was more accurate and precise in predicting observed values compared to the 90-90, 120-120 and 180-180 cm algorithms, based on greater r^2 (0.73), lower MSEP (0.94) and AAE (0.44), and higher CCC (0.85).

The average duration of observed BU events recorded during the 7-d data collection period was 0.87 min per h. The electronic BU duration was affected ($P < 0.05$) by the algorithm used define BU events. The electronic BU duration based on the 90-90 and 120-120 cm algorithms were less ($P < 0.05$) than observed BU duration, whereas, the electronic BU durations based on the 150-150 and 180-180 cm algorithms did not differ from observed BU duration. . As the virtual boundary used to define BU events was increased from 90 to 180 cm, the duration of electronic BU events increased from 0.43 to 1.08 min per h. Interestingly, the only BU algorithm that overestimated BU duration was the 180-180 cm algorithm. The electronic BU duration generated by the 150-150 cm algorithm was deemed more accurate and precise at determining the duration of BU events, based on greater r^2 (0.79), lower MSEP (0.88), lower AAE (0.37) and higher CCC (0.89). The observed and electronic data based on the 150-150 cm algorithm for frequency and duration of BU events is presented in **Figure 3.7.**

The sensitivity, specificity and accuracy of the CattleTraq® system to detect the presence of animals at the brush for each BU algorithm is presented in **Table 3.4.** The sensitivity of the electronic system to detect animal attendance at the brush was highest for the 180-180 cm algorithm and lowest for the 90-90 cm algorithm. The specificities of the electronic system for lack of animal attendance at the brush were high for all BU algorithms (99%). The 180-180 cm algorithm had the highest (79%) and the 90-90 cm algorithm the lowest accuracies (68%), with the 120-120 and 150-150 cm algorithms being intermediate in accuracy.

Discussion

Bunk visit frequency and duration

Previous research has evaluated the efficacy of implementing passive or ultra-wideband RFID systems within the feedlot industry. While other technologies such as Insentec® (Insentec B.V., Marknesse, the Netherlands) have shown extremely high accuracy (99%) for predicting feeding behavior and intake, this system is gated and only allows for a single animal to eat from a bunk at a time as a barrier prevents others from eating by raising when an EID is detected, and lowering when that animal leaves the bunk (Chapinal et al., 2007). Mendes et al. (2011) and also validated the GrowSafe® (GrowSafe Systems, Calgary, Canada) system for monitoring feeding behavior traits and reported correlations for BV frequency and duration of 68 and 81%, respectively. The sensitivity and specificity values (73.2 and 98.6%) from the first trial were comparable to those witnessed by DeVries et al. (2003), who validated an earlier version of the GrowSafe® system (87.2 and 99.2%, respectively). However, the GrowSafe® system, although not gated, only allows for one animal to use a single bunk at a time. For more animals to eat concurrently, more bunks must be added to each pen. In contrast, a validation study conducted by Wolfger et al. (2015) reported high sensitivity and specificity (95 and 76%) of SensOor tags equipped with accelerometers monitoring feeding events in crossbred steers. Additionally, the Wolfger et al. (2015) study evaluated feeding time on a per min basis, while our BV frequency and duration trial recorded BV duration on a per s basis, thus potentially increasing the incidences of falsely identifying an animal in the bunk. However, the sensitivity and specificity results for BV events observed in this study are comparable to other systems, indicating that the CattleTraq® system may be an effective tool for monitoring cattle location and behavior on a per second basis.

Other recent advantages in RFID sensors and receivers that track BV frequency and duration that require less intensive feed bunk system have been developed. In a system similar to CattleTraq®, Brown-Brandl et al. (2011) reported a 0.94 and 0.98 correlation value for observed BV frequency and duration, slightly higher than the values reported from the first trial. The Brown-Brandl et al. (2011) system utilizes passive RFID tags that communicate with receivers located within pipes along the feed bunk, similar to the structure used in trial 1.

Overall differences in each of the technologies discussed should be considered when comparing the accuracy of each individual systems capabilities. As this system operates with an open feed bunk that is present in most feedlots across the United States, the CattleTraq® system may require less maintenance to install as it is compatible with current feedlot infrastructure. While this system can detect individual location and presence at the feed bunk, a drawback of this system is the inability to monitor individual animal intake. Despite this setback, the CattleTraq® system has shown to accurately predict an animal’s appearance or absence from a bunk, which sets this system apart from competitors in terms of monitoring feeding behavior patterns and requires no adaptation period, nor renovation to the feed bunks or the pens.

Brush use frequency and duration

Previous research has not currently evaluated the accuracy of automatically monitoring BU behavior within the feedlot industry. Results from the BU frequency and duration trial demonstrated that the CattleTraq® system is currently unable to accurately record BU behavior, despite the favorable results from monitoring BV frequency and duration. Although correlation values were favorable for frequency and duration across the two larger dimensions, this did not translate into high sensitivity or accuracy values. Unlike Toaff-Rosenstein et al. (2017) who also monitored a RFID system for BU behavior, the second trial saw the CattleTraq® system consistently underestimate BU frequency and duration, implying that the algorithms used need to be widened to allow for the system to register posterior BU events. Specificity was high (99%) for the second trial, indicating the system was able to accurately register when an animal was not using the brush, and thus not registering false positives. As each steer utilized the brush for an average of 52 s per recorded h, overall specificity was expected to be high. This led to an inflated calculation for accuracy, but this number was still moderate to low (68-79%) for all algorithms. Compared to the automated brush system utilized by Toaff-Rosenstein et al. (2017), sensitivity was lower in the second trial, but less variable (36-58%). Toaff-Rosenstein et al. (2017) reported 54-100% sensitivity and 59-98% specificity for the 16 heifers utilized in the study. Therefore, the specificity for the second trial was consistently higher (99%) when compared to previous research.

Accuracy values were not reported by Toaff-Rosenstein et al. (2017), but as the sensitivity and specificity values were highly variable, the same trend would be expected for accuracy calculations. As the trial evaluated several dimensions with sub-par results for sensitivity and accuracy, but moderate to high correlation values, further enhancing the dimensions and refining the algorithm used to calculate BU start and end times may ensure more favorable results in a future study.

Compared to similar technologies, this system was able to consistently predict when an animal was eating from a bunk. However, without measuring feed intake or other feeding behavior patterns, there were limitations to this technology that should be explored further to determine if future renditions of the tags or receivers can measure those behaviors. The CattleTraq® system did experience intermittent periods of data loss caused by a faulty breaker. Despite this concern, the system does not require any major modifications to the current open bunks that are standard within the feedlot industry, unlike other competitors. While maintenance is key for this system to fully function, the CattleTraq® system accurately recorded both BV duration and frequency and could be a vital tool in more quickly identifying morbid animals while also assisting in improving bunk management practices.

Limited research has been conducted on the efficacy of utilizing an automatic RFID system to monitor BU in feedlot animals and thus requires more alterations, such as adding a pressure sensor to the brush to register when an animal is utilizing the structure and to provide a safeguard for false positives recorded by the CattleTraq® system. Although changes in feeding and activity behavior patterns have consistently aided in more quickly identifying the onset of disease (Toaff-Rosenstein et al., 2018; Toaff-Rosenstein et al., 2016; Pillen et al., 2016; Belaid et al., 2019), an effective strategy for accurately automating this process has not been developed. Further research should be conducted to refine the algorithms to increase the precision of monitoring BU behavior patterns before this method can be applied within a feedlot setting to potentially aid in more quickly identifying the onset of BRD in newly-received feedlot calves.

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Table 3.1 Effects of bunk visit (BV) algorithms on frequency and duration of BV events.

Trait	Mean	SD	R^2	MSEP[1]	AAE[2]	CCC[3]
BV frequency, events/h						
Observed	15.1^{a}	16.0	--	--	--	--
0-0 cm	22.7^{d}	22.75	0.75	14.1	8.68	0.87
0-5 cm	14.0^{a}	14.0	0.81	7.10	4.16	0.90
0-10 cm	10.4^{b}	10.7	0.81	9.14	5.38	0.90
0-15 cm	7.68^{c}	8.21	0.79	12.2	7.58	0.87
BV duration, min/h						
Observed	12.0^{a}	12.1	--	--	--	--
0-0 cm	9.08^{c}	9.65	0.86	5.93	3.29	0.93
0-5 cm	10.3^{bc}	10.7	0.88	4.82	2.32	0.94
0-10 cm	11.1^{ab}	11.4	0.91	4.32	1.90	0.95
0-15 cm	11.9^{a}	12.1	0.89	4.11	1.74	0.94

[abcd] means separated by different letters for each trait differ from the observed $P < 0.05$; [1]MSEP = mean square error of prediction; [2]AAE = average absolute error observed - predicted; [3]CCC = concordance correlation coefficient.

Table 3.2 Effects of the algorithms on sensitivity, specificity, and accuracy of the electronic system to detect bunk visit attendance.

Trait	Sensitivity[1]	Specificity[2]	Accuracy[3]
0-0 cm	84.1	92.2	88.2
0-5 cm	73.6	95.1	84.4
0-10 cm	78.2	93.6	85.9
0-15 cm	81.6	91.6	86.6

[1] Sensitivity = true positive rate, percent of time the system correctly identified the animal within the feed bunk; [2] Specificity = true negative rate, percent of time the system correctly identified the animal outside of the bunk; [3] Accuracy = overall system accuracy, the average of sensitivity and specificity at that out of bunk rule.

Table 3.3 Effects of brush usage (BU) algorithms on frequency and duration of BU events.

Trait	Mean	SD	R^2	MSEP[1]	AAE[2]	CCC[3]
BU frequency, events/h						
Observed	0.98^{ab}	1.73	--	--	--	--
90-90 cm	0.69^{c}	1.4	0.67	1.03	0.50	0.82
120-120 cm	0.84^{a}	1.62	0.72	0.93	0.45	0.85
150-150 cm	0.97^{ab}	1.74	0.73	0.94	0.44	0.85
180-180 cm	1.09^{b}	1.93	0.67	1.13	0.52	0.82
BU duration, min/h						
Observed	0.87^{ab}	1.85	--	--	--	--
90-90 cm	0.43^{d}	1.08	0.72	1.18	0.49	0.85
120-120 cm	0.63^{c}	1.50	0.78	0.92	0.37	0.88
150-150 cm	0.83^{b}	1.83	0.79	0.88	0.37	0.89
180-180 cm	1.08^{a}	2.31	0.71	1.27	0.49	0.84

^{abcd} means separated by different letters for each trait differ $P < 0.05$; [1]MSEP = mean square error of prediction; [2]AAE = average absolute error observed - predicted; [3]CCC = concordance correlation coefficient.

Table 3.4 Effects of the algorithms on sensitivity, specificity, and accuracy of the electronic system to detect brush attendance.

Trait	Sensitivity[1]	Specificity[2]	Accuracy[3]
90-90 cm	35.7	99.5	67.6
120-120 cm	45.7	99.4	72.6
150-150 cm	52.8	99.3	76.1
180-180 cm	58.3	99.2	78.8

[1] Sensitivity = true positive rate, percent of time the system correctly identified the animal within the feed bunk; [2] Specificity = true negative rate, percent of time the system correctly identified the animal outside of the bunk; [3] Accuracy = overall system accuracy, the average of sensitivity and specificity at that out of bunk rule.

Figure 3.1 An overhead view of the feed bunks equipped with an ultra-wideband RFID system to measure observed BV events.

Figure 3.2 An overhead view of the brushes in pens equipped with an ultra-wideband RFID system to measure observed BU events.

Figure 3.3 Ultra-wideband RFID receivers used to capture electronic feeding behavior in trial 1.

Figure 3.4 Overview of a feed bunk. The green ovals denote ulta wide-band RFID receivers. The virtual line parallel to the feed bunk at 0 cm was used to start a BV event. The y-axis denotes the virtual line the steers needed to cross to end a bunk visit (BV) event at 0, 5, 10, or 15 cm.

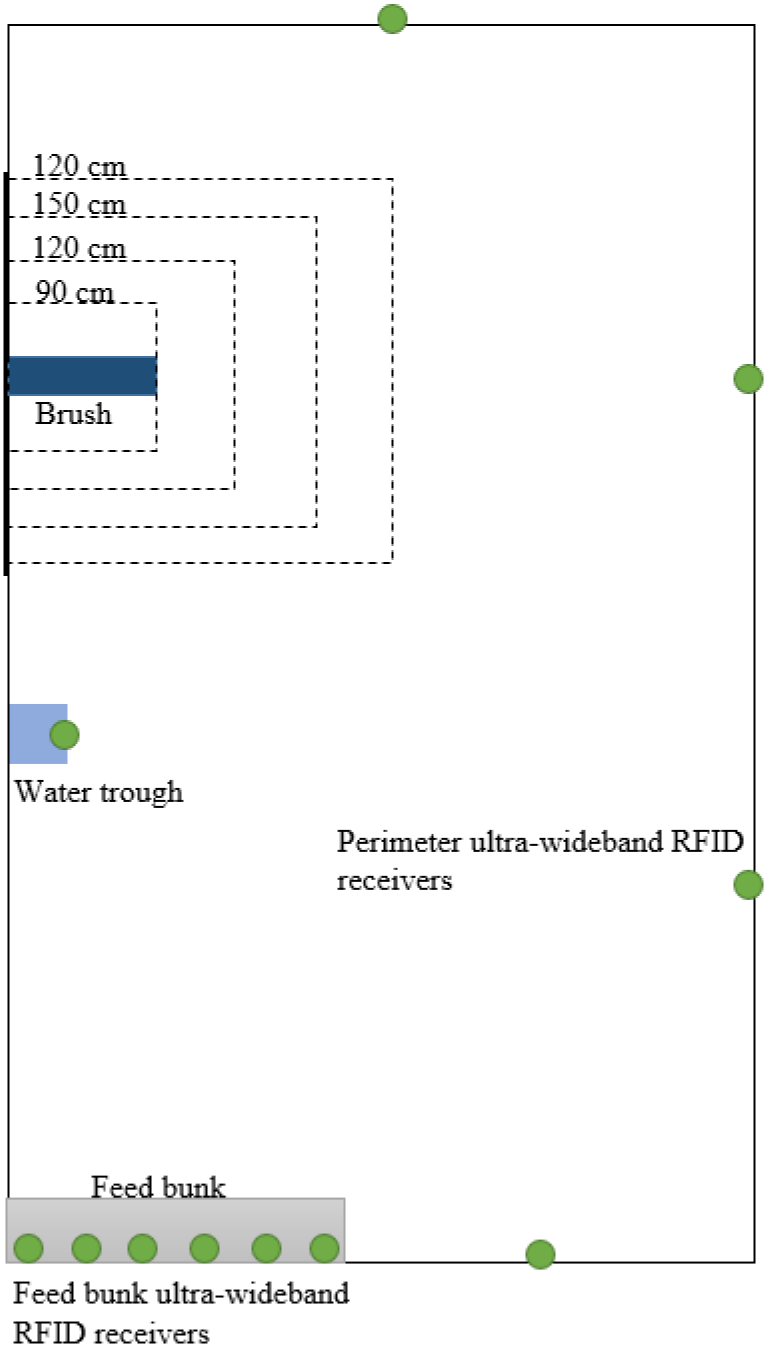
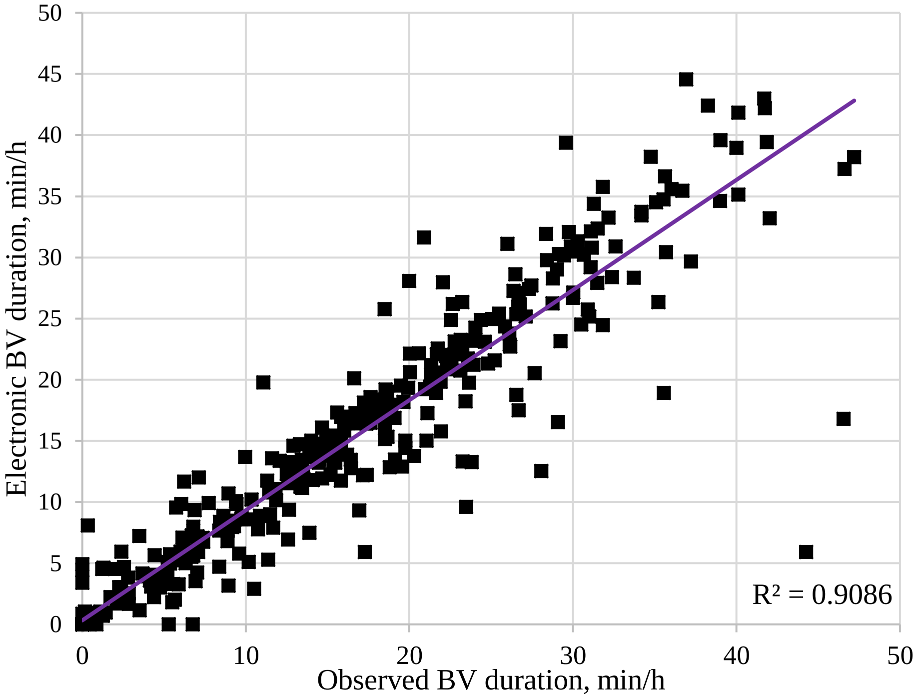


Figure 3.5 Overview of a pen with a brush. Green circles denote receivers, and the dark blue rectangle represents the brush. Each of the dotted lines represent the virtual perimeter (x and y axis) around the brush for each algorithm (90-90, 120-120, 150-150, 180-180 cm). Design is not created to scale.



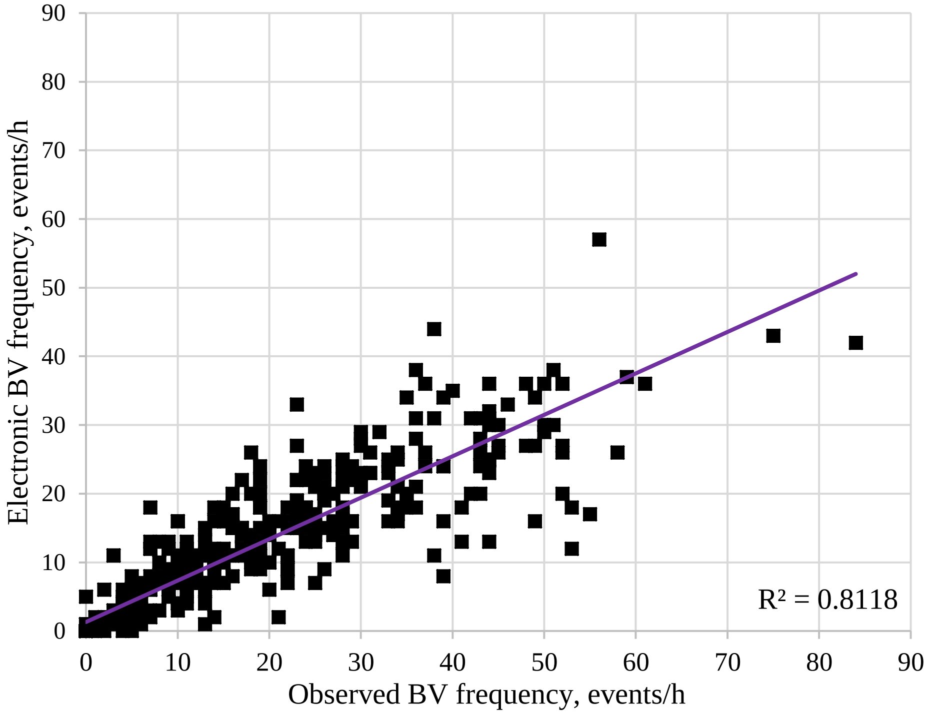
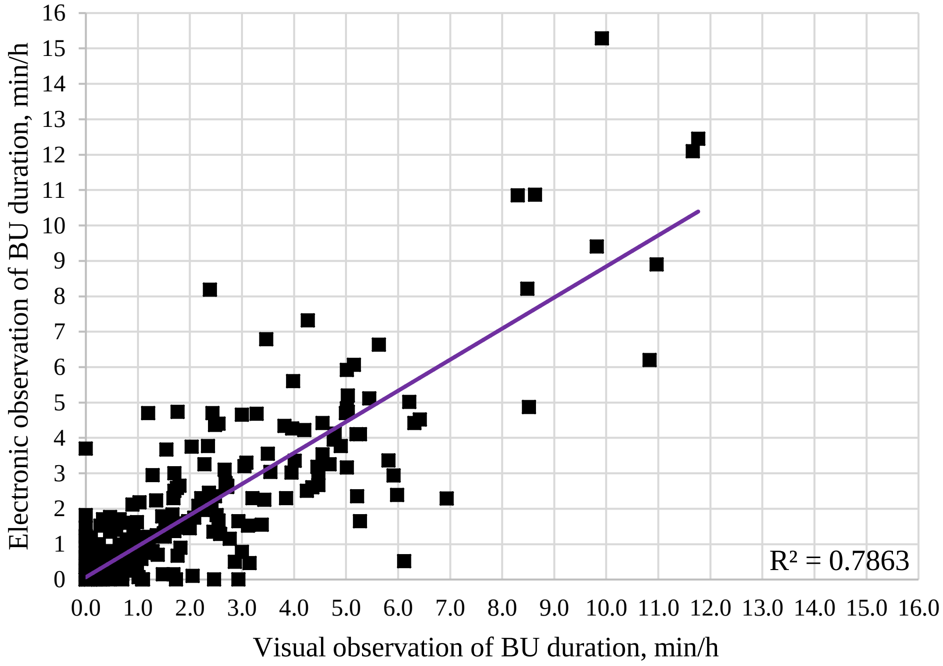


Figure 3.6 Electronic vs. observed bunk visit (BV) events using the 0-10 cm algorithm for duration (top panel) and frequency (bottom panel).



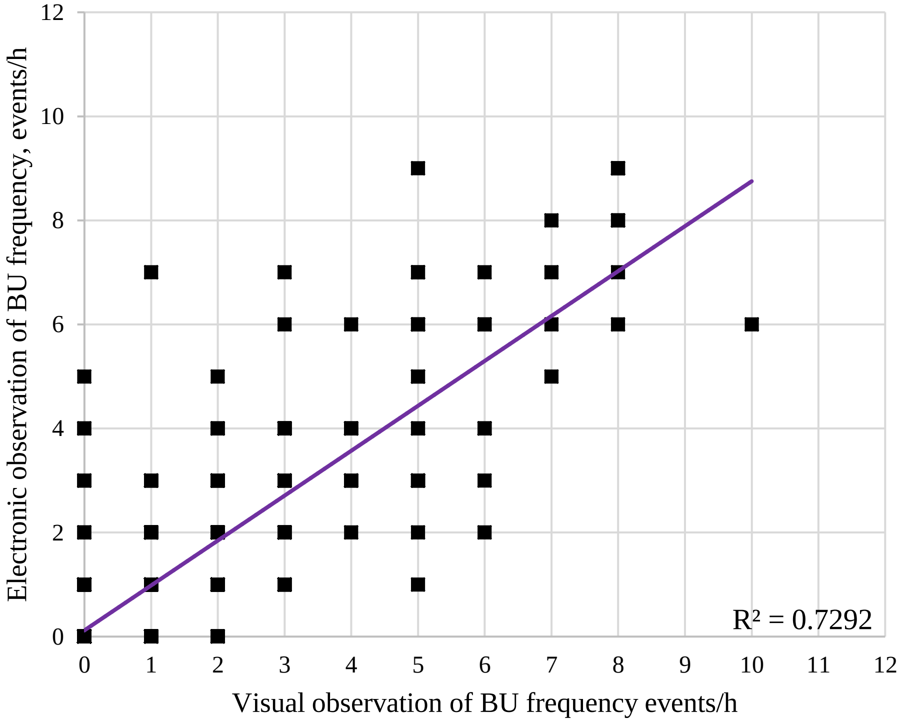


Figure 3.7 Electronic vs. observed brush usage (BU) events using the 150-150 cm algorithm for duration (top panel) and frequency (bottom panel).

CHAPTER IV

CONCLUSIONS

A potential strategy to provide food to an ever growing population is to develop alternatives to antibiotic feed additives to improve feed efficiency. An emphasis on disease prevention rather than treatment has emerged, thus research into naturally occurring feed additives has become more common in recent years. The objectives of the study in chapter 2 were to evaluate the effects of direct-fed microbials (DFM) with or without monensin plus tylosin on the performance, feeding behavior patterns and feed efficiency of steers transitioned to a high-concentrate diet. Crossbred steers were randomly assigned to 1 of 4 treatments (n = 32) in a 2 x 2 factorial design, with Factor 1 being diets with DFM (25 g/d; Natur's Way) or without DFM (CON), and Factor 2 being diets with monensin (40 g/ton) and tylosin (10 g/ton; MON) or without MON (CON). Average daily gain was higher, feed efficiency and RFI was improved for the steers fed monensin and tylosin diets during the grower/transition period. The DFM-fed steers had a lower ADG and tended to have a higher RFI compared to steers not supplemented with DFM. Steers fed the monensin diets had a decrease in daily variances of bunk visit and meal frequency events during the grower/transition period. There were MON x DFM interactions ($P < 0.10$) for ADG and F:G during the finisher period. Numerically, steers had a 4.7% lower F:G when the MON diet without DFM was fed, whereas, F:G was higher in steers fed the MON diet containing DFM. During the finisher period, steers fed MON diets had lower ($P < 0.01$) DMI and lower RFI ($P < 0.01$; -0.23 vs 0.23 kg/d). Conversely, DFM-fed steers had higher RFI compared to respective controls. MON-fed steers consumed less DMI, spent 9% more time consuming meals, thus had a 14% slower meal eating rate than steers not supplemented with monensin. Results from this study demonstrated minimal improvements on performance and feeding behavior traits in cattle supplemented with DFM. Although the magnitude of improvement in feed efficiency due to MON was small, results demonstrated that MON may minimize digestive upsets by reducing daily variation in feeding behavior during diet transition and slow meal-eating rate on high-grain diets.

Increasing the productivity of an animal by improving the welfare or feeding program are effective strategies to maximize the economic and environmental sustainability of the beef industry. By understanding the feeding behavior and luxury behavior patterns of feedlot cattle, producers are able to select for more productive animals and potentially more quickly identify the onset of disease. Chapter 3 displayed the results of the two validation trials of an ultra-wideband RFID system for both feeding behavior and brush usage behavior patterns. The CattleTraq® system has shown it can predict bunk visit frequency and duration with coefficients of determination of 0.91 and 0.91, respectively when the 0-10 cm out of bunk algorithm was applied. Using the same algorithm for sensitivity and specificity, the system presented values of 78% and 94%, respectively, with a combined accuracy of 86%. These results are favorable for the system and validates the first objective of the overall study.

For the second trial within chapter 3, results demonstrate that the CattleTraq® system is not currently able continuously monitor brush usage frequency and duration. Although the coefficients of determination were relatively high at 0.73 for brush usage frequency and 0.79 for brush usage duration for the chosen algorithm of 150-150 cm, this did not translate to high sensitivity or specificity values. The system reported a sensitivity and specificity value of 52.8% and 99%, respectively for the chosen algorithm (150-150 cm). This led to an overall accuracy of 76%, therefore more refining to the algorithms utilized should be further researched to elucidate the proper algorithm to use to continuously monitor brush usage behavior.