ASSOCIATIONS OF FEEDING BEHAVIOR PATTERNS WITH INTER-ANIMAL VARIATION IN FEED EFFICIENCY AND PRE-CLINICAL RESPONSES TO INFECTIOUS DISEASE IN BEEF CATTLE

A Thesis

by

KIRBY S. JACKSON

Submitted to the Office of Graduate and Professional Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Chair of Committee,	Gordon E. Carstens
Committee Members,	William B. Pinchak
	Luis O. Tedeschi
Head of Department,	H. Russell Cross

May 2015

Major Subject: Animal Science

ABSTRACT

The objective of study 1 was to examine the associations between feeding behavior traits and performance and residual feed intake (RFI) in Brangus steers (N = 84). Steers with low-RFI phenotypes consumed 19% less ($P < 0.01$) DM intake while BW and ADG were similar compared to high-RFI steers. Steers with low RFI also spent 21% less time at the feed bunk, had 6% fewer ($P < 0.05$) bunk visit (BV) events, and tended ($P = 0.08$) to have 11% shorter meal durations per day than steers with high RFI. There were no differences in carcass quality or carcass income, therefore the reduction in feed cost of the low-RFI steers resulted in an increase ($P < 0.05$) in net revenue of $145 per animal compared to high-RFI steers. Time to bunk (TTB) was quantified on a daily basis as the interval length between feed truck delivery and the first BV event. Time to bunk was weakly correlated ($P < 0.05$) in a negative manner with ADG (-0.27) and positively correlated with exit velocity (0.25) and F:G ratio (0.25). Steers with low-TTB phenotypes gained 18% faster ($P < 0.05$), tended ($P = 0.08$) to have 11% more favorable F:G, and resulted in $88 more net revenue per animal ($P < 0.05$) than steers with high TTB. Results from this study demonstrated that animals with divergent phenotypes for RFI exhibited distinctive feeding behavior patterns, suggesting that feeding behavior traits could be useful as phenotypic biomarkers for RFI. The objective of study 2 was to characterize deviations in DM intake and feeding behaviors in bulls (N = 231) exhibiting clinical symptoms of bovine respiratory disease (BRD). The bulls were separated into 2 cohort groups based on observed clinical illness (N = 30) or those treated metaphylactically Draxxin (N = 201). A 2-slope broken-line regression model was applied separately on a population basis to the clinically-ill and metaphylaxis-treated cohorts to identify inflection points in DM intake and feeding behavior traits. The model detected inflection points for DM intake were 6.79 and 3.81 d prior to observed clinical illness or metaphylaxis treatment, respectively. Furthermore, the model detected inflection points for individual feeding behavior traits that (BV frequency and duration, Head down duration, maximum non-feeding interval, and non-feeding interval SD) ranged from 14.19 to 1.32 d prior to observed clinical illness, and from 12.59 to 3.79 d prior to metaphylaxis treatment. To further assess the value of monitoring deviations in feeding behavior traits as a method for pre-clinical detection of infectious disease individual CUSUM charts were constructed in a daily iterative manner to replicate real-time data analysis. The CUSUM model based on DM intake yielded a high proportion of true positives (87%; model predicted animal as ill) and high model test efficiency (89%) in the clinically-ill cohort, whereas, in the metaphylaxis-treated cohort the proportion of true positives detected (71%) and test efficiency (84%) were slightly lower. While time of model detection prior to observed clinical illness based on DM intake was not different (0.9 d; $P > 0.10$), time of model detection prior to metaphylaxis treatment was different (3.0 d; $P < 0.05$). Using BV duration, model times of detection were 2.7 ($P < 0.05$) and 7.9 d ($P < 0.05$) prior to clinical observation or metaphylaxis treatment, respectively. Results from study 2 demonstrated that use of statistical process control models to examine deviations in feeding behaviors were effective at predicting clinical symptoms of BRD, and that feeding behavior traits were more predictive than DM intake for pre-clinical detection of morbidity events in growing bulls.

DEDICATION

I would like to dedicate this thesis to my family. Without their loving support none of this would have been possible. They were there to share in the highs and lows and always left me with a smile on my face. Their guidance has led me to accomplish so much and will continue to do so as I move on to the next step of this amazing journey.

ACKNOWLEDGEMENTS

I would like to thank my committee chair, Dr. Gordon Carstens, and my committee members, Dr. Luis Tedeschi, and Dr. William Pinchak, for their guidance and support throughout the course of this research. I would also like to thank Miss Yu Fu, Dr. Jim Wall and Dr. Banerjee for their insight and collaboration on this project.

Thanks also go to my friends and colleagues here in the department who have helped me during my research. Also for their support and source of constant entertainment that were always present while working together.

Finally, I would like to thank my girlfriend Joan. You have been there through thick and thin and it has made a world of difference.

TABLE OF CONTENTS

Page

CHAPTER

LIST OF FIGURES

LIST OF TABLES

TABLE Page

CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

Introduction

The use of feeding behavior traits as phenotypic biomarkers of growth efficiency and for pre-clinical detection of morbidity in beef cattle has the potential to improve profitability in the beef industry. With advancements in computer technology to quantify individual-animal feeding behavior traits in a cost-effective manner, the opportunity to monitor the health status of animals may well improve current feedlot management practices. In addition, use of these technologies may further influence the implementation of individual cattle management systems that segregate cattle based on predictive outcome groups, which would allow producers to improve the overall efficiency of production systems.

Feed Efficiency

One strategy to increase net returns for beef cattle production systems is to select for improved genetic merit for feed efficiency. Since feed cost is second only to purchase cost of animals in the variable costs of beef cattle production systems, increasing efficiency can play a large role in the net revenue generated. In addition, since approximately 70-75% of the energy requirements needed by the beef cow/calf sector of the beef industry can be attributed to the support of maintenance energy requirements, lowering overall energy requirements would also decrease the input costs of the breeding herd (Ferrell and Jenkins, 1985). If current performance standards can be maintained and individual-animal efficiency improved, the inputs to a beef production system could be reduced and net revenue increased proportionally (Arthur et al., 2001).

There are many different ways to evaluate feed efficiency in cattle, one of which is feed conversion ratio (FCR), which is the ratio of feed intake to body weight gain. Feed conversion ratio has been found to be moderately heritable in beef cattle (Bishop et al., 1991), and also is widely used to evaluate the quality of diets and the effects of management practices on the efficiency of production in the growing and finishing stages of the beef production cycle (Carstens and Tedeschi, 2006).

There are, however, disadvantages to the use of FCR as a selection trait in beef cattle, as FCR is known to be negatively correlated with average daily gain (ADG) and body weight (BW). This indicates that favorable selection for FCR would result in an increase in mature cow size, which would lead to an increase in energy requirements and corresponding higher feed requirements (Arthur et al., 2001).

Feed efficiency can also be evaluated using residual gain (RG), which is a measure of the efficiency of an animal to gain body weight. Residual gain is the difference between actual body weight gain and expected gain based on a regression of ADG on feed intake and mid-test $BW^{0.75}$. As RG is positively correlated with growth traits, favorable selection for RG may also result in larger mature cow size.

Another method of assessing feed efficiency is residual feed intake (RFI), which Arthur et al. (2001) concluded was the preferred selection trait for improvement of postweaning feed efficiency of beef cattle. Koch et al. (1963) first proposed RFI as a measure of feed efficiency that would be independent of growth traits, which is one way that RFI differs from FCR. An animal’s RFI is calculated by comparing that animal’s actual intake to the expected intake for its maintenance and growth based on individual body weight and performance characteristics (eg. growth, milk, or pregnancy status).

Calculating RFI on an individual-animal basis requires the collection of individual intake records, which can be time consuming and expensive. There are multiple ways to collect individual intake records for beef cattle including use of Calan gate feeders, and electronic intake measurement system such as GrowSafe® System (Airdrie, AB, Canada). This feed intake measurement system uses radio frequency identification (RFID) to individually record animal feed intake and feeding behavior. The GrowSafe system only allows one animal at a time to access the feed bunk, which records the weight disappearance of feed to compute individual-animal intake.

To calculate RFI, on an individual basis predicted intake calculated by the regression of feed intake on mid-test $^{BW0.75}$ and ADG is subtracted from actual DM intake. Residual feed intake is a measure of the individual variation in feed intake not attributed to the animal's maintenance requirement or growth rate (Archer et al., 1999). Similar to FCR, the heritability estimates of RFI in beef cattle range from 0.16 to 0.43 (Herd et al., 2003).

Selecting animals with favorable genetic merit for RFI can positively impact the net revenue of beef production systems. If for example, RFI were reduced by 1 kg/d, feed cost for feedlot steers on feed for 200 d at $0.30 per kg feed DM would result in a feed cotst savings of $60 per animal. Net returns for these animals would be increased proportionally as performance traits and carcass incomes would not be affected.

Bovine Respiratory Disease

Bovine respiratory disease (**BRD**) is a disease complex caused by a variety of bacterial or viral pathogens that can be brought on by placing animals in stressful situations due to transportation, handling, comingling, and adverse weather conditions. Bovine respiratory disease is the most prevalent and costly disease faced by the United

States feedlot industry (Smith, 1998), and accounts for approximately 75% of morbidity and 50-70% of mortality cases annually in feedlot cattle (Galyean et al., 1999).

Animals experiencing morbidity have been shown to generate less revenue than healthy animals due to treatment costs, decreased performance, and lower carcass quality. Multiple studies have attempted to quantify the costs associated with respiratory illness in feedlot cattle. Smith (1998) concluded that the value of morbid calves was $0.19 to $0.35 less per kilogram than for healthy calves because of decreased performance and increased medical expenses. It was also reported that of total morbidity, 65-80% occurred during the first 45 days of a feeding period with 67-82% of the total due to respiratory illness. Fulton et al. (2002), evaluated the economic impact by comparing cattle that were not treated for BRD (healthy) with cattle treated either 1, 2, or 3 times. The animals treated 1x, 2x, and 3x or more treatments during the trial generated $40.64, $58.35, and $291.93 less net revenue, respectively, than the animals that were never treated. Snowder et al. (2006) conducted a study to characterize genetic, environmental, and economic factors related to BRD in a dataset representing 18,112 calves. The study reported that steers were more likely to have BRD than heifers possibly due to the effect of castration before entering the feedlot. The study also reported that the economic cost of lower gains and treatment for BRD was estimated to be $13.90 per head for a 1,000 hd feedlots excluding the labor and handling costs. These studies demonstrate the substantial economic impact resulting from the treatment cost and loss of production due to respiratory disease in finishing cattle.

Decreased performance is one of the largest expenses associated with subclinical and clinical cases of BRD. Snowder et al. (2006) reported that calves experiencing a period of BRD had 0.04 kg/d lower ADG than animals that were healthy throughout the feeding period. They reported that infected animals could be expected to be 8 kg lighter than healthy animals at the end of a 200 day feeding period. Wittum et al. (1996) also reported lower gains (-0.08 kg/d) in animals that had lung lesions attributed to respiratory illness. In agreement with these results, Gardner et al. (1999) reported that animals with lung lesions present at harvest had lower (-0.15 kg/d) gains, lighter HCW (-13.3 kg), lower marbling scores, and higher Warner Bratzer shear force values than steers without lung lesions present at harvest.

Another reason for reduced income is the cost of treating respiratory illnesses. Fulton et al. (2002) examined the impact of mortality across 24 herds totaling 417 calves in an Oklahoma feedlot. The study reported a treatment cost per herd that ranged from $0.00-$20.70 per animal with the largest treatment costs incurred by the herds with the largest incidence of BRD. Snowder et al. (2006) estimated an average treatment cost of $15.57 per animal treated for BRD. These costs represent a significant reduction in profit for animals experiencing BRD related morbidity events.

Subjective Visual Methods to Evaluate Animal Health

For effective treatment, animals with BRD must be identified as early as possible in the disease process. This is often not the case given that current methods rely on subjective evaluation by trained pen riders to detect clinical symptoms such as depression or nasal discharge. Cattle, as prey animals, tend to mask overt clinical symptoms of illness to avoid drawing attention to themselves by predators. Clinical symptoms also tend to appear later in the disease process, which limits the effectiveness of drug therapy. The current method of subjective evaluation uses clinical scores to estimate the severity of illness. Typical clinical scores involve 4 components including evaluations of respiratory insult, digestive insult, temperature score and lethargy. These factors are combined to represent an overall morbidity score that is used to determine if microbial therapy is required. Numerous studies have shown poor to fair relationships between animals treated for BRD and the presence of lung lesions at harvest. Wittum et al. (1996), examined the relationship between lung lesions at harvest, and treatment for BRD in 469 feedlot steers, and found that while 72% of the steers had lung lesions present at time of harvest only 35% had been previously treated for respiratory illness. Pulmonary lesions were observed in 68% of the untreated steers and 78% of the treated steers. Gardner et al. (1999) reported that only 48% of cattle treated for BRD had lung lesions, and that 37% of the cattle not treated also had lung lesions at harvest, indicating that current methods of BRD detection are not adequate to accurately detect sick cattle.

Remote Sensing Technologies to Detect Morbidity in Animals

Various remote sensing technologies have been developed to evaluate real-time measurement of core-body temperatures. Rectal temperature is often used as an indicator of illness but it can be difficult to obtain because it requires the removal of an animal from a pen to obtain measurements. For this reason, there has been recent interest in evaluating methods to remotely record internal temperature. Rose-Dye et al. (2011) evaluated the use of remote rumen temperature boluses to detect deviations in temperature in response to exposure to either bovine viral diarrhea or Mannheimia haemolytica. The experimental animals were fitted with rumen boluses that transmitted temperature data at minute intervals. They reported high correlations (r = 0.89) between rumen temperature and rectal temperature, and found that challenged animals had higher rumen temperatures than the control animals. Timsit et al. (2011) also evaluated the use of rumen temperature boluses to detect changes to core-body temperature in 24 bulls. Animals that experienced a period of reticulo-rumen hyperthermia (**RH**) were evaluated for symptoms of BRD. Of the 52 RH episodes, BRD was diagnosed 38 times resulting in a positive predictive value of 73%. The clinical detection of BRD occurred from 12 to 136 h after a RH episode. These results indicate that use of internal temperature may be effectively used for early pre-clinical detection of BRD.

Another method that has been evaluated to detect changes in temperature is infrared thermography. Infrared thermography detects the infrared energy emitted from an object and displays the amount of energy in temperature. One advantage of infrared thermography is the ability to detect temperature at a distance compared with traditional rectal temperatures that requires animals to be restrained. Schaefer et al. (2004) conducted a study using infrared thermography to detect deviations in skin surface temperature in 15 heifers. The study compared temperature data from 10 calves infected with bovine viral diarrhea virus to 5 control animals that were housed separately to remove the risk of transmission from the infected animals. The study concluded that the infected animals had elevated temperatures from several days to as much as 1 week prior to when clinical symptoms were observed. In another study conducted by Schaefer et al. (2007), infrared thermography was used to assess morbidity in 133 weaned calves. They reported that positive predictive values were 10% greater, negative predictive values were 20% greater, and overall test efficiency was 16% greater compared to the industry standard of clinical scoring. In addition, Schaefer et al. (2007) found that changes in temperature occurred from 4 to 6 d prior to the onset of observed clinical symptoms.

There has also been some interest in examining the relationships between physical activity and morbidity. Theurer et al. (2013b) examined the effects of pneumonia on the behavior and physiology responses of 18 beef heifers. The experimental animals were fitted with accelerometers, pedometers, and positioning devices for 9 d after 10 of the animals were challenged with *Mannheimia haemolytica*. All calves exposed to *Mannheimia haemolytica* had lung lesions at harvest indicating that all animals experienced pneumonia. The exposed calves spent less time at the hay and grain feeders and spent more time lying after exposure compared to control calves. There was also a significant interaction between the treatment group and trial day for the pedometer data, where exposed calves took fewer steps than healthy calves. These results indicate that changes in physical activity are also predictive of clinical symptoms associated with BRD.

Feeding Behavior to Predict Morbidity

Another method that may be useful in assessing the health status of animals involves monitoring of feeding and drinking behavior. Multiple studies have evaluated the relationship between feed efficiency and feeding behavior traits in healthy animals. McGee et al. (2014) reported significant correlations between RFI and bunk visit frequency and duration, feeding bout frequency and duration, and meal frequency in steers. Similar to these results, Nkrumah et al. (2006) reported strong correlations between bunk visit duration and RFI, DM intake, and feed conversion ratio in growing bulls. Another study by Hafla et al. (2013) reported that low RFI animals spent 26% less time at the feed bunk and cow RFI was strongly correlated (0.61) with bunk visit frequency and moderately correlated (0.35) with bunk visit duration. Kelly et al. (2010b) examined the repeatability of feeding behavior traits between growing and finishing phases in beef heifers. The study reported repeatability estimates for feeding duration, feeding events, feed intake per feeding event, and eating rate of 0.65, 0.73, 0.76, and 0.74, respectively, between the growing and finishing phases. These studies present evidence of moderate relationships between feeding behaviors and RFI in cattle. Moreover, feeding behavior traits are highly repeatable, and are positively associated with DM intake.

Feeding behaviors could also be early indicators of BRD because appetite depression is one of the first clinical responses to BRD. Daniels et al. (2000) reported healthy calves spending 33% more time at the feed bunk and having more visits to the feed bunk than morbid calves. Sowell et al. (1999) examined the relationship between health and feeding behavior in two trials, with 108 and 143 animals, respectively. Animals were fitted with passive radio frequency identification (RFID) tags to record feeding and watering behavior. In the first trial, morbid animals spent less time at the feed bunk and had fewer feeding bouts than the healthy animals. Healthy animals spent an average of 60 min a day at the feed bunk compared to 46 min for the morbid animals. In the second trial, there was no difference in feeding duration, but the morbid animals had fewer feeding and drinking bouts than the healthy animals.

Urton et al. (2005) examined feed bunk attendance in 26 dairy cows at risk for clinical metritis over a 3-wk trial period. During the trial period, 69% of the animals displayed clinical symptoms of metritis. On average, the metritic cattle spent 22 min a day less time at the feed bunk and for every 10 min decrease in average feeding duration animals were twice as likely to become metritic. Using a 75 min threshold for average daily feeding time, metritis could be detected with a sensitivity and specificity of 89 and 62%, respectively. Goldhawk et al. (2009) examined the differences in feeding behavior traits between healthy cows, and cows with subclinical ketosis. Results showed that cows with subclinical ketosis consumed 20% less feed, and had 22% fewer feeding bouts and spent less time feeding than healthy cows. Similar to Urton et al. (2005) a 10 min decrease in feeding duration resulted in a 1.9 times higher likelihood of developing ketosis.

One of the limitations to using feeding behavior to detect morbidity is that current available methods to record feeding behavior are cost prohibitive to use on a large scale basis. One of the more widely used systems is the GrowSafe system (Airdrie, AB, Canada), which allows for the recording of individual measurements of feeding intake and feeding behavior traits. One drawback to the GrowSafe system is the high input costs of the system due to the need for each feed bunk to include load bars to weigh feed. This system continuously records weight entering and leaving the trough that is then matched to an individual animal feeding record. Due to the need for a cost effective method for feeding behavior detection, there has been some interest in the development of active RFID technology for this purpose.

The Use of Statistical Process Control to Evaluate Feeding Behaviors

Another limitation to the use of feeding behavior to detect morbidity is the lack of effective predictive algorithms to accurately detect morbidity. One of the methods being evaluated for this purpose involves the use of statistical process control (**SPC**). Statistical process control is a method that can be used to monitor, control, and improve production through statistical analysis (De Vries and Reneau, 2010). Statistical process control is a way to track changes over time in a manner that allows for the application of statistical procedures to indicate changes that are not due to the natural variation in the data stream. Statistical process control was founded by Walter Shewhart in the 1920 to improve industrial manufacturing processes. The basic principles of SPC are derived from the study of variation, and the theory that there are two causes of variation, common and special. Common cause variation comes from the normal variability produced by any process. Special cause variation is the result of external factors acting on the process that significantly impacts the variance between outputs. The control chart is one way to analyze and visualize the variation within a process (Thor et al., 2007). The simplest form of the control chart is the Shewhart chart, which plots the average of a set of samples against the time each set was taken. The values are then evaluated against control lines which are set at 3 SD for the entire data set. If a value exceeds the distance of 3 SD from the mean of the process, the system is deemed out of control. Another type of control chart is the cumulative summation (**CUSUM**) chart. A CUSUM chart is designed as the cumulative summations of the distance of each sample mean from the average of all the sample means. The values are then plotted against the control lines, which are set using the SD of the entire data set. The CUSUM chart is valuable for detecting relatively minor shifts in the overall mean value due to special-cause variation.

There have been a small number of studies that have used some form of SPC to evaluate changes in animal behavior to detect morbidity. In one such study, Quimby et al. (2001) used SPC in a retrospective analysis to evaluate the effectiveness of feeding behavior to detect morbidity in newly received feedlot cattle. The study incorporated the use of passive RFID technology to collect feeding duration data for individual animals. The individual-animal records were analyzed using CUSUM charts to detect deviations in behaviors resulting from morbidity events, which were then compared to the date of clinical detection by experienced pen riders. Quimby et al. (2001) concluded that use of

SPC methods to monitor feeding behavior allowed for the detection of morbidity between 4.5 and 3.7 d earlier than observed by experienced pen riders. The results also showed a high accuracy for the detection of morbidity with a positive predictive value, negative predictive value, and a test efficiency of 87, 91, and 90% respectively. Lukas et al. (2008) used a combined CUSUM and Shewhart charting scheme to detect changes in water and DM intake of dairy cows. The study was designed to test whether there were differences in water and feed intake due to disease or estrus. The individual-animal data were fit to a regression model to obtain residuals, and the residuals were then plotted to each chart type to detect shifts in behavior. This combined chart strategy allowed the researchers to correctly detect the incidence of disease even during the first week of lactation.

Researchers have evaluated the use of SPC in other animal species as well. Madsen and Kristensen (2005) examined deviations in water intake of growing pigs to detect disease. Continuous water intake was collected for each animal then split into one hour increments for evaluation. A dynamic linear model was used to model the data and then to predict the next time step of data, and the residuals between the predicted and actual data were charted using a CUSUM chart. This method allowed for the detection of morbidity events about one day prior to clinical signs of illness. Cornou et al. (2008) also used SPC to evaluate swine operations. The study focused on detecting estrus, lameness, and other health disorders. The method employed was the use of CUSUM charts on data collected from electronic sow feeders. The study reported a sensitivity of 39% for the detection of health disorders not related to lameness, which was significantly higher than by detection by observational methods alone. The objectives of this study were to examine associations of feeding behavior traits with performance and feed efficiency and as pre-clinical detectors of morbidity in beef cattle.

CHAPTER II

CHARACTERIZATION OF FEEDING BEHAVIOR AND TEMPERAMENT TRAITS AS PHENOTYPIC BIOMARKERS OF FEED EFFICIENCY AND PERFORMANCE IN BEEF CATTLE

Introduction

Managers of livestock production systems aim to generate long-term maximal profit by increasing productivity and(or) improving efficiency of feed utilization within the production cycle. Profit is the difference between the total costs of inputs and the value of revenue generated by the production system. One strategy to reduce the input costs of beef production is to select cattle with favorable genetic merit for feed efficiency.

Improvements in feed efficiency in cattle will not only reduce the cost of producing beef, but will also mitigate the overall impact of cattle production systems on the environment. Sixty to 70% of the variable costs associated with the production of beef cattle can be attributed to feed costs. One drawback to selecting cattle for improved feed efficiency is the need for costly equipment to collect individual-animal feed intake data. Thus, there is a need for more cost-effective methods to collect individual-animal data that can be used to identify those cattle with favorable genetic merit for feed efficiency. Cattle that exhibit increased rates of gain have increased profit due to the increase in carcass revenue. The use of individual cattle management system that sort cattle into various outcome groups to enable management systems to be differentially applied to optimize performance efficiency offers considerable potential to improve overall system performance. The objective of this study is to identify feeding behavior and temperament traits that are associated with inter-animal variation in feed efficiency and performance in beef cattle.

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.

Eighty-four Angus cross steers from the Circle X Ranch (Bryan, TX) were used in this study. The steers were housed at the Texas A&M University Beef Cattle Systems Research Center (College Station, TX). Upon arrival at the research facility, cattle were fitted with passive, half-duplex transponder ear tags (Allflex USA Inc., Dallas, TX), dewormed with Valbazen Drench (Pfizer Animal Health), placed in group pens (30’ x 60’) and adapted to a high-energy diet using a series of step up diets during a 21-d period. After adaptation to the diet (Table 2.1), steers were moved into 4 pens (32’ x 60’) equipped with electronic feed bunks (GrowSafe System LTD., Airdrie, AB, Canada). The steers were thereafter fed ad libitum for 98 d while being rotated between the GrowSafe and group pens (Table 2.2). Body weights were measured during the study as outlined in Table 2.2 and individual intake data was collected daily during the periods that the animals were housed in the GrowSafe pens.

Upon completion of the individual feeding phase, the steers were transported to a commercial feed yard (Graham Land and Cattle Co., Gonzalez TX) and fed a high grain diet in group pens. The steers were weighed upon arrival at the feed yard and prior to transport for harvest. Steers were fed for a total of 250 d during the entire study period.

Table 2.1. Ingredient and chemical composition of the experimental diet.

Item	
Ingredient	*As-fed basis %*
Corn	73.7
Chopped hay	6.0
Cottonseed hulls	6.0
Cottonseed meal	6.0
Molasses	5.0
Mineral Premix[1]	2.5
Urea	0.8
Chemical Composition	*Dry matter basis*
Dry matter %	90.8
CP, %DM	12.4
NDF, %DM	20.1
ME, Mcal/kg DM	3.0

[1] Mineral Premix contained minimum 15.5% Ca, 2800 ppm Zn, 1200 ppm Mn, 12 ppm Se, 14 ppm Co, 30 ppm I, 45.4 KIU/kg Vit-A, 2.3 KIU/kg Vit-D, 726 IU/kg Vit-E, 1200 ppm Monensin, and 400 ppm Tylosin.

Table 2.2. Experimental protocol for collection of BW, exit velocity, feed intake, and feeding behavior.

Week of Study	Period	Location	BW[1]	Exit Velocity[1]
1	Adaptation	Group pens	BW-initial	
2				
3				
4	Period 1	GrowSafe pens	BW-day 0	EV-day 0
5				
6				
7		Group pens	BW-day 21	
8				
9	Period 2	GrowSafe pens	BW-day 35	
10				
11		Group pens	BW-day 49	
12				
13	Period 3	GrowSafe pens	BW-day 63	
14				
15		Group pens	BW-day 77	
16	Period 4	GrowSafe pens		
17		Group pens	BW-day 91	
18			BW-day 98	EV-day 98

[1] BW and exit velocity data collected at the start of the week.

GrowSafe Data Collection

The GrowSafe system (DAQ 6000E) used in this study consisted of feed bunks equipped with load bars to measure feed disappearance, and stanchions with neck bars to prevent more than one animal from eating from the feed bunk at a given time. Antenna within each feed bunk detected animal presence by recording the radio-frequency identification tags upon entry to a feed bunk. Feed intake was allocated to each individual-animal based on continuous recordings of feed disappearance during each bunk visit (BV) event. Along with individual feed intake data, the system also recorded each BV, the EID number, scale number and time stamp, which was logged in the data-acquisition computer. The GrowSafe system used in this study has a scanning rate frequency of 1.5 s.

A subroutine of the GrowSafe 6000E software, Process Feed Intakes was used to compute feed intake and BV data. All default settings as previously defined (GrowSafe, 2009) were used in this study. For this study, the parameter setting of 100 s was used as recommended by Mendes et al. (2011). Feeding behavior and intake data were omitted from all analyses for 2 d due to system failure when the proportion of daily feed supply assigned to individual animals (average feed disappearance) was less than 95%. Average feed disappearance for the 51 d of good data was 98.56%.

Diet samples were collected weekly and composited by weight at the end of the trial and moisture analysis was conducted by drying in a forced-air oven for 48 h at 105°C. Chemical analysis was conducted by an independent laboratory (Cumberland Valley Analytical Services Inc., Hagerstown, MD).

Feeding behavior data was based on in-to-out events to the feed bunk (bunk visit frequency and duration) recorded by the GrowSafe system. Bunk visit event data were clustered into meal events after meal criterion, defined as the longest non-feeding interval that is still part of a meal, was determined for each animal (Bailey et al., 2012). A Gaussian-Weibull distribution model was fitted to log-transformed non-feeding interval data, and the intercept of the two distributions used to define meal criterion (Yeates et al., 2001). Meal criterion was used to compute individual-animal meal data (meal frequency, meal duration, and meal size).

Exit velocity measurements were taken on days 0 and 98 of the trial. Exit velocity was measured as time in seconds for an animal to traverse 2.44 m after leaving a squeeze chute. Time to bunk was measured daily as the length of interval between feed truck delivery and the first BV event each day.

Steers were harvested at Sam Kane Beef (Corpus Christi, TX). Animals were stunned via captive bolt pistol, exsanguinated, and individual carcass measurements obtained for hot carcass weight (HCW), 12th-13th rib fat thickness (BF); longissimus muscle area (LMA); kidney, pelvic, hart fat (KPH), and marbling score (MS) were collected by trained university personnel after a 48 h chill at -4°C (data not presented). Carcass value ($ / kg HCW) was calculated from a grid formula with a base price of $245 per 45.5 kg, with premiums and discounts applied for yield and quality grades. Individual carcass income was based on HCW multiplied by carcass value for each animal.

Economic Analysis

Net revenue was determined as carcass income minus costs for feeder calf, yardage ($0.25/hd/d), processing ($30/hd), interest, transportation ($38/hd), and feed costs ($0.31/kg $_{\mathrm{DM}}$). Feeder calf price was estimated using a 45.5 kg price slide calculated from the 3-yr mean price of feeder steers during the month that the steers were received for the individual feeding period from Circle X Land and Cattle Co. Interest was calculated at a 5% annual rate on feeder calf cost and 50% of feed costs. Feed intake was based on actual feed consumed during the feed-intake measurement period, and model-predicted intake adjusted for RFI. Model-predicted intakes were computed using the Cornell Value Discovery System (Tedeschi et al., 2004). The model accounts for individual-animal variation in predicted feed intake using individual-animal body weight, ADG, and carcass traits. The adjustment of model-predicted intakes during the group-feeding periods was based on the assumption that relative rank for RFI determined during the 52 d feed-intake measurement period was maintained during the entire feeding period. Arthur et al. (2011) measured RFI in Charolais bulls fed a moderate energy diet starting at 9 months of age, and compared genetic variation and heritability estimates when RFI was measured for 6 and 10 months on feed while fed the same diet. The phenotypic and genetic correlations between RFI measured for 6 and 10 months was 0.82 and 0.86, indicating that while some re-ranking of RFI occurred, RFI was fairly consistent regardless of length of the measurement period.

Statistical Analysis

PROC GLM in SAS (SAS Institute Inc., Cary, NC) was used to calculate RFI as the difference between actual and expected DM intake from linear regression of DM intake, ADG and mid-test BW$^{0.75}$ (Koch et al., 1963). Residual gain (RG) was calculated from linear regression of ADG on DM intake and mid-test BW$^{0.75}$(Koch et al., 1963).

A linear PROC MIXED model (SAS Institute Inc., Cary, NC) was used to examine the effects of RFI group (low, medium, and high based on ± 0.5 standard deviations from mean RFI of 0.0 ± 0.74) and TTB group (low, medium, and high based on ± 0.5 standard deviations from mean TTB of 54.2 ± 29.9) on performance, feed efficiency, feeding behavior, and carcass traits. The stepwise option of PROC REG (SAS Institute Inc., Cary, NC) was used to determine between-animal variation in net revenue attributed to carcass and performance traits. Both linear and quadratic terms were evaluated for performance and carcass measurements. The dependent variable was net revenue per steer. Correlations between performance, DM intake, and feeding behavior traits were calculated using the PROC CORR procedure (SAS Institute Inc., Cary, NC).

Results

Performance, Feed Efficiency, and Temperament

Six steers were identified as being morbid during the early part of the study, but all responded quickly to antimicrobial treatment and none were removed from the study. The DM intake and performance of the steers were within the expected range given their age and the experimental diet that was fed (Table 2.3). As expected, during the 98-d trial period, ADG of the steers was 1.5 kg/d with a range of 0.74 to 2.1 kg/d. Similarly, DM intake and F:G were 9.58 and 6.57 kg/d respectively, which is within the previously reported range (Richardson et al., 2001; Kolath et al., 2006). Residual feed intake averaged 0.0 kg/d and ranged from -2.17 kg/d for the most efficient steer to 1.89 kg/d for the least efficient. Average daily gain was positively correlated ($P < 0.001$) with DM intake (0.52), residual gain (RG, 0.68), and negatively correlated with F:G (-0.82; Table 2.4). As expected, DM intake was positively correlated ($P < 0.001$) with initial BW (0.51) and RFI (0.71). Initial exit velocity was correlated ($P < 0.05$) with ADG and F:G and correlated ($P = 0.05$) with DM intake. Time to bunk (TTB) was negatively correlated ($P < 0.01$) with ADG (-0.27), and positively correlated with initial exit velocity (0.29), and F:G (0.25).

Table 2.3. Summary statistics of performance, feed intake, feed efficiency, exit velocity, and feeding behavior traits for Brangus steers.

Item[1]	Mean	SD	Minimum	Maximum
Performance and Temperament:				
Initial BW, kg	282	14.3	249	314
Final BW, kg	429	32.3	351	517
ADG, kg/d	1.5	0.28	0.74	2.1
Initial exit velocity, m/s	4.41	1.03	1.98	7.17
Final exit velocity, m/s	3.54	1.47	0.15	6.77
Time to bunk, min	54.2	29.9	14.5	189.7
Feed efficiency:				
DMI, kg/d	9.58	1.04	6.66	12.51
F:G ratio	6.57	1.27	4.55	11.4
Residual feed intake, kg/d	0	0.74	-2.17	1.89
Residual gain, kg/d	0	0.21	-0.53	0.57
Bunk visit (BV) traits:				
BV frequency, events/d	45.3	8.9	28.1	79.4
BV duration, min/d	93.2	19.4	60.8	149.5
Non-feeding frequency, events/d	43.7	12.5	26.3	104.2
Non-feeding duration, min/d	1282	29	1200	1328
Meal traits:				
Meal frequency, events/d	11.1	2.3	6.2	18.4
Meal duration, min/d	141	24	94	204
Meal criterion, min	7.45	2.81	1.62	20.12
Meal length, min/event	14.3	4.2	7.5	26.5
Meal size, kg/event	1.13	0.27	0.67	1.93
Eating rate, g/min	69.4	12.6	43.6	111.4
Intensity traits:				
Head down duration (HD), min/d	62.8	22.3	22.3	121.1
HD:BV duration	0.66	0.13	0.33	0.87
HD:Meal duration	0.44	0.12	0.18	0.77
Profit traits:				
Feed cost, $/hd[2]	714.11	86.50	507.10	914.05
Carcass income, $/hd[3]	2099.00	142.77	1723.00	2472.00
Net revenue, $/hd[4]	243.07	124.14	-55.64	544.47

[1] Feed intake and behavior data collected for 52 d; growth data for 98 d.

[2] Feed cost computed from actual feed intake collected during individual feeding phase and model predicted feed intake adjusted for RFI.

[3] Carcass income calculated from carcass measurements taken at time of harvest.

[4] Net revenue calculated from carcass income minus all expenses accrued during both the individual and group fed phases.

Table 2.4. Pearson correlations among performance, feed efficiency and temperament traits for Brangus steers.

Trait[1]	ADG	Initial exit velocity	Time to bunk	DM intake	F:G	Residual feed intake	Residual gain
Initial BW	0.09	-0.10	-0.07	**0.51***	0.20	-0.01	**-0.66***
ADG		**-0.32***	**-0.27***	**0.52***	**-0.82***	0.00	**0.68***
Initial exit velocity			**0.29***	-0.21	**0.22***	-0.02	-0.15
Time to bunk				-0.12	**0.25***	0.03	-0.14
DM intake					0.00	**0.71***	0.00
F:G						**0.41***	**-0.76***
Residual feed intake							-0.03

[1] Feed intake data collected for 52 d; growth data for 98 d.
*Correlations differ from zero at P < 0.05.

Feeding Behavior Traits

Summary statistics for feeding behaviors are presented in Table 2.3. Bunk visit duration and frequency were 93.2 min/d and 45.3 events/d, which is within the range of previously reported studies (Lancaster et al., 2009; Hafla et al., 2013). Average meal duration and frequency, based on individual-animal meal criterion, was 141 min/d and 11.1 events/d, respectively, with an average meal criterion of 7.45 min.

Bunk visit duration, HD duration and meal duration were all positively correlated ($P < 0.05$) with DM intake and RFI (Table 2.5). Meal duration was also negatively correlated with initial exit velocity. Meal size and eating rate were positively correlated ($P < 0.01$) with DM intake with correlation coefficients of 0.39 and 0.35 respectively. In contrast, these 3 feeding behavior traits were not correlated with ADG or the 2 feed efficiency traits (RG and F:G) that are strongly correlated with ADG. Initial exit velocity was negatively correlated with ADG ($P < 0.01$) and tended ($P = 0.06$) to be negatively correlated with DM intake. Initial exit velocity was also positively correlated ($P = 0.04$) with F:G.

Table 2.5. Pearson correlations between performance and feeding behavior traits for Brangus steers.

Trait[1]	ADG	IEV	TTB	DM intake	F:G	RFI	RG
Bunk visit (BV) traits:							
BV frequency, events/d	0.15	**-0.25***	**-0.27***	0.04	-0.11	0.10	0.16
BV duration, min/d	0.20	**-0.26***	-0.20	**0.45***	0.05	**0.43***	0.01
Non-feeding event frequency, events/d	0.06	-0.13	-0.15	-0.00	-0.07	0.05	0.07
Non-feeding event duration, min/d	-0.06	0.17	0.10	**-0.27***	-0.14	**-0.26***	0.09
Meal traits:							
Meal frequency, events/d	0.14	0.11	**-0.27***	0.08	-0.13	0.02	0.09
Meal duration, min/d	0.17	**-0.34***	**-0.26***	**0.28***	0.02	**0.29***	0.07
Meal criterion, min	-0.09	-0.05	0.05	-0.09	0.10	-0.05	-0.04
Meal length, min/event	0.00	**-0.28***	0.09	0.12	0.11	0.14	-0.04
Meal size, kg/event	0.16	-0.20	**0.25***	**0.39***	0.08	**0.25***	-0.06
Eating rate, g/min	0.16	0.20	**0.23***	**0.35***	-0.02	0.17	-0.03
Intensity traits:							
Head down duration (HD), min/d	0.20	**-0.23***	-0.18	**0.39***	0.01	**0.34***	-0.02
HD:BV duration	0.13	-0.15	-0.12	0.20	-0.03	0.12	-0.02
HD:Meal duration	0.15	-0.09	-0.07	**0.33***	0.01	**0.25***	-0.02
Profit traits:							
Feed cost, $/hd	0.18	-0.09	-0.01	**0.79***	**0.30***	**0.85***	-0.02
Carcass income, $/hd	**0.61***	**-0.25***	-0.20	**0.55***	**-0.32***	0.15	**0.25***
Net revenue, $/hd	**0.55***	-0.21	**-0.22***	-0.01	**-0.60***	**-0.42***	**0.42***

[1] Feed intake and behavior data collected for 52 d; growth data for 98 d.

*Correlations differ from zero at $P < 0.05$.

Divergent Phenotypes for RFI

The effects of RFI classification (based on ± 0.50 SD from the mean RFI of 0.0 ± 0.74) on performance, feed efficiency and feeding behavior traits are presented in Table 2.6. Steers with high RFI consumed 19% more feed and had a 21% higher F:G than steers with low RFI. In addition, steers with high RFI also spent 21% more ($P < 0.01$) time at the bunk, had 28% more ($P < 0.01$) HD time, and 6% more ($P < 0.01$) visits to the feed bunk than the low-RFI steers. Meal duration tended ($P = 0.06$) to be longer for high-RFI steers, although the other meal traits did not differ between the RFI groups. As expected, steers with high RFI had higher ($P < 0.001$) feed costs ($800 vs. $637 per animal) compared to low-RFI steers because of greater DM intakes. Likewise, steers in the low-RFI group generated on average $145 per animal more net revenue than the high-RFI steers.

Divergent Phenotypes for Time to Bunk

The effects of TTB classification (based on ± 0.50 SD from mean TTB of 54.2 ± 29.9) on performance, feed efficiency and feeding behavior traits are presented in Table 2.7. Steers with low TTB had an 18% greater ($P < 0.01$) ADG than high-TTB steers. At the end of the trial, low-TTB steers weighed ($P < 0.05$) 27 kg less and tended ($P = 0.07$) to have a higher F:G ratio. Steers with high TTB had 5.8 fewer BV events and 1.8 fewer meal events per day than low-TTB steers. No differences were observed between the TTB groups for DM intake, RFI, or RG. As there was no difference in DM intake, differences in feed costs were not detected between TTB groups. Steers in the low TTB group generated $119.98 higher carcass incomes and consequently yielded $88.28 more net revenue than the high-TTB steers.

Table 2.6. Comparison of performance, feed efficiency, and feeding behavior traits for steers with divergent phenotypes for RFI[1]

Item[2]	Low RFI	Medium RFI	High RFI	SE	P-value
No. of steers	28	33	23	--	--
Performance and Temperament:					
Initial BW, kg	281	283	282	3	0.89
Final BW, kg	430	428	430	7	0.98
ADG, kg/d	1.52	1.48	1.51	0.06	0.90
Initial exit velocity, m/s	4.41	4.28	4.59	0.22	0.56
Final exit velocity, m/s	3.65	3.24	3.87	0.31	0.28
Time to bunk, min	50.3	56.2	56.2	6.3	0.70
Feed efficiency:					
DM intake, kg/d	8.80	9.59	10.50	0.17	0.001
F:G ratio	5.91	6.71	7.19	0.25	0.001
RFI, kg/d	-0.776	0.015	0.923	0.069	0.001
RG, kg/d	0.021	-0.011	-0.009	0.040	0.78
Bunk visit (BV) traits:					
BV frequency, events/d	45.8	42.5	48.7	1.8	0.05
BV duration, min/d	86.0	91.4	104.4	3.8	0.01
Non-feeding frequency, events/d	45.9	39.6	46.9	2.5	0.05
Non-feeding duration, min/d	1288	1285	1271	5.93	0.08
Meal traits:					
Meal frequency, events/d	10.9	11.0	11.5	0.5	0.64
Meal duration, min/d	135	140	151	5	0.06
Meal criterion, min	7.34	7.91	6.91	0.59	0.42
Meal length, min/event	13.8	14.5	14.5	0.9	0.77
Meal size, kg/event	1.07	1.16	1.18	0.06	0.27
Eating rate, g/min	66.5	70.2	71.7	2.6	0.31
Intensity traits:					
Head down duration (HD), min/d	57.5	59.6	73.9	4.5	0.05
HD:BV duration	0.655	0.643	0.692	0.028	0.40
HD:Meal duration	0.418	0.427	0.482	0.024	0.11
Profit traits:					
Feed cost, \$/hd[3]	636.94	719.78	799.91	12.34	0.001
Carcass income, \$/hd[4]	2078.17	2119.29	2093.76	29.90	0.52
Net revenue, \$/hd[5]	301.66	253.44	156.89	23.27	0.001

[1] Low, medium, and high RFI phenotypes based on ± 0.50 SD from mean RFI of 0.00 (SD = .73).

[2] Feed intake and feeding behavioral data were collected for 52 d; growth data for 98 d.

[3] Feed cost computed from actual feed intake collected during individual feeding phase and model predicted intake adjusted for RFI.

[4] Carcass income calculated from carcass measurements taken at time of harvest.

[5] Net revenue calculated from carcass income minus all expenses accrued during both the individual and group fed phases.

Table 2.7. Comparison of performance, feed efficiency, and feeding behavior traits for steers with divergent phenotypes for TTB[1]

Item[2]	Low TTB	Medium TTB	High TTB	SE	P- value
No. of steers	34	31	19	--	--
Performance and Temperament:					
Initial BW, kg	283	283	280	3	0.69
Final BW, kg	436	434	409	7	0.008
ADG, kg/d	1.56	1.54	1.32	0.06	0.006
Initial exit velocity, m/s	4.15	4.36	4.96	0.23	0.019
Final exit velocity, m/s	3.14	3.5	4.31	0.33	0.021
Time to bunk, min	30.1	54.3	97.2	3.6	0.0001
Feed efficiency:					
DMI, kg/d	9.76	9.63	9.17	0.24	0.14
F:G ratio	6.43	6.37	7.16	0.29	0.07
RFI, kg/d	0.051	-0.031	-0.041	0.172	0.87
RG, kg/d	0.023	0.011	-0.06	0.044	0.29
Bunk visit (BV) traits:					
BV frequency, events/d	48.6	43.3	42.8	2	0.02
BV duration, min/d	94.7	96	85.9	4.4	0.17
Non-feeding frequency, events/d	46.5	41.4	42.5	2.9	0.24
Non-feeding duration, min/d	1284	1277	1286	7	0.48
Meal traits:					
Meal frequency, events/d	12	10.7	10.2	0.5	0.02
Meal duration, min/d	146	141	132	5	0.13
Meal criterion, min	7.23	7.64	7.52	0.65	0.83
Meal length, min/event	13.53	14.7	14.93	0.97	0.41
Meal size, kg/event	1057	1168	1217	61	0.08
Eating rate, g/min	67.66	69.87	71.61	2.89	0.53
Intensity traits:					
Head down (HD), min/d	64.2	65.7	55.5	5.1	0.26
HD:BV duration	0.665	0.672	0.635	0.031	0.63
HD:Meal duration	0.432	0.459	0.417	0.027	0.43
Profit calculation:					
Feed cost, $/hd[3]	726.48	709.12	700.12	19.93	0.53
Carcass Income, $/hd[4]	2138.10	2104.60	2018.10	31.37	0.011
Net revenue, $/hd[5]	271.31	248.91	183.03	27.72	0.042

[1] Low, medium, and high phenotypes based on ± 0.50 SD from mean TTB of 54.23 (SD = 29.9).

[2] Feed intake and feeding behavioral data were collected for 52 d; growth data for 98 d.

[3] Feed cost computed from actual feed intake collected during individual feeding phase and model predicted intake adjusted for RFI.

[4] Carcass income calculated from carcass measurements taken at time of harvest.

[5] Net revenue calculated from carcass income minus all expenses accrued during both the individual and group fed phases.

Discussion

With the recent developments of active RFID technology, the potential to measure individual-animal feeding behavior patterns on a large scale could become a reality. For such a system to be economically feasible, the economic benefits must outweigh the cost of implementing the technology. One potential application of such as system would be decision-support tools to identify animals with more favorable performance and feed efficiency. Individual-animal variation in feeding behavior and temperament traits may have value as indicator traits for economically relevant traits such as feed efficiency or performance and could potentially be collected using active RFID systems. With this in mind the objective of this trial is to characterize those feeding behavior and temperament traits that could be potential phenotypic biomarkers of economically relevant traits.

The current study supports previous research demonstrating that feeding behavior traits in cattle have weak to moderate correlations with feed efficiency traits such as DM intake and RFI (Nkrumah et al., 2007; Kelly et al., 2010a; McGee et al., 2014). The low to moderate correlations presented by Nkrumah et al. (2007) between feeding behavior traits, DM intake and RFI are comparable with those presented in the current study. Their study reported a positive correlation between BV duration and RFI of 0.49 which is similar to the correlation of 0.43 found in the current study.

Analysis of the RFI group comparisons from the current study support those reported recently by McGee et al. (2014). Steers with low RFI spent less ($P < 0.01$) time at the feed bunk and had fewer BV events than steers with high RFI, which is similar to previous research (Nkrumah et al., 2007; McGee et al., 2014). In the current study, steers with more efficient RFI phenotypes ate less ($P< 0.0001$) while maintaining the same eating rate and therefore spent less time at the bunk each day. Also, in agreement with previous research (Doventas et al., 2011), there was no difference in initial or final BW, or ADG between the divergent RFI groups, as RFI is independent of growth traits (Archer et al., 1999). As there was no difference in carcass weight (data not presented) or carcass income between the RFI groups, the average increase in net revenue ($145 per animal) observed by the low-RFI steers was the result of lower DM intakes.

Steers classified as high TTB (> 0.5 SD above mean TTB of 54.2 ± 29.9) took an average of 67 min longer to consume their first meal each morning compared to steers classified as low TTB (< 0.5 SD below the mean TTB of 54.2 min). The steers with high TTB had 20% faster ($P < 0.02$) initial and 37% faster ($P < 0.03$) final exit velocities than steers with low TTB indicating that the high-TTB steers had more excitable temperaments than low-TTB steers. Although TTB classification did not affect initial BW, the high TTB steers had 27% lower final BW and 15% lessor ADG indicating that TTB may be more related to performance than feed efficiency. This is further supported by the fact that TTB was weakly correlated with ADG, but was not correlated with either DM intake or RFI. Steers in the high TTB group tended ($P = 0.07$) to have a higher F:G ratio than the steers in the low-TTB group, which was presumably due to difference in ADG.

As steers in the low-TTB group had increased gains and therefore finished the study with higher carcass weights, they generated $88 more net revenue per animal than steers in the high-TTB groups. Additionally, as there were no differences observed in adjusted back fat depth, longissimus muscle area, calculated yield grade, or Warner

Bratzer shear force values between the TTB groups (data not presented), carcass income was 6% greater (P < 0.02) and net revenue 48% greater for low-TTB steers.

This study supports previous research that cattle with divergent phenotypes for RFI have distinctive feeding behavior patterns. This study also demonstrates the potential of using feeding behavior as an indicator of RFI to identify cattle with improved feed efficiency. Furthermore, the use of temperament traits to identify cattle with superior performance could prove useful in identifying cattle that are more profitable to produce. Further research is warranted to more fully explore the possibilities of using feeding behavior and temperament traits as phenotypic biomarkers of feed efficiency and performance in beef cattle.

CHAPTER III

CHANGES IN FEEDING BEHAVIOR PATTERNS AND DRY MATTER INTAKE PRIOR TO CLINICAL SYMPTOMS ASSOCIATED WITH BOVINE RESPIRATORY DISEASE IN GROWING BULLS

Introduction

Bovine respiratory disease (BRD) is the most prevalent and costly disease in U.S. feedlot cattle, accounting for approximately 75% of morbidity and 50-75% of mortality cases annually (Galyean et al., 1999). Although the costs of drug therapy and feedlot deaths associated with BRD are substantial, the true economic impact of this disease is even greater when reductions in animal productivity and carcass value are considered (Wittum et al., 1996; Smith, 1998; Fulton et al., 2002). Early detection and treatment of disease has been reported to improve the efficacy of antimicrobial therapy (Ferran et al., 2011). Current methods used to detect sick animals rely on subjective evaluations of clinical symptoms of illness by skilled pen riders. Prior research has shown the associations between animals treated for clinical signs of BRD and subsequent incidence of lung lesions postharvest to be moderate to low (Wittum et al., 1996; Gardner et al., 1999). Thus, there is a critical need to develop more accurate animal-health monitoring systems to mitigate the economic impact of BRD.

Changes in DM intake and behavioral patterns associated with feeding are among the earliest signs of clinical illness expressed in cattle. Furthermore, increases in core body temperature in response to infectious disease is known to be associated with reduced appetite (Hart, 1988). With the advancements in technology to record individual DM intake and feeding behaviors there is an opportunity to further evaluate the behavioral responses to illness. Prior research has shown that steers with clinical symptoms of BRD spent 30% less time at the feed trough than healthy steers (Sowell et al., 1999). In addition heifers challenged with *Mannheimia haemolytica* spent less time at the feed bunk and less time in close proximity to the hay feeder than non-challenged control heifers (Theurer et al., 2013b). Daniels et al. (2000) concluded that over the course of 3 21-d trials morbid calves spent on average 30 min/d less time at the feed bunk and had 3 fewer events/d than healthy calves. The morbid calves also had lower gains ($P < 0.001$; -0.03 kg/d) than healthy calves (0.78 kg/d).

To more accurately detect disease in cattle fed in confinement, specific behavioral responses need to be evaluated for their ability to predict morbidity events in cattle. The objective of this study was to identify and quantify DM intake and feeding behavior traits that change in response to an acute spontaneous outbreak of bovine respiratory disease.

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. Growing purebred bulls (N = 231) consigned from independent producers for the purpose of evaluating performance and feeding efficiency were used in this study. Although all bulls were previously vaccinated against viral and bacterial pathogens using variable vaccine products, all bulls were re-vaccinated upon arrival at the test facility for infectious bovine rhinotracheitis, parainfluenza-3 virus, bovine viral diarrhea, bovine respiratory syncytial virus (Pyramid 5, Boehringer Ingelheim), and *Haemophilus somnus*, *Pasteurella* *multocida*, and clostridial diseases (Ultrabac7, Zoetis Animal Health), and treated for internal parasites (Valbazen, Zoetis Animal Health). In addition, bulls were fitted with passive, half-duplex transponder ear tags (Allflex USA Inc., Dallas, TX), and adapted to the test diet (Table 3.1) for 28 d prior to the start of a 70-d study.

Table 3.1. Ingredient and chemical composition of the experimental diet.

Item	
Ingredient	*As-fed basis %*
Steam-flaked corn	33.6
Sorghum silage	20.0
Roughage pellet	19.3
Cottonseed hulls	14.4
Cottonseed meal	5.2
Premix	7.5
Chemical Composition	*Dry matter basis*
Dry matter %	75.9
CP, %DM	14.1
NDF, %DM	34.5
ME, Mcal/kg DM	2.40

The bulls were housed in 1 of 9 pens each equipped with 4 electronic feed bunks (GrowSafe System Ltd., Airdrie, Alberta, Canada) to measure daily feed intake and feeding behavior traits. The GrowSafe system (DAQ 6000E) used in this study consisted of feed bunks equipped with load bars to measure feed disappearance, and antenna within each feed bunk to record animal presence by detection of radio-frequency identification tags during feeding events. Feed intake was allocated to individual animals based on continuous recordings of feed disappearance during feeding events, and a subroutine of the GrowSafe 6000E software (Process Feed Intakes) used to compute feed intake. In addition to collecting individual feed intake data, the system also recorded each bunk visit (**BV**) event, the EID number, scale number and time stamp, which was logged in the data-acquisition computer. In addition to the feeding behavior traits, time to bunk (**TTB**) was calculated using the statistical processing tool R and is defined as the length of the interval between delivery of feed via feed truck and an animal’s first feeding event. A description of the feeding behavior traits evaluated in this study is presented in Table 3.2.

During the 70-d trial, bulls were evaluated twice daily for clinical signs of illness, and weighed at 14-d intervals. Diet samples were collected weekly and composited by weight at the end of the trial. Chemical analysis of the diet was conducted by an independent laboratory (Cumberland Valley Analytical Services Inc., Hagerstown, MD).

Table 3.2. Definition of feeding behavior traits analyzed in this study.

Trait	Definition
Bunk visit (BV) duration, min/d	Sum of the lengths of all BV events recorded each day
BV frequency, events/d	Number of BV events recorded each day
Head down duration, min/d	Number of EID recordings each day multiplied by the read rate of the GrowSafe system
Time to bunk, min	Length of interval between feed truck delivery and the first BV event each day
Maximum non-feeding interval (NFI), min	Length of the maximum interval between 2 consecutive BV events each day
NFI standard deviation, min	SD of the lengths of all NFI recorded each day
Eating rate, g/min	Daily DM intake divided by daily BV duration

Experimental Cohorts. Within a 10-d period beginning on day 28 of the trial, 30 bulls were treated for clinical symptoms associated with BRD. Thereafter, in response to reductions in DM intake (Figure 3.1), feedlot personnel administered metaphylaxis therapy (Tulathromycin; Draxxin®, Zoetis Animal Health) on day 38 of the trial to all remaining bulls (N = 201). Although diagnostic tests were not conducted to conclusively confirm presence of BRD, the decline in DM intake and observed clinical symptoms indicated the presence of acute respiratory illness.

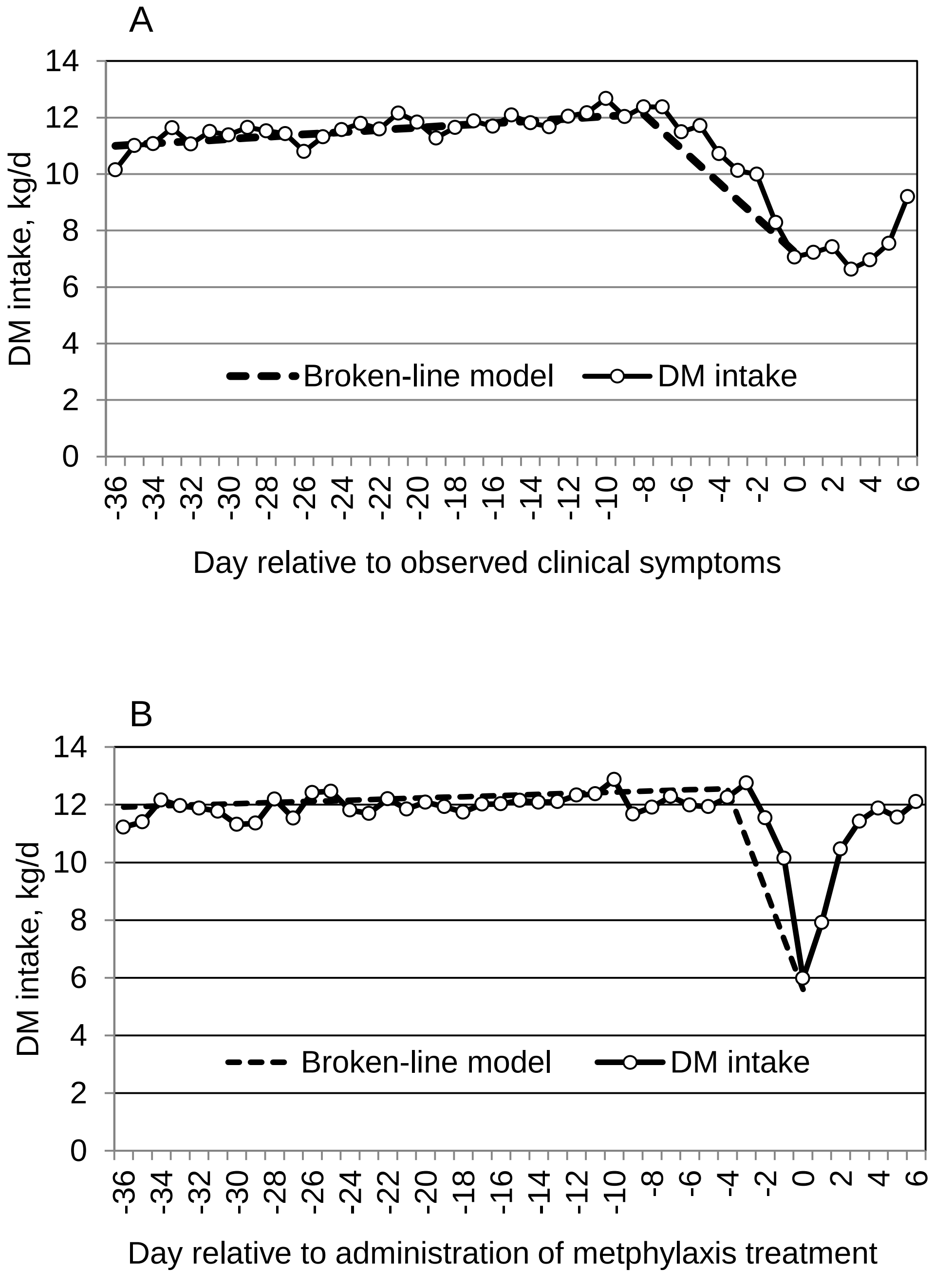

Figure 3.1. Average daily DM intake for the clinically-ill cohort (A) and the metaphylaxis-treated cohort (B). The 2-slope broken-line regression is plotted using data from day -36 to day clinical symptoms of illness were observed (A) and from day -36 to day of metaphylaxis treatment (B).

To examine deviations in DM intake and feeding behavior relative to onset of clinical symptoms of disease, the bulls in this study were separated into 2 cohorts. The clinically-ill cohort consisted of bulls that were identified as being morbid from day 28 to 38 of the study by feedlot personnel based on observed clinical symptoms (N = 30). All bulls in this cohort exhibited variable clinical symptoms associated with BRD including nasal discharge, depression lethargy, and anorexia. Twenty seven of these bulls had elevated rectal temperatures (mean = 40.5^{o}C, range = 39.7 to 42.1). All bulls in the clinically-ill cohort were administered antimicrobial therapy (Enrofloxacin; Baytril 100, Bayer Health Care LLC, Shawnee Mission, KS) and returned to their respective pens. The metaphylaxis-treated cohort consisted of the remaining bulls (N = 201) that were subsequently administered Tulathromycin on day 38 of the study. Clinical symptoms of illness were not observed in this cohort prior to metaphylaxis therapy, and diagnostic tests were not performed to confirm the presence of BRD. However, the observed decline in average DM intake prior to metaphylaxis therapy suggested that bulls in this cohort were experiencing some type of acute illness.

Statistical Analysis

Dry matter intake and feeding behavior traits were fit to a two-slope broken-line regression model using the PROC NLIN procedure of SAS (SAS Institute Inc., Cary, NC). Daily and 3-d rolling averages were computed for BV duration and frequency, head-down (**HD**) duration, TTB, maximum non–feeding interval (**NFI**), NFI standard deviation, eating rate, and DM intake relative to the day of individual-animal treatment for clinical illness in the clinically-ill cohort, and relative to day of Tulathromycin administration (day 38) in the metaphylaxis-treated cohort. The 3-d rolling average was defined as the sequential average of the day of trial and the day preceding and following each trial day. The 3-d rolling average was evaluated to determine if the reduction in day-to-day variance would improve model fitness while retaining sufficient specificity to adequately represent the original trend of the data. Prior to fitting regression models, the data was first plotted and the nadir or apex was visually identified. The model was fit to the interval between the beginning of the trial and the visually identified point, and the dependent variable evaluated for time-series deviations prior to detection of the morbidity event in the clinically-ill cohort, or prior to the day of Tulathromycin administration in the metaphylaxis-treated cohort. The general model for the 2-slope broken-line regression as described by Coma et al. (1995) was:

$$Y = L + U (R - X_{LR}) + V (X_{GR} - R)$$

where L is the ordinate, R the abscissa of the inflection in the curve, U is the linear slope of the line for $X < R$, and V is the linear slope of the line for $X > R$. The inflection point (R; breakpoint) was considered as the day that DM intake or individual feeding behavior traits began to deviate.

Results

Clinically-Ill Cohort

Dry matter intake and performance of bulls were within the expected range given the age of the bulls and the experimental diet that was fed. Dry matter intakes averaged 9.3 kg/d during the first 38 days on study and ranged from 7.4 to 11.6 kg/d. Average daily gain for the bulls was 1.32 kg/d and ranged from 0.70 to 2.11 kg/d for the first 42 d on trial. Bunk visit duration and frequency were 90.0 min/d and 42.2 events/d, respectively, and were within the range previously reported (Lancaster et al., 2009; Hafla et al., 2013). Time to bunk averaged 84.4 min/d with a range of 32.9 to 217.3 min/d. The maximum NFI and NFI SD averaged 416.7 and 96.9 min/d respectively.

Results from the 2-slope broken-line regression analysis of the clinically-ill cohort are presented in Table 3.3 for the daily and 3-day rolling averages. Analysis of daily average data for DM intake revealed a breakpoint at 6.79 d ($P < 0.0001$) prior to when clinical illness was observed, with slopes for DM intake being 0.05 and -0.62 kg/d before and after the detected breakpoint, respectively. The R^2 of the daily model for DM intake was 0.94 with a MSE of 0.15. For the clinically-ill cohort, DM intake decreased 39.3% from the breakpoint until the day of clinical observation. Eating rate was not as predictive as DM intake with the breakpoint being detected 1.32 d prior to clinical observation. The slopes for eating rate before and after the breakpoint were 0.7 and 122.4 g/min, respectively.

Table 3.3. Estimation of breakpoints in DM intake and feeding behavior traits using 2-slope broken-line regression models for the clinically-ill cohort (N = 30).

2-slope broken-line regression model	Regression model parameters[1] L	R	U	V	R^2	MSE
Daily average:						
DM intake, kg/d	12.7	-6.79	0.05	-0.62	0.94	0.15
Eating rate, g/min	142.2	-1.32	0.66	122.40	0.96	36.4
Bunk visit (BV) duration, min/d	95.4	-7.24	-0.04	-4.45	0.82	32.0
BV frequency, events/d	48.6	-7.58	0.17	-2.89	0.67	9.9
Head down duration, min/d	71.1	-6.26	-0.10	-5.08	0.84	15.3
Time to bunk, min/d	82.3	-1.48	0.39	73.75	0.52	421.3
Maximum non-feeding interval (NFI), min/d	588.7	-39.49	5.26	1.61	0.19	1359
NFI SD, min/d	92.5	4.70	0.05	13.94	0.87	37.3
3-day rolling average:						
DM intake, kg/d	12.6	-6.71	0.04	-0.61	0.97	0.06
Eating rate, g/min	143.7	-2.88	0.69	80.15	0.91	26.2
Bunk visit (BV) duration, min/d	93.9	-5.34	-0.10	-7.59	0.92	10.0
BV frequency, events/d	53.6	-14.19	0.34	-1.18	0.69	9.5
Head down duration, min/d	71.6	-7.21	-0.08	-4.00	0.88	10.0
Time to bunk, min/d	78.1	-3.23	0.21	26.13	0.46	184.4
Maximum non-feeding interval (NFI), min/d	433.0	16.13	1.08	30.27	0.18	617.7
NFI SD, min/d	97.1	-3.00	0.22	31.27	0.62	25.7

[1] L = intercept; R = breakpoint; U = slope before breakpoint; V = slope after breakpoint.

The detected breakpoints for BV duration and frequency were 7.24 and 7.58 d prior to clinical observation, with both breakpoints occurring prior to the detected breakpoint for DM intake by 0.45 and 0.79 d, respectively. The breakpoint for HD duration was 6.26 d prior to clinical observation, but occurred 0.53 d following the DM-intake breakpoint. For all 3 of these feeding behavior traits, the linear slopes were essentially zero before the respective breakpoints and decreased thereafter at a rate of 4.4 min/d, 2.9 events/d and 5.1 min/d for BV duration, BV frequency and HD duration, respectively. A breakpoint for TTB was not detected until 1.48 d prior to clinical observation, with the slope for TTB increasing at a rate of 73.8 min/d after the breakpoint was detected. The model accuracy for maximum NFI ($R^2 = 0.19$) was poor demonstrating that this feeding behavior trait was ineffective as a predictor of clinically illness. Although model accuracy for NFI SD was higher ($R^2 = 0.87$), the detected breakpoint occurred 4.7 d after clinical detection of illness was observed.

Results from the analysis of 3-d rolling average data for DM intake were similar to that found for daily average data. The breakpoint was detected at 6.71 d prior to clinical observation of illness, which was 0.08 d later compared to analysis of daily average data. Moreover, the slopes before and after the breakpoints were similar regardless whether daily or 3-d rolling average DM intakes were evaluated. The model accuracy was numerically improved (R^2 0.97) when the 3-d rolling average compared to daily DM intake data were evaluated.

Compared to analysis of daily average data for eating rate, use of the 3-d rolling average for eating rate increased the breakpoint by 1.56 d prior to clinical detection. The slope before the breakpoint was very similar but the slope after the break was decreased to 80.15 g/min. The eating rate model had the highest R^2 for the daily average data.

Analysis of 3-d rolling average data for feeding behavior data revealed different results. The breakpoint for BV duration decreased by 1.9 d to 5.34 d prior to clinical observation, while the breakpoint in BV frequency was detected at -14.2 d prior to clinical observation, which was a 6.6 d increase in detection time. Head-down duration increased by 0.95 d to 7.21 d prior. The R^2 these 3 feeding behavior traits were numerically higher compared to the respective models using daily average data.

The breakpoint for TTB was increased in the rolling average model to 3.23 d prior to clinical observation although the R^2 was lower (0.457). The slope after the breakpoint was decreased by 47.1 min/d to 26.1 min/d for the rolling average model. The models for maximum NFI and NFI SD were not improved by use of 3-d rolling average data. Furthermore, estimates of model accuracy were less when the 3-d rolling average data were evaluated compared to use of daily averages.

Metaphylaxis-Treated Cohort

The DM intakes and performance of bulls in the metaphylaxis-treated cohort were within the expected range given their age and the experimental diet that was fed. DM intakes averaged 10.0 kg/d during the first 38 d on trial and ranged from 6.1 to 13.6 kg/d. Average daily gain for the bulls was 1.64 kg/d with a range of 0.27 to 3.08 kg/d for the first 42 d on trial. BV frequency and duration were 44.0 events/d and 95.8 min/d and were within the previously reported range (Hafla et al., 2013; McGee et al., 2014) . Time to bunk averaged 73.6 min/d and ranged from 22.8 to 140.5 min/d. The maximum NFI averaged 397.2 min/d and the NFI SD averaged 89.0 min/d.

Table 3.4. Estimation of breakpoints in DM intake and feeding behavior traits using 2-slope broken-line regression models for the metaphylactic-treated cohort[1].

2-slope broken-line regression model	Regression model parameters[2]					
	L	R	U	V	R^2	MSE
Daily average:						
DM intake, kg/d	12.5	-3.81	0.02	-1.51	0.81	0.31
Eating rate, g/min	147.9	-8.20	0.81	31.20	0.90	15.7
Bunk visit (BV) duration, min/d	88.7	-0.09	-0.37	21.93	0.61	16.6
BV frequency, events/d	45.8	-8.19	0.04	-5.79	0.32	13.4
Head down duration, min/d	63.5	-8.31	-0.38	-6.92	0.69	9.5
Time to bunk, min/d	71.7	-3.79	0.11	16.93	0.36	377.5
Maximum non-feeding interval (NFI), min/d	393.7	-0.80	0.10	259.20	0.73	430.9
NFI SD, min/d	84.6	-11.58	-0.07	1.54	0.24	85.2
3-day rolling average:						
DM intake, kg/d	12.4	-2.59	0.02	-1.74	0.93	0.05
Eating rate, g/min	144.9	-11.46	0.71	5.15	0.93	6.0
Bunk visit (BV) duration, min/d	89.0	-5.91	-0.37	0.01	0.75	5.2
BV frequency, events/d	45.7	-7.89	0.03	-3.49	0.40	6.6
Head down duration, min/d	64.6	-10.00	-0.36	-1.78	0.84	3.8
Time to bunk, min/d	72.3	-3.00	0.13	21.76	0.16	98.3
Maximum non-feeding interval (NFI), min/d	392.3	-3.00	0.03	16.81	0.06	143.7
NFI SD, min/d	84.8	-12.59	-0.07	0.91	0.50	11.0

[1] Tulathromycin (Draxxin®).

[2] L = intercept; R = breakpoint; U = slope before breakpoint; V = slope after breakpoint.

The results from the 2-slope broken-line regression models for the daily and 3-d rolling average data for the metaphylaxis-treated cohort are presented in Table 3.4. Analysis of daily average data for DM intake revealed a breakpoint at 3.81 d ($P < 0.0001$) prior to metaphylaxis treatment, the slope before the breakpoint was essentially zero (0.02) and after the breakpoint was -1.51 kg/d. DM intake decreased 49.8% from the breakpoint to the day of metaphylaxis therapy. Contrary to what was observed in the clinically-ill cohort, eating rate was one of the first traits to be detected prior to metaphylaxis treatment, with the breakpoint being detected 8.2 d prior to treatment. The rate of change in eating rate after the breakpoint was 31.2 min/d.

Analysis of the daily averages model for BV frequency revealed a breakpoint 8.19 d prior to metaphylaxis treatment, which was 4.38 d prior to the breakpoint for DM intake. The breakpoint for HD duration was 8.31 d prior to metaphylaxis treatment and 7.74 d prior to the breakpoint for DM intake. The predicted slope after the breakpoint for HD duration was -5.79 min/d. For time to bunk, a breakpoint was detected 3.79 d prior to metaphylaxis treatment, with TTB increasing at a rate of 16.9 min from the breakpoint until metaphylaxis treatment. The breakpoints detected for BV duration and maximum NFI observed were 0.09 and 0.80 d, respectively, indicating that these traits were not predictive of clinical illness.

The analysis of the 3-d rolling average revealed that the breakpoint for DM intake was 2.59 d prior to treatment, which was 1.22 d later compared to the analysis of the daily average data. Model accuracy of the 3-d rolling average DM intake ($R^2 = 0.93$) was higher than that observed for the daily average data ($R^2 = 0.88$).

The breakpoint for eating rate based on the 3-d rolling average data was detected 11.5 d prior to metaphylaxis treatment. The rate of increase in eating rate after the breakpoint (5.15 g/min) was substantially less then what was detected based on the daily average data. Closeness of fit for eating rate was high for eating rate regardless of whether daily or 3-d rolling average data were analyzed.

Although the 3-d rolling average model for BV duration yielded a breakpoint 5.91 d prior to metaphylaxis treatment the predicted slope was essentially 0 and probably not related to the BRD event. The rolling average model for BV frequency was very similar to the daily model with a 0.3 d later breakpoint and a 2.3 event/d reduction in the slope after the breakpoint. The rolling average increased the breakpoint for HD duration to 10 d prior to intake and the slope after the break point was decreased to -1.78 min/d. All 3 of these traits observed the highest model accuracy for the rolling average models over the daily average models.

The 3-d rolling average of NFI SD yielded a somewhat higher model accuracy (R^2= 0.50) and predicted the breakpoint to be 1.01 d sooner than the daily average (R^2= 0.24). Model accuracy for both TTB (R^2 = 0.16) and maximum NFI (R^2 = 0.06) was much lower for the 3-d rolling average than the daily average.

Discussion

The objective of this study was to characterize changes in DM intake and feeding behavior traits preceding the display of clinical symptoms of illness associated with BRD in growing bulls. This type of information could lead to the development of prediction algorithms to detect cattle experiencing morbidity. Identification of morbid cattle earlier in the disease process would potentially improve the efficacy of antimicrobial therapy (Ferran et al., 2011). Results from this study demonstrated that deviations in DM intake and feeding behavior traits occurred well before clinical symptoms were observed. Furthermore, the detected breakpoints for several of the feeding behavior traits occurred prior to the breakpoint for DM intake suggesting that deviations in behavioral patterns associated with feeding activities may be more sensitive for pre-clinical detection of morbidity than deviations in DM intake.

Prior research has demonstrated that DM intake is reduced in cattle experiencing acute health challenges (Gonzalez et al., 2008; Lukas et al., 2008). This is in part because of reduced appetite as the cattle are most likely experiencing a fever (Hart, 1988). In agreement with prior studies, the bulls in this study experienced a large reduction in DM intake prior to onset of observed clinical symptoms. The differences in the breakpoints experienced by the 2 cohort groups can partially be explained by the standardizing all for the animals in the clinically-ill cohort to the day of detection while the metaphylaxis-treated cohort were all compared to the same trial day. With the bulls in the metaphylaxis-treated cohort most likely being in variable stages of the disease process the later detection was not unexpected. Results presented by Wolfger et al. (2015) agree with the breakpoint detection of the clinically-ill cohort, as they reported a change in DM intake as soon as 7 d prior to observation of illness could increase the risk of developing BRD. Furthermore, results from Wolfger et al. (2015) also support the breakpoint in BV duration as they reported an increase in mean meal time up to 7 d prior to visual detection was associated with decreased risk for developing BRD.

Other studies have reported on the feeding behavioral changes in feedlot cattle experiencing BRD-related morbidity events. In one such study, Sowell et al. (1999) concluded that animals experiencing a period of BRD had reduced time spent at the feed bunk. Furthermore they found that a smaller portion of the sick cattle were present at the feed bunk during the first morning feeding compared with healthy cattle. This is in agreement with the results of the current study where BV duration and frequency both observed breakpoints more than 7 d prior to clinical detection for the clinically-ill cohort. In another such study, Theurer et al. (2013b) used tri-axial triangulation devices to analyze behavioral changes in heifers challenged with *Mannheimia haemolytica.* Although individual-animal DM intakes were not recorded, the challenged calves spent less time near the grain and hay bunk in the days following the challenge. They also concluded that calves in the challenged group spent more time lying down and took fewer steps during the days following challenge. Their findings support the results from the current study that feeding behavior traits tended to break prior to clinical observation of sickness. The findings further support the observed increase in slope for maximum NFI after the breakpoint as the animals were most likely engaging in reduced physical activity resulting in more time between BV events. Quimby et al. (2001) used statistical process control to detect BRD up to 4 d prior to observation of illness. They concluded that monitoring of feeding behaviors could offer an alternative method of morbidity detection that was more predictive than visual assessment. This is supported by the results of the clinically-ill cohort where, excluding the NFI traits, both DM intake and feeding behavior broke prior to clinical observation of morbidity.

It was interesting to note that eating rate increased 1 to 3 d prior to observed clinical detection of illness, and 8 to 11 d prior to metaphylaxis treatment. Because both DM intake and BV duration decreased prior to clinical illness, this finding suggests that the magnitude of the decline in BV duration must have exceeded that for DM intake. Perhaps the bulls were trying to reduce energy expenditures associated with ingestion of feed by consuming relatively large meals at faster rates while concurrently minimizing the physical activities associated with feed bunk attendance.

The results from this study support previous research that has compared behavioral patterns associated with feeding activities between healthy and morbid cattle. Further, the results suggest that deviations in feeding behavior patterns preceding the display of clinical symptoms of illness in beef cattle may be useful in development of predictive algorithms for pre-clinical detection of BRD. Advancements in active RFID technology may facilitate development of animal health monitoring systems based on deviations in feeding behavior. Further research is warranted to develop more accurate predictive algorithms based on deviations in feeding behavior for pre-clinical detection of infectious disease.

CHAPTER IV

PRECLINICAL DEVIATIONS IN FEEDING BEHAVIOR AS AN EARLY INDICATOR OF BOVINE RESPIRATORY DISEASE

Introduction

Current methods of disease detection rely on the use of skilled pen riders to visually assess animals on a daily basis for clinical symptoms of illness. Since cattle are prey animals with inherent instincts to mask signs of illness it takes highly experienced individuals to make accurate and timely decisions regarding treatment of animals experiencing morbidity events. Animals with sub-clinical disease that do not display overt clinical symptoms are typically not treated. Moreover, previous research has shown the relationship between animals treated for clinical symptoms of BRD and the incidence of postharvest lung lesions indicative of respiratory tract disease to be moderate to low (Wittum et al., 1996; Gardner et al., 1999; Buhman et al., 2000). These results indicate the need for more accurate and objective methods to detect morbidity in beef cattle.

Many studies have examined the use of remote sensing technologies for morbidity detection in livestock, including rumen and tympanic temperature sensors, accelerometers, infrared thermography, and feeding behavior (Mertens et al., 2010; Theurer et al., 2013a). These remote-sensor technologies have been evaluated based on their ability to provide more accurate pre-clinical detection for morbidity events associated with respiratory tract disease. Remote sensing technologies have been evaluated for practicality and accuracy of BRD detection in beef cattle. Schaefer et al. (2007) used infrared thermography to detect BRD in weaned calves fed in a group pen setting, and reported that infrared thermography could detect incidence of BRD 4 to 6 d prior to observed clinical symptoms with a test efficiency of 71%, which was much higher than the 55% observed by the industry practice of clinical scoring. Rose-Dye et al. (2011) reported that the use rumen temperature sensors was effective in detecting BRD in beef cattle challenged with *Mannheimia haemolytica* and/or bovine viral diarrhea virus. Another use of remote sensing technologies is to collect feeding and watering behaviors. Feeding behavior traits have been shown to be highly repeatable during the growing and finishing periods (Kelly et al., 2010b) suggesting that deviations in feeding behavior may be useful pre-clinical indicators of infectious disease. One of the obstacles to the use of feeding behavior to detect morbidity events is the lack of objective evaluation techniques to determine health status. Few studies have evaluated methods to objectively detect deviations in behavioral patterns associated feeding activities associated with the onset of disease. In one such study, Quimby et al. (2001) applied statistical process control procedures to feeding behavior data collected by RFID technology to identify cattle with BRD. Individual-animals were fitted with RFID tags and sensors in fence line troughs were used to record time spent at the feed bunk and number of times animals visited the feed troughs during each trial day. At the end of the trial individual CUSUM charts for feed bunk attendance were constructed for each animal and the results compared to observed BRD cases identified by feedlot personnel. Quimby et al. (2001) reported that morbidity could be detected by the CUSUM charts 3 to 4 d prior to observational detection with an overall accuracy of 87%. In another such study, Madsen and Kristensen (2005) applied statistical process control procedures to a stochastic model for drinking behavior in piglets. In this study, hourly water intake was modeled and the residuals between the expected and actual water intake was plotted using CUSUM charts. The authors concluded that deviations in water intake were effective in predicting illness up to 24 h before clinical symptoms of illness were observed in piglets.

The objectives of the current study were to evaluate the use of statistical process control procedures to predict clinical illness based on deviations in DM intake and feeding behavior patterns, and to determine which feeding behavior traits were most the most effective for pre-clinical detection of respiratory disease in cattle.

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. Growing purebred bulls (N = 231) consigned from independent producers for the purpose of evaluating performance and feeding efficiency were used in this study. Although all bulls were previously vaccinated against viral and bacterial pathogens using variable vaccine products, all bulls were re-vaccinated upon arrival at the test facility for infectious bovine rhinotracheitis, parainfluenza-3 virus, bovine viral diarrhea, bovine respiratory syncytial virus (Pyramid 5, Boehringer Ingelheim), and *Haemophilus somnus*, *Pasteurella multocida*, and clostridial diseases (Ultrabac7, Zoetis Animal Health), and treated for internal parasites (Valbazen, Zoetis Animal Health). In addition, bulls were fitted with passive, half-duplex transponder ear tags (Allflex USA Inc., Dallas, TX), and adapted to the test diet (Table 3.1) for 28 d prior to the start of a 70-d study.

The bulls were housed in 1 of 9 pens each equipped with 4 electronic feed bunks (GrowSafe System Ltd., Airdrie, Alberta, Canada) to measure daily feed intake and feeding behavior traits. The GrowSafe system (DAQ 6000E) used in this study consisted of feed bunks equipped with load bars to measure feed disappearance, and antenna within each feed bunk to record animal presence by detection of radio-frequency identification tags during feeding events. Feed intake was allocated to individual-animals based on continuous recordings of feed disappearance during feeding events, and a subroutine of the GrowSafe 6000E software (Process Feed Intakes) used to compute feed intake. In addition to collecting individual feed intake data, the system also recorded each bunk visit (**BV**) event, the EID number, scale number and time stamp, which was logged in the data-acquisition computer. In addition to the feeding behavior traits, time to bunk (**TTB**) was calculated using the statistical processing tool R and is defined as the length of the interval between delivery of feed via feed truck and an animal's first feeding event. A description of the feeding behavior traits evaluated in this study is presented in Table 3.1.

During the 70-d trial, bulls were evaluated twice daily for clinical signs of illness, and weighed at 14-d intervals. Diet samples were collected weekly and composited by weight at the end of the trial. Chemical analysis of the diet was conducted by an independent laboratory (Cumberland Valley Analytical Services Inc., Hagerstown, MD).

Experimental Cohorts. Within a 10-d period beginning on day 28 of the trial, 30 bulls were treated for clinical symptoms associated with BRD. Thereafter, in response to reductions in DM intake, feedlot personnel administered metaphylaxis therapy (Tulathromycin; Draxxin®, Zoetis Animal Health) on day 38 of the trial to all remaining bulls (N = 201). Although diagnostic tests were not conducted to conclusively confirm presence of BRD, the decline in DM intake and observed clinical symptoms indicated the presence of acute respiratory illness.

To examine deviations in DM intake and feeding behavior relative to onset of clinical symptoms of disease, the bulls in this study were separated into 2 cohorts. The clinically-ill cohort consisted of bulls that were identified as being morbid from day 28 to 38 of the study by feedlot personnel based on observed clinical symptoms (N = 30). All bulls in this cohort exhibited variable clinical symptoms associated with BRD including nasal discharge, depression lethargy, and anorexia. Twenty seven of these bulls had elevated rectal temperatures (mean = 40.5^{o}C, range = 39.7 to 42.1). All bulls in the clinically-ill cohort were administered antimicrobial therapy (Enrofloxacin; Baytril 100, Bayer Health Care LLC, Shawnee Mission, KS) and returned to their respective pens. The metaphylaxis-treated cohort consisted of the remaining bulls (N = 201) that were subsequently administered Tulathromycin on day 38 of the study. Clinical symptoms of illness were not observed in this cohort prior to metaphylaxis therapy, and diagnostic tests were not performed to confirm the presence of BRD. However, the observed decline in average DM intakes prior to metaphylaxis therapy suggested that bulls in this cohort were experiencing some type of acute illness.

Description of CUSUM Model

Control charts are graphical displays used to determine if time series data is in a state of statistical control. The charts contain a centerline that represents either the mean or target value for the data when the process is in a controlled state. Upper and lower control lines are used to define when a process is in or out of statistical control, with the process being deemed out of control once the data exceeds either of the control lines. There are a variety of control charts that can be implemented to detect deviations in a process such as the Shewhart, CUSUM, and exponentially weighted moving average (EWMA) charts. Control charts have been used in a wide variety of applications ranging from in-line monitoring of industrial manufacturing to healthcare (Roan and Hu, 1995; Woodall, 2006). Mertens et al. (2010) presented a review of the applications of control charts as a tool to support livestock production that focused on the opportunities associated with applying control charts to the increasing availability of data generated by real-time monitoring systems in livestock production systems. They concluded that implementing tools such as statistical process control procedures would be crucial for the implementation of these monitoring systems.

The CUSUM chart is designed to detect minor, persistent deviations in the process mean for a given variable of interest (Hawkins, 1992). The CUSUM chart is a cumulative summation of the differences between each successive data point and the target value or process mean. CUSUM charts can be either 1 or 2-sided depending on the type of change in the process to be detected and both have been used for detecting morbidity in livestock (Quimby et al., 2001; Lukas et al., 2008). For this study, a two-sided CUSUM chart was selected as it allows for the detection of changes in the mean in either the upward or downward direction independently. The CUSUM chart requires user-specified parameters μ_0, σ, Δ, K, and H. The process mean or target value, μ_0, and standard deviation, σ, are computed from the original data. The magnitude of change required to be detected by the chart, Δ, and the magnitude of deviation of an observation from the mean, K, referred to as the reference value, are calculated in standard deviation units. H referred to as the decision interval and calculated in standard deviation units, are the distance away from the mean required to conclude the process is out of control. Once the user specifies Δ, then K and H are computed to optimize the detection of out of control events while keeping false positives to a minimum. Most applications of CUSUM charts have found that using values of $\Delta/2$ for K and 4σ or 5σ for H to work well in most applications.

CUSUM Model Statistical Analysis

Individual CUSUM charts were computed for each animal in a daily iterative manner for 2 trial periods; period 1 (day 0-38) for which all animals were considered clinically ill and period 2 (days 42-69) for which all animals were considered clinically healthy. The separation of the trial into 2 periods allowed for each animal to serve as a both a true positive and a true negative for evaluating the accuracy of CUSUM models.

When designing the CUSUM charts, the commonly used value of $\Delta/2$ was used for the reference value K. The decision interval H was evaluated at three different levels; 4, 3.5, and 3 sigma from the process mean. Sigma was tested across multiple settings to determine sensitivity of the models to changing parameter settings. Evaluating the models at these different parameter settings allowed for the optimization of the decision interval.

The feeding behavior traits that were evaluated are defined in Table 3.2. Based on results from results from the 2-slope broken line models presented in Chapter III, day of pre-clinical detection of illness for DM intake, BV duration, BV frequency, and HD duration were based on the first point to cross the lower control limit as these traits displayed decrease in slope prior to observed clinical detection (Figure 4.1). Pre-clinical detection of illness based on eating rate, TTB, maximum NFI, and NFI standard deviation were based on the first point to cross the upper control limit as the previously reported rate of changes in these traits were positive prior to observed clinical detection.

A 2-behaviorial trait model was also evaluated, which was designed as a confirmatory rule where a minimum of 2 behavior traits were required to go out of control before pre-clinical detection of illness was confirmed. For example, if the CUSUM models for BV duration and frequency were individually detected at 3 and 4 d prior to observed clinical illness, the day of detection based on the 2-behavioral model would be 3 d prior to observed clinical illness.

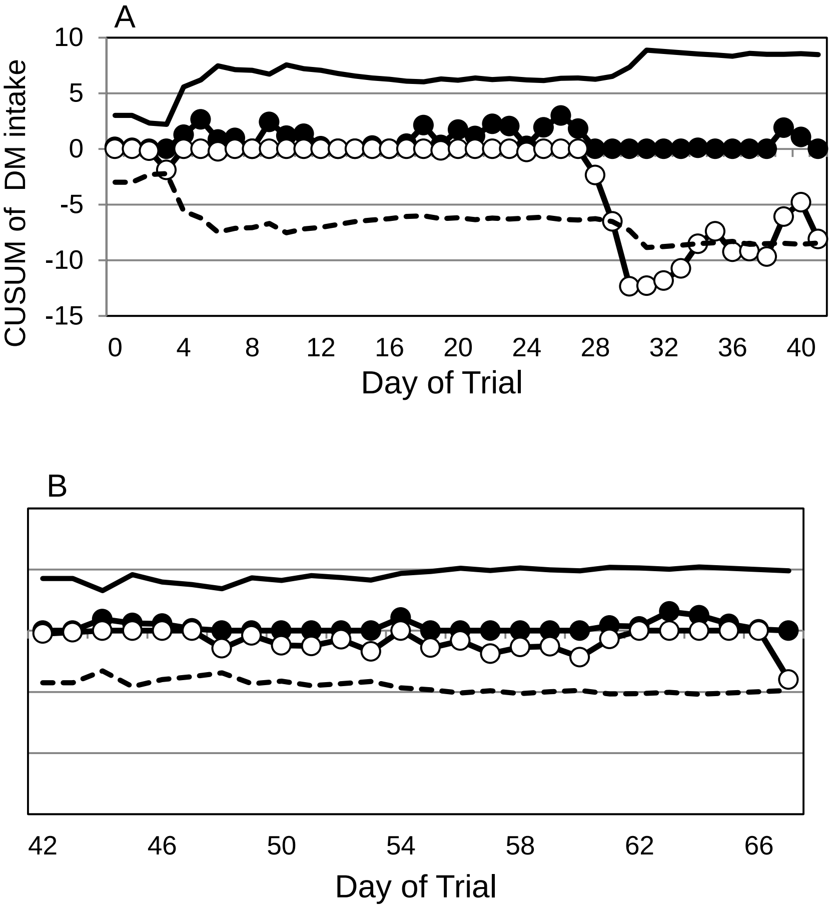

Figure 4.1. Cumulative sum chart of an individual animal identified as morbid during period 1 (A) and healthy during period 2 (B). Pre-clinical detection based on DM intake occurred when the lower CUSUM (open circles) crossed the lower control limit (dashed line).

In the clinically-ill cohort, the day of CUSUM model detection was evaluated relative to the day of individual-animal treatment for clinical illness, whereas, in the metaphylaxis-treated cohort day of CUSUM model detection was evaluated relative to day of Tulathromycin administration (day 38). A t-test was performed to determine if the difference between CUSUM model day of detection and observed clinical detection was significant at $P < 0.05$

T-tests were also performed to examine if differences were present between the day of detection for feeding behavior traits and the day of detection for DM intake.

The overall test efficiency of the CUSUM models for DM intake and each of the feeding behavior traits was determined as the total number of correct detections (True Positives + True Negatives) divided by the total number of observations.

Results

Clinically-Ill Cohort

Descriptive Statistics. The DM intakes and performance of the bulls were within the expected range given the age of the bulls and the experimental diet that was fed. Dry matter intake averaged 9.3 kg/d during period 1 and increased to 9.8 kg/d during period 2. Performance traits also increased from period 1 to period 2 with ADG increasing from 1.32 to 1.54 kg/d and G:F ratio increasing from 0.14 to 0.61.

The means ± SD for BV frequency and duration in period 1 (42.2 ± 12.5, 90.0 ± 21.3) were with the range previously reported in studies with growing steers and bulls (Buhman et al., 2000; Daniels et al., 2000; Hafla et al., 2013). Furthermore, the means ± SD for BV frequency and duration were 40.1 and 93.9 during period 2, indicating that these 2 feeding behavior traits were consistent before and after clinical illness. Likewise, the means ± SD for maximum NFI and the SD of NFI were similar between period 1 (416.7 ± 79.1, 96.9 ± 20.7) and period 2. In contrast, the average TTB was numerically higher during period 1 (84.4 ± 43.8 min) compared to period 2 (54.0 ± 35.8 min). As reported in chapter 2 in growing steers, TTB was weakly correlated with exit velocity in a positive manner, suggesting that steers with more excitable temperaments tended to wait longer before initiating the first BV event following feed truck delivery. The reduction in TTB from period 1 to 2 may indicate that bulls were becoming more acclimated to feedlot personnel and feed truck delivery as the study progressed.

Effect of Sigma on CUSUM Model Results. Ideally, the CUSUM model would detect 100% of bulls observed to be clinically ill (True positive) during period 1 and detect 100% of bulls to be healthy (True negative) during period 2. To evaluate which sigma was optimal for detection of clinical illness in this retrospective study, model results were compared at 4, 3.5 and 3 sigma (Table 4.1). As expected, as sigma used in the CUSUM models was reduced from 4 to 3, the proportion of true positives (model predicted animal as ill) increased during period 1 and the proportion of true negatives (model predicted animal as healthy) during period 2 decreased for DM intake and all feeding behavior traits (data not shown). With the exception of eating rate, model test efficiencies were lower at 3 sigma compared to 4 sigma as the reduction in the proportion of true negatives was greater than the increase in true positives. The model test efficiencies were numerically highest for all traits at 3.5 sigma, except for eating rate. Thus, only the CUSUM model results using 3.5 sigma are presented below.

Table 4.1. Test efficiencies of process-control models (CUSUM method using 4, 3.5, and 3 sigma control lines) of DM intake and feeding behavior traits for detection of clinical illness in the clinically-ill cohort (N = 30) of growing bulls.

Process-control models	Test efficiency (sigma = 4)	Test efficiency (sigma = 3.5)	Test efficiency (sigma = 3)
Single-feed-intake trait models			
DM intake, kg/d	0.88	0.89	0.75
Eating rate, g/min	0.75	0.77	0.80
Single-behavior trait models			
Bunk visit (BV) duration, min/d	0.85	0.87	0.73
BV frequency, events/d	0.79	0.80	0.72
Head down duration, min/d	0.85	0.89	0.80
Time to bunk, min/d	0.65	0.72	0.43
Maximum non-feeding interval (NFI), min/d	0.67	0.74	0.57
NFI SD, min/d	0.82	0.84	0.60
Two-behavior trait model[4]	0.90	0.92	0.57

[1]Test efficiency = (TP + TN) ÷ total number of animals.

CUSUM Models to Detect BRD. Results from CUSUM model detections of clinical illness during periods 1 and 2 are presented in Table 4.2. The CUSUM model for DM intake yielded the highest proportion of true positives (87%) during period 1 of all the single-trait models, however, time of detection based on DM intake did not differ (P > 0.10) from day of observed clinically illness. During period 2, only 10% false positives (model predicted animal as ill) were detected by the CUSUM model based on DM intake. The CUSUM model for eating rate detected only 63% true positives during period 1, but yielded the earliest day of detection (P < 0.05) of all traits at 6.4 d prior to observed clinical illness. Interestingly, the CUSUM model for eating rate was the only feeding behavior based model where detection occurred prior to day of detection based on DM intake. Day of detection based on eating rate occurred ($P < 0.5$) 5.1 d prior to detection based on DM intake.

Analysis of the single-behavior trait models revealed that HD duration detected the greatest proportion of true positives during period 1 (80%), with day of detection being 3.0 d prior ($P < 0.05$) to observed clinical illness. Day of detection by the CUSUM model for BV duration, but not BV frequency was also significantly different from day of observed clinical illness (2.7 d). The test efficiencies for both BV and HD duration were high (87-89%). The CUSUM models based on TTB, maximum NFI, and NFI SD yielded less accurate test efficiencies, and the day of detection did not differ ($P > 0.05$) from day of clinical observation for these traits.

The CUSUM model based on the 2-behavior trait rule yielded the highest test efficiency (0.92) of all the traits, with the average of detection being 2.5 d prior to clinical observation of illness. During period 1 the model detected 93% of the bulls as true positives and during period 2 only detected 10% of the bulls as false negatives.

Table 4.2. Evaluation of process-control models (CUSUM method using 3.5-sigma control lines) of DM intake and feeding behavior traits for detection of clinical illness in the clinically-ill cohort (N = 30) of growing bulls during periods 1 and 2.

	Period 1 (Days 0 to 38; Clinically ill)				Period 2 (Days 42-69; Clinically healthy)		
Process-control model	Time of detection[1], d	Time prior to treatment[2], d	Time prior to Intake[3], d	True positives, %	Time of detection[1], d	True negatives, %	Test efficiency
Single-feed-intake trait models							
DM intake, kg/d	32.4	-0.9	--	87%	63	90%	0.89
Eating rate, g/min	27.6	-6.4*	-5.1*	63%	67	90%	0.77
Single-behavior trait models							
Bunk visit (BV) duration, min/d	30.7	-2.7*	-1.2	77%	44	97%	0.87
BV frequency, events/d	31.0	-2.2	-1.6	70%	61	90%	0.80
Head down duration, min/d	30.4	-3.0*	-1.2	80%	60	97%	0.89
Time to bunk, min/d	32.2	-0.6	-0.6	60%	54	83%	0.72
Maximum non-feeding interval (NFI), min/d	32.5	-0.5	0.9	50%	66	97%	0.74
NFI SD, min/d	32.1	-1.1	-0.5	77%	65	90%	0.84
Two-behavior trait model[4]	30.8	-2.5*	-1.7	93%	65	90%	0.92

[1] Average time of detection that process-control models were deemed out of control for Periods 1 and 2.

[2] Average difference between time of observed clinical detection and process-model detection (*Difference significant at $P < 0.05$).

Metaphylaxis-Treated Cohort

Descriptive Statistics. Bulls in the metaphylaxis-treated cohort exhibited DM intakes and performance traits within the expected range given their age and the experimental diet that was fed. During period 1 of the study DM intake averaged 10.0 kg/d and increased to 10.7 kg/d during period 2. The bulls in the metaphylaxis-treated cohort gained 0.2 kg/d less in period 2 than in period 1 with an ADG of 1.64 and 1.44 kg/d respectively. One of the bulls lost weight during period 2 which may have caused the reduction in ADG. Gain to feed ratio was also reduced to from 0.165 in period 1 to 0.137 in period 2. Eating rate was greater during period 2 than during period 1 of the trial.

The means ± SD for BV frequency and duration in period 1 (44.0 ± 11.6, 95.8 ± 20.2) were within the range previously reported in studies with growing steers and bulls (Buhman et al., 2000; Daniels et al., 2000; Hafla et al., 2013). The means ± SD for BV frequency and duration decreased slightly to 42.5 ± 10.0 and 91.8 ± 18.9 for period 2 indicating that these traits remained relatively steady throughout the trial. Likewise, the means ± SD for maximum NFI and the SD of NFI were similar between period 1 (397.2 ± 52.6, 89.0 ± 13.3) and period 2 (383.8 ± 50.0, 87.8 ± 12.9). In contrast, as seen in the clinically-ill cohort, the average TTB was decreased from period 1 (73.6 ± 39.1, 49.4 ± 26.9) compared to period 2. As TTB is more indicative of temperament it is likely that as the trial progressed animals became acclimated to the feedlot personnel and feed truck delivery.

Effect of Sigma on CUSUM Model Results. Similar to what was observed in the clinically-ill cohort, as sigma used in the CUSUM models was reduced from 4 to 3, the proportion of true positives increased during period 1 and the proportion of true negatives during period 2 decreased for DM intake and all feeding behavior traits (data not shown). As the proportion of true positives in period 1 increased to a greater degree than the proportion of false positives in period 2 the test efficiencies of all the models applied to the metaphylaxis-treated cohort were highest when the decision interval was set at 3 sigma (Table 4.3). Although the test efficiency was highest for the 3 sigma control lines, the proportion of false positives was deemed to be greater than was acceptable and the decision was made to use the control lines set at 3.5 sigma for this cohort.

Table 4.3. Test efficiencies of process-control models (CUSUM method using 4, 3.5, and 3 sigma control lines) of DM intake and feeding behavior traits for detection of clinical illness associated with bovine respiratory disease (BRD) in the metaphylaxis-treated cohort (N = 201) prior to metaphylactic treatment[1] on day 38 of the trial.

Process-control models	Test efficiency (sigma = 4)	Test efficiency (sigma = 3.5)	Test efficiency (sigma = 3)
Single-feed-intake trait models			
DM intake, kg/d	0.77	0.84	0.89
Eating rate, g/min	0.76	0.66	0.81
Single-behavior trait models			
Bunk visit (BV) duration, min/d	0.62	0.69	0.76
BV frequency, events/d	0.60	0.61	0.63
Head down duration, min/d	0.68	0.74	0.79
Time to bunk, min/d	0.58	0.57	0.64
Maximum non-feeding interval (NFI), min/d	0.61	0.64	0.72
NFI SD, min/d	0.67	0.71	0.74
Two-behavior trait model[4]	0.75	0.81	0.82

[1] Tulathromycin (Draxxin®).

[2] Test efficiency = (TP + TN) ÷ total number of animals.

CUSUM Model Detection of Clinical Illness. Results from CUSUM model detection in the metaphylaxis-treated cohort during period 1 and 2 are presented in Table 4.4. The CUSUM model for DM intake yielded the highest test efficiency (0.84) of all the models evaluated with 71% true positives and 96% true negatives. The average detection for DM intake occurred on day 35 of the trial which was 3 d prior to administration of metaphylaxis therapy. The CUSUM model for eating rate was less accurate (Test efficiency = 0.66) but was very predictive of the morbidity event with the average detection occurring 10.6 d prior to treatment and 9.1 d prior to DM intake detection.

Analysis of the single-behavior trait models revealed that all traits observed average detection significantly ($P < 0.05$) prior to treatment. Average out of control detections were observed > 7 d prior to treatment for BV frequency, duration, HD duration, and TTB. Head down duration yielded the greatest test efficiency (0.74) and was the most predictive of the morbidity event with average detection occurring 9.6 d before metaphylaxis therapy and 7.1 d before DM intake. The NFI SD model observed the second highest test efficiency (0.71) and was able to detect out of control events 4.9 d before treatment was administered. Although it was one of the earliest traits to signal BV frequency detected the smallest proportion of true positives at 30% resulting in a test efficiency of 0.61.

In this cohort, the CUSUM model based on the 2-behavior trait rule observed the greatest test efficiency (0.81) of the feeding behaviors, with the average detection occurring 6.5 d before treatment. With average detection occurring 3.2 d before the DM intake model, the 2-trait model was not as predictive as several single-behavior models but the percentage of true positives was much higher.

Table 4.4. Evaluation of process-control models (CUSUM method using 3.5-sigma control lines) of DM intake and feeding behavior traits for detection of bovine respiratory disease (BRD) in the metaphylaxis-treated cohort (N = 201) prior to (Period 1) and following (Period 2) metaphylactic treatment[1] on day 38 of the trial.

	Period 1 (Days 0-38; 201 animals administered metaphylactic treatment on day 38)				Period 2 (Days 42-69; 197 animals observed to be clinically healthy)		
Process-control model	Time of detection, d	Time prior to treatment[2], d	Time prior to Intake[3], d	True positives, %	Time of detection, d	True negatives, %	Test Efficiency
Single-feed intake trait models							
DM intake, kg/d	35.0	-3.0*	--	71%	55	96%	0.84
Eating rate, g/min	27.3	-10.6*	-9.1*	62%	59	69%	0.66
Single-behavior trait models					45		
Bunk visit (BV) duration, min/d	30.1	-7.9*	-4.2*	39%	57	98%	0.69
BV frequency, events/d	28.6	-9.5*	-3.9*	30%	58	91%	0.61
Head down duration, min/d	28.4	-9.6*	-7.1*	49%	59	98%	0.74
Time to bunk, min/d	31.7	-6.3*	-3.5*	34%	63	80%	0.57
Maximum non-feeding interval (NFI), min/d	34.8	-3.2*	0.1	32%	62	96%	0.64
NFI SD, min/d	33.1	-4.9*	-1.8*	49%	62	93%	0.71
Two-behavior trait model[4]	31.5	-6.5*	-3.2*	68%	62	93%	0.81

[1] Tulathromycin (Draxxin®).

[2] Average time of detection that process-control models were deemed out of control for Periods 1 and 2

[3] Average difference between time of observed clinical detection and process-model detection (*Difference significant at P < 0.05).

[4] Average difference between time of process-model detection for DM intake and process-model detection for each feeding behavior trait (*Difference significant at P < 0.05).

Discussion

While diagnostic tests were not conducted to confirm presence of bovine respiratory disease (BRD), bulls in the clinically-ill cohort displayed clinical symptoms associated with respiratory tract infection, and 28 of the 30 bulls had elevated rectal temperatures (> 39.7 ^{o}C) upon examination. Moreover, the reduction in DM intake prior to anti-microbial therapy (clinically-ill cohort) and metaphylaxis treatment (metaphylaxis-treated cohort), and rapid recovery in DM intake thereafter (Figure 4.2) strongly suggested that the majority of the bulls in this study had BRD. The acute and widespread nature of the apparent outbreak of respiratory tract disease in these bulls provided an opportunity to retrospectively examine deviations in DM intake and feeding behavior patterns relative to the onset of observed clinical symptoms or metaphylaxis treatment.

It has been well documented that animals experiencing morbidity events have distinct changes in their behavioral patterns. Hart (1988) described the most common behavioral signs associated with illness including lethargy, depression, anorexia, and reduction in grooming, and hypothesized that morbid animals become less physically active and have lower appetites to conserve body heat and energy reserves. Based on a 2-slope broken-line regression analysis (see Chapter III), DM intake declined by 39.3% in 6.79 d prior to observation of clinical illness (clinically-ill cohort), and by 40.2% in 3.81 d prior to metaphylaxis treatment (metaphylaxis-treated cohort).

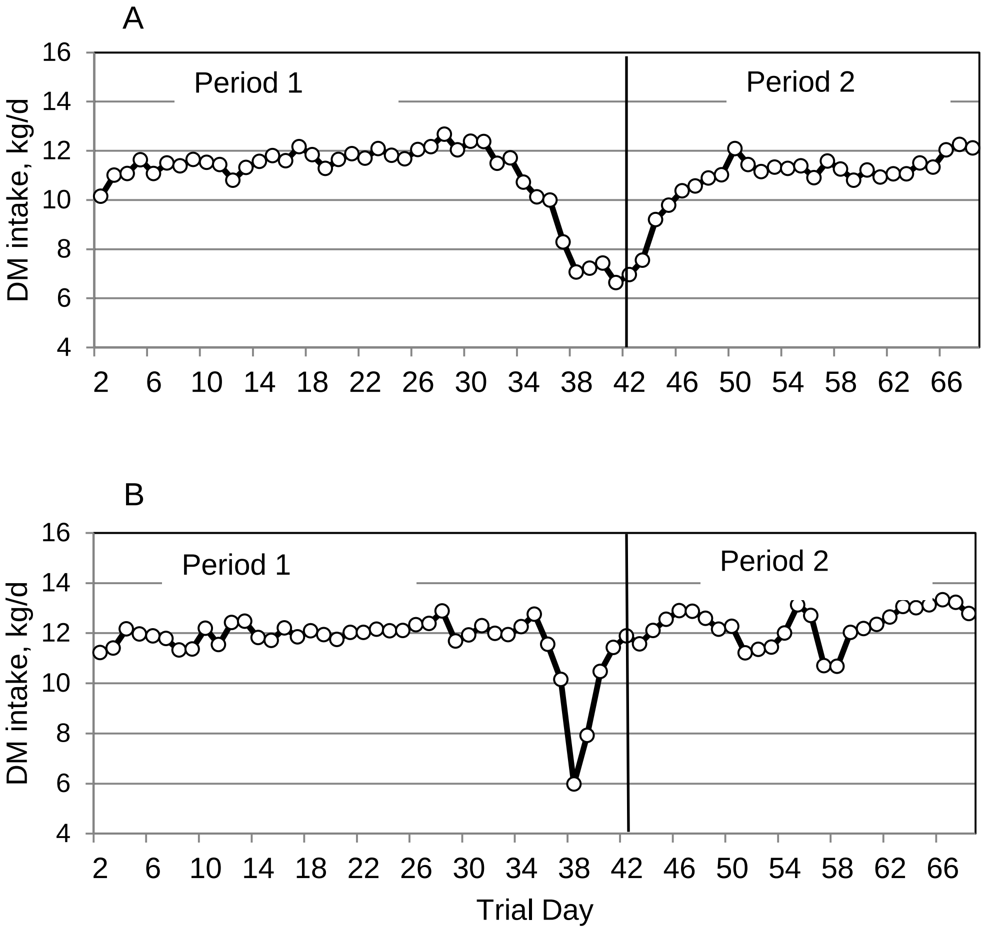

Figure 4.2. Average daily DM intake for the clinically-ill (A) and metaphylaxis-treated cohorts (B) during period 1 (all animals clinically-ill) and period 2 (all animals clinically healthy) of the study.

Sowell et al. (1999) measured behavioral patterns associated with feeding and drinking activities in healthy and morbid (BRD) steers using a GrowSafe system designed to quantify frequency and duration of feed bunk and water trough attendance using passive RFID technology. Two 32-d studies were conducted with high-risk calves, with morbid steers spending less time at the feedbunk and visiting the feedbunk fewer times per day compared to the healthy steers. In the second study, there was no difference in BV duration, but morbid cattle had 38% fewer BV events than healthy animals. This is comparable to the detection of sustained reductions in BV frequency and duration by the CUSUM models in the current study. In a more recent study, Wolfger et al. (2015) demonstrated that as average meal intake and BV frequency increased the risk for developing BRD decreased. Moreover, they observed that changes in meal intakes and BV frequencies were detected as much as 7 d prior to clinical observation of morbidity. These results are supportive of results from the current study, with the behavior-based CUSUM models detecting illness in metaphylaxis-treated cohort 3 to 10 d prior to metaphylaxis treatment.

The accuracies of the CUSUM models based on the use of BV and HD duration, and the 2-trait rule (0.87, 0.89, 0.92) for the clinically-ill cohort were comparable to those reported by Quimby et al. (2001), who reported a test efficiency of 87% for CUSUM models based on feed bunk attendance. The corresponding accuracies of the CUSUM models for BV and HD duration, and the 2-trait rule in the metaphylaxis-treated cohort were lower (0.69, 0.74, 0.81). This may be partially explained by the fact that bulls in this cohort were likely in variable stages of the disease process when they were administered metaphylaxis treatment. Moreover, it is also likely that some of the bulls in this cohort were not clinically ill at the time treatment was administered.

Quimby et al. (2001) also reported that the average day of detection was 3.7 to 4.5 d prior to observed clinical illness by experienced pen riders, which is intermediate between the results found in the current study. Based on the CUSUM model using the 2-trait rule, clinical illness was detected 2.5 d prior to observed clinical illness (clinically-ill cohort) and 6.5 d prior to metaphylaxis treatment (metaphylaxis-treated cohort). Using infrared thermography (IRT) to measure changes in skin-surface temperature, Schaefer et al. (2007) was able to detect clinical illness 4 to 6 d prior to observed clinical symptoms of BRD, with a 71% test efficiency. Also among the technologies previously evaluated are (Timsit et al., 2011) the use of reticulo-rumen boluses equipped with temperature sensors, and found that rumen hyperthermic episodes occurred 12 to 136 h prior to observed clinical symptoms of disease, with a positive predictive value of 73%.

The improvement in the CUSUM model accuracies based on the 2-behavior trait rule compared to the model accuracies based on use of single-behavioral traits in both cohorts suggests that a multivariate approach to the development of statistical process control models could further improve the accuracy and robustness of algorithms to predict BRD using feeding behavior traits. With recent developments in active RFID technology to remotely measure behavioral activities in cattle, the development of algorithms for pre-clinical detection of illness due to infectious disease will enable animals to be treated earlier in the disease process to improve efficacy of anti-microbial treatment and reduce the economic impact of BRD in the beef industry. With growing concern about antimicrobial resistant bacterial and the potential effect from antimicrobial use in livestock the need for accurate pre-clinical detection is increasing. Moreover, early detection of infectious disease has to potential to reduce the frequency and dose of antimicrobial medications administered (Ferran et al., 2011).

CHAPTER V

SUMMARY

Livestock production systems aim to generate long-term maximal profit by increasing animal production and efficiency within the production cycle. Profit is a balance between the costs of inputs and the value of revenue generated by the production system. Therefore, profit can be influenced by decreasing input costs and(or) increasing the value of outputs. The studies presented focus on 2 strategies to improve the profitability of the beef cattle industry; selection for cattle that have more favorable phenotypes for feed efficiency and development of methods for more accurate pre-clinical detection of infectious diseases in cattle.

Results from study 1 demonstrated that steers with divergent phenotypes for RFI exhibited distinct behavioral traits that could be used to differentiate animals with more favorable feed efficiency. Steers identified with low RFI spent 21% less time at the feedbunk and had 6% fewer meals per day than steers with high RFI. Because the steers in the low RFI group had 19% lower DM intakes they produced $145 per animal more revenue than steers in the high RFI group. Furthermore, steers identified with high-TTB had 18% lower gains than steers with low-TTB. Steers in the low TTB group produced on average $88 per head more profit than high TTB steers. The results indicate that TTB was weakly associated with temperament, and that it was more correlated with performance traits than feed efficiency.

Economic losses associated with the detection and treatment of BRD play a significant role in the overall profit of a beef production system. In study 2 bulls were shown to have distinct behavioral changes prior to observation of clinical symptoms associated with BRD. Furthermore, these changes were shown to occur from 14.19 to 1.32 d prior to observed clinical illness and from 12.59 to 3.79 d prior to metaphylaxis treatment. In general animals tended to spend less time at the feed bunk and have fewer bunk visits in the days leading up to a BRD event.

Using these observations, statistical process control procedures were able to detect bulls between 0.9 and 3.0 d prior to observation of clinical symptoms or metaphylaxis treatment, respectively, using DM intake. Furthermore, detection using BV duration could identify bulls 2.7 and 7.9 d prior to observation of clinical symptoms or metaphylaxis treatment, respectively, and was therefore more predictive than DM intake at detecting pre-clinical symptoms of BRD. In addition, the improvement in test efficiency of the 2-trait behavioral rule base indicates that the development of a multivariate approach to detect morbidity animals could further improve the precision and accuracy of detection algorithms.

Advancements in active RFID technology could provide a vehicle to collect individual-animal feeding behavior traits that could be used to detect disease and identify animals with more favorable phenotypes for RFI. Future research should be conducted to advance the development of these decision support tools for the beef cattle industry.

LITERATURE CITED

Archer, J. A., E. C. Richardson, R. M. Herd, and P. F. Arthur. 1999. Potential for selection to improve efficiency of feed use in beef cattle: a review. Australian Journal of Agricultural Research 50: 147-161.

Arthur, P. F., J. A. Archer, D. J. Johnston, R. M. Herd, E. C. Richardson, and P. F. Parnell. 2001. Genetic and phenotypic variance and covariance components for feed intake, feed efficiency, and other postweaning traits in Angus cattle. J Anim Sci 79: 2805-2811.

Bailey, J. C., L. O. Tedeschi, M. M. ED, J. E. Sawyer, and G. E. Carstens. 2012. Technical note: Evaluation of bimodal distribution models to determine meal criterion in heifers fed a high-grain diet. J Anim Sci 90: 2750-2753.

Bishop, M. D., M. E. Davis, W. R. Harvey, G. R. Wilson, and B. D. VanStavern. 1991. Divergent selection for postweaning feed conversion in Angus beef cattle: II. Genetic and phenotypic correlations and realized heritability estimate. J Anim Sci 69: 4360-4367.

Buhman, M. J., L. J. Perino, M. L. Galyean, T. E. Wittum, T. H. Montgomery, and R. S. Swingle. 2000. Association between changes in eating and drinking behaviors and respiratory tract disease in newly arrived calves at a feedlot. American Journal of Veterinary Research 61: 1163-1168.

Carstens, G. E., and L. O. Tedeschi. 2006. Defining feed efficiency in beef cattle. Proc. BIF 38th Annual Meeting: 12-21 Choctaw, MS.

Coma, J., D. Carrion, and D. R. Zimmerman. 1995. Use of Plasma Urea Nitrogen as a Rapid Response Criterion to Determine the Lysine Requirement of Pigs. J. Anim Sci. 73: 472-481.

Cornou, C., J. Vinther, and A. R. Kristensen. 2008. Automatic detection of oestrus and health disorders using data from electronic sow feeders. Livestock Science 118: 262-271.

Crews, D. H., G. E. Carstens, and P. A. Lancaster. 2006. Case Study: A Multiple Trait Selection Index including Feed Efficiency. The Professional Animal Scientist 22: 65-70.

Daniels, T. K., J. G. P. Bowman, B. F. Sowell, M. E. Branine, and M. E. Hubbert. 2000. Effects of Metaphylactic Antibiotics on Behavior of Feedlot Calves. The Professional Animal Scientist 16: 247-253.

De Vries, A., and J. K. Reneau. 2010. Application of statistical process control charts to monitor changes in animal production systems. J Anim Sci 88: E11-24.

Doventas, A., B. Karadag, A. Curgunlu, A. Bilici, N. Sut, D. S. Erdincler, T. Beger, and V. Tezcan. 2011. Replicability and reliability of pain assessment forms in geriatrics. Archives of gerontology and geriatrics 53: e55-60.

Ferran, A. A., P. L. Toutain, and A. Bousquet-Melou. 2011. Impact of early versus later fluoroquinolone treatment on the clinical; microbiological and resistance outcomes in a mouse-lung model of Pasteurella multocida infection. Veterinary microbiology 148: 292-297.

Ferrell, C. L., and T. G. Jenkins. 1985. Cow type and the nutritional environment: nutritional aspects. J Anim Sci 61: 725-741.

Fulton, R. W., B. J. Cook, D. L. Step, A. W. Confer, J. T. Saliki, M. E. Payton, L. J. Burge, R. D. Welsh, and K. S. Blood. 2002. Evaluation of health status of calves and the impact on feedlot performance: assessment of a retained ownership program for postweaning calves. Canadian journal of veterinary research = Revue canadienne de recherche veterinaire 66: 173-180.

Galyean, M. L., L. J. Perino, and G. C. Duff. 1999. Interaction of cattle health/immunity and nutrition. J Anim Sci 77: 1120-1134.

Gardner, B. A., H. G. Dolezal, L. K. Bryant, F. N. Owens, and R. A. Smith. 1999. Health of finishing steers: effects on performance, carcass traits, and meat tenderness. J Anim Sci 77: 3168-3175.

Goldhawk, C., N. Chapinal, D. M. Veira, D. M. Weary, and M. A. von Keyserlingk. 2009. Prepartum feeding behavior is an early indicator of subclinical ketosis. Journal of dairy science 92: 4971-4977.

Gonzalez, L. A., B. J. Tolkamp, M. P. Coffey, A. Ferret, and I. Kyriazakis. 2008. Changes in feeding behavior as possible indicators for the automatic monitoring of health disorders in dairy cows. Journal of dairy science 91: 1017-1028.

Hafla, A. N., G. E. Carstens, T. D. Forbes, L. O. Tedeschi, J. C. Bailey, J. T. Walter, and J. R. Johnson. 2013. Relationships between postweaning residual feed intake in heifers and forage use, body composition, feeding behavior, physical activity, and heart rate of pregnant beef females. J Anim Sci 91: 5353-5365.

Hart, B. L. 1988. Biological basis of the behavior of sick animals. Neuroscience and biobehavioral reviews 12: 123-137.

Hawkins, D. M. 1992. Evaluation of Average Run Lengths of Cumulative Sum Charts for an Arbitrary Data Distribution. Commun Stat Simulat 21: 1001-1020.

Herd, R. M., J. A. Archer, and P. F. Arthur. 2003. Reducing the cost of beef production through genetic improvement in residual feed intake: Opportunity and challenges to application. J. Anim Sci. 81: E9-17.

Kelly, A. K., M. McGee, D. H. Crews, Jr., A. G. Fahey, A. R. Wylie, and D. A. Kenny. 2010a. Effect of divergence in residual feed intake on feeding behavior, blood metabolic variables, and body composition traits in growing beef heifers. J Anim Sci 88: 109-123.

Kelly, A. K., M. McGee, D. H. Crews, Jr., T. Sweeney, T. M. Boland, and D. A. Kenny. 2010b. Repeatability of feed efficiency, carcass ultrasound, feeding behavior, and blood metabolic variables in finishing heifers divergently selected for residual feed intake. J Anim Sci 88: 3214-3225.

Koch, R. M., K. E. Gregory, D. Chambers, and L. A. Swiger. 1963. Efficiency of Feed Use in Beef Cattle. J. Anim Sci. 22: 486-&.

Kolath, W. H., M. S. Kerley, J. W. Golden, and D. H. Keisler. 2006. The relationship between mitochondrial function and residual feed intake in Angus steers1. J. Anim. Sci. 84: 861-865.

Lancaster, P. A., G. E. Carstens, F. R. Ribeiro, L. O. Tedeschi, and D. H. Crews, Jr. 2009. Characterization of feed efficiency traits and relationships with feeding behavior and ultrasound carcass traits in growing bulls. J Anim Sci 87: 1528-1539.

Lukas, J. M., J. K. Reneau, and J. G. Linn. 2008. Water intake and dry matter intake changes as a feeding management tool and indicator of health and estrus status in dairy cows. Journal of dairy science 91: 3385-3394.

Madsen, T. N., and A. R. Kristensen. 2005. A model for monitoring the condition of young pigs by their drinking behaviour. Computers and Electronics in Agriculture 48: 138-154.

McGee, M., J. A. Ramirez, G. E. Carstens, W. J. Price, J. B. Hall, and R. A. Hill. 2014. Relationships of feeding behaviors with efficiency in RFI-divergent Japanese Black cattle. J Anim Sci 92: 3580-3590.

Mendes, E. D., G. E. Carstens, L. O. Tedeschi, W. E. Pinchak, and T. H. Friend. 2011. Validation of a system for monitoring feeding behavior in beef cattle. J Anim Sci 89: 2904-2910.

Mertens, K., E. Decuypere, J. De Baerdemaeker, and B. De Ketelaere. 2010. Statistical control charts as a support tool for the management of livestock production. The Journal of Agricultural Science 149: 369-384.

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

Nkrumah, J. D., E. K. Okine, G. W. Mathison, K. Schmid, C. Li, J. A. Basarab, M. A. Price, Z. Wang, and S. S. Moore. 2006. Relationships of feedlot feed efficiency, performance, and feeding behavior with metabolic rate, methane production, and energy partitioning in beef cattle. J Anim Sci 84: 145-153.

Quimby, W. F., B. F. Sowell, J. G. P. Bowman, M. E. Branine, M. E. Hubbert, and H. W. Sherwood. 2001. Application of feeding behaviour to predict morbidity of newly received calves in a commercial feedlot. Can J Anim Sci 81: 315-320.

Richardson, E. C., R. M. Herd, V. H. Oddy, J. M. Thomspon, J. A. Archer, and P. F. Arthur. 2001. Body composition and implications for heat production of Angus steer progeny of parents selected for and against residual feed intake. Aust J Exp Agr 41: 1065-1072.

Roan, C., and S. J. Hu. 1995. Monitoring and classification of dimensional faults for automotive body assembly. Int J Flex Manuf Syst 7: 103-125.

Rose-Dye, T. K., L. O. Burciaga-Robles, C. R. Krehbiel, D. L. Step, R. W. Fulton, A. W. Confer, and C. J. Richards. 2011. Rumen temperature change monitored with remote rumen temperature boluses after challenges with bovine viral diarrhea virus and Mannheimia haemolytica. J Anim Sci 89: 1193-1200.

SAS Institute Inc. 2015. The data analysis for this paper was generated using SAS software, Version 9.4 of the SAS System for Windows. Copyright (c) 2002-2012 SAS Institute Inc. SAS and all other SAS Institute Inc. product or service names are registered trademarks or trademarks of SAS Institute Inc., Cary, NC, USA.

Schaefer, A. L., N. Cook, S. V. Tessaro, D. Deregt, G. Desroches, P. L. Dubeski, A. K. W. Tong, and D. L. Godson. 2004. Early detection and prediction of infection using infrared thermography. Can J Anim Sci 84: 73-80.

Schaefer, A. L., N. J. Cook, J. S. Church, J. Basarab, B. Perry, C. Miller, and A. K. Tong. 2007. The use of infrared thermography as an early indicator of bovine respiratory disease complex in calves. Res Vet Sci 83: 376-384.

Siivonen, J., S. Taponen, M. Hovinen, M. Pastell, B. J. Lensink, S. Pyorala, and L. Hanninen. 2011. Impact of acute clinical mastitis on cow behaviour. Applied Animal Behaviour Science 132: 101-106.

Smith, R. A. 1998. Impact of disease on feedlot performance: a review. J Anim Sci 76: 272-274.

Snowder, G. D., L. D. Van Vleck, L. V. Cundiff, and G. L. Bennett. 2006. Bovine respiratory disease in feedlot cattle: environmental, genetic, and economic factors. J Anim Sci 84: 1999-2008.

Sowell, B. F., M. E. Branine, J. G. Bowman, M. E. Hubbert, H. E. Sherwood, and W. Quimby. 1999. Feeding and watering behavior of healthy and morbid steers in a commercial feedlot. J Anim Sci 77: 1105-1112.

Tedeschi, L. O., D. G. Fox, and P. J. Guiroy. 2004. A decision support system to improve individual cattle management. 1. A mechanistic, dynamic model for animal growth. Agricultural Systems 79: 171-204.

Theurer, M. E., D. E. Amrine, and B. J. White. 2013a. Remote noninvasive assessment of pain and health status in cattle. The Veterinary clinics of North America. Food animal practice 29: 59-74.

Theurer, M. E., D. E. Anderson, B. J. White, M. D. Miesner, D. A. Mosier, J. F. Coetzee, J. Lakritz, and D. E. Amrine. 2013b. Effect of Mannheimia haemolytica pneumonia on behavior and physiologic responses of calves during high ambient environmental temperatures. J Anim Sci 91: 3917-3929.

Thor, J., J. Lundberg, J. Ask, J. Olsson, C. Carli, K. P. Harenstam, and M. Brommels. 2007. Application of statistical process control in healthcare improvement: systematic review. Quality & safety in health care 16: 387-399.

Timsit, E., S. Assie, R. Quiniou, H. Seegers, and N. Bareille. 2011. Early detection of bovine respiratory disease in young bulls using reticulo-rumen temperature boluses. Veterinary journal 190: 136-142.

Urton, G., M. A. G. von Keyserlingk, and D. M. Weary. 2005. Feeding behavior identifies dairy cows at risk for metritis. Journal of dairy science 88: 2843-2849.

Wittum, T. E., N. E. Woollen, L. J. Perino, and E. T. Littledike. 1996. Relationships among treatment for respiratory tract disease, pulmonary lesions evident at slaughter, and rate of weight gain in feedlot cattle. Journal of the American Veterinary Medical Association 209: 814-&.

Wolfger, B., K. S. Schwartzkopf-Genswein, H. W. Barkema, E. A. Pajor, M. Levy, and K. Orsel. 2015. Feeding behavior as an early predictor of bovine respiratory disease in North American feedlot systems. J Anim Sci 93: 377-385.

Woodall, W. H. 2006. The use of control charts in health-care and public-health surveillance. Journal of Quality Technology 38: 89-104.

Yeates, M. P., B. J. Tolkamp, D. J. Allcroft, and I. Kyriazakis. 2001. The use of mixed distribution models to determine bout criteria for analysis of animal behavior. Journal of Theor. Biol. 213: 413-425.