THE RELATIONSHIP BETWEEN RESIDUAL FEED INTAKE AND FEEDING BEHAVIOR IN GROWING HEIFERS

A Thesis

by

GLENDA MARIE BINGHAM

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

MASTER OF SCIENCE

August 2007

Major Subject: Animal Science

THE RELATIONSHIP BETWEEN RESIDUAL FEED INTAKE AND FEEDING BEHAVIOR IN GROWING HEIFERS

A Thesis

by

GLENDA MARIE BINGHAM

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

MASTER OF SCIENCE

Approved by:

Chair of Committee,	Theodore Friend
Committee Members,	Gordon Carstens
	Merwyn Kothmann
Head of Department,	Gary Acuff

August 2007

Major Subject: Animal Science

ABSTRACT

The Relationship Between Residual Feed Intake and Feeding Behavior in Growing Heifers. (August 2007)

Glenda Marie Bingham, B.S., Texas A&M University

Chair of Advisory Committee: Dr. Theodore Friend

The objective of this study was to determine if feeding behavior traits are correlated with performance and feed efficiency traits in growing heifers. Individual dry matter intake (DMI) was measured in Brangus heifers (n = 115) fed a roughage-based diet (ME = 2.1 Mcal/kg) for 70 d using Calan gate feeders (6 heifers/pen). Residual feed intake (RFI) was computed as the residuals from linear regression of DMI on mid-test $BW^{0.75}$ and average daily gain (ADG). Heifers with the highest (n = 18) and lowest (n = 18) RFI were identified for feeding behavior measurements. During days 28 through 56 of the 70-d feeding trial, continuous video recordings were obtained for all heifers. Video images of two sets of four 24-h periods, two weeks apart, were analyzed for the focal animals. All occurrences of feeding were timed and counted per day, and the eight 24-h periods averaged to derive the overall feeding event (FE) and meal duration and frequency for each focal heifer. Total feeding event duration was defined as the total min per day the animal's head was down in the feed bunk. A meal included all visits an animal made to the feed bunk that were separated by less than 5 min.

The mean RFI values for the low and high RFI heifers were (mean ± SE) -1.03 and 1.00 ± 0.03 kg/d, respectively. Low RFI heifers consumed 21.9% less ($P < 0.0001$) DMI, but had similar BW and ADG compared to high RFI heifers. Heifers with low RFI spent more time ($P < 0.0001$) eating (152 vs 124 ± 4.26 min/d) at a lower eating rate (62.8 vs 99.6 ± 3.28 g/min), but had similar FE frequencies compared to high RFI heifers. Feeding event duration was negatively correlated with RFI while FE frequency and FE eating rate were positively correlated with RFI. However, meal duration and frequency were not correlated with RFI. Therefore, measuring FE characteristics could prove more useful than analyzing meals when trying to predict RFI. Additionally, eating rate appeared to be more closely related to RFI than any of the other feeding behavior traits measured.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Although feed inputs represent the largest variable cost in producing beef, genetic selection has remained focused on output traits, such as growth and carcass quality. The beef industry can improve profitability through reductions in feed inputs as well as increases in product outputs. In order to accomplish this goal, the industry should select cattle that more efficiently utilize feed resources. Many feed efficiency traits have been evaluated over the years, but some of those traits are related to growth rate, such that gain and mature size would be increased if used for selection, resulting in increased feed costs. Traditionally, attempts to improve feed efficiency in beef cattle have selected for feed conversion ratio (FCR), a ratio of feed intake to weight gain. Because FCR is inversely related to growth traits, selection for FCR in growing cattle will likely lead to larger mature cows (Herd and Bishop, 2000), increase feed costs for the breeding herd and not necessarily improve profitability. Residual feed intake (RFI), or net feed intake, was first identified by Koch et al. (1963) as a feed efficiency trait that was independent of growth traits. It is expressed as the difference between actual feed intake and the feed an animal is expected to consume based on its body size. Therefore, RFI is a measure of the variation in feed intake beyond that which is needed for maintenance and growth requirements (Archer et al., 1999). Cattle identified as having low RFI have

---

This thesis follows the style and format of the Journal of Animal Science.

substantially lower feed intakes than high RFI cattle without noticeable changes in body weight or growth rates (Arthur et al., 2001b).

Recent research has shown that such feeding behaviors as duration and frequency of bunk attendance may be related to feed efficiency traits. Schwartzkopf-Genswein et al. (2002) determined that FCR was negatively correlated with daily feeding duration measurements. Lancaster et al. (2005a) demonstrated a negative relationship between feeding duration and frequency and RFI in growing bulls.

REVIEW OF LITERATURE

Feed Conversion Ratio

Feed conversion ratio (FCR) has commonly been used to measure feed efficiency in cattle (Archer et al., 1999). Feed conversion ratio is a measure of an animal's efficiency in converting feed into body mass. Specifically, FCR is the weight of the feed eaten divided by the body weight gain over a specified period of time. Feed conversion ratio does not attempt to partition feed intake into growth and maintenance components (Arthur et al., 1996). Because feed required for maintenance accounts for an estimated 60-65% of the total feed cost associated with the cow herd, Arthur et al. (1996) proposed that feed efficiency traits should attempt to account for variation in maintenance energy requirements. Another limitation to FCR as a measure of feed efficiency is that FCR is negatively correlated with ADG (Koots et al., 1994). Animals that have a low FCR are considered efficient users of feed. However, it has been found that selection to reduce FCR and improve efficiency results in an increase in growth rate and therefore an increase in mature cow size. This is due to FCR being negatively correlated with growth traits. Increases in cow size result in higher feed requirements and thus an increase in feed costs for maintenance (Herd and Bishop, 2000). Feed conversion ratio of growing animals is largely a function of growth patterns, and if an increase in feed requirements for maintenance of the breeding herd offsets the gains in growth efficiency there will be no change in production system feed efficiency (Arthur et al., 2004). Consequently, selection based on FCR will not necessarily improve the feed efficiency of integrated beef operations.

Residual Feed Intake

Residual feed intake (RFI) is an alternative measure of feed efficiency that has gained considerable attention in recent years. Koch et al. (1963) first proposed the use of RFI as an attempt to partition feed intake into growth and maintenance components. It is thought to be related to requirements needed to maintain the animal independent of growth, size, appetite and level of production (Basarab et al, 2001; Arthur et al., 2001a). Residual feed intake is defined as the difference between an animal's actual feed intake and its expected feed requirements for growth and maintenance. These requirements are calculated from the phenotypic regression of feed intake on production and maintenance. The residual feed is the feed that cannot be accounted for by production or maintenance. There are two commonly used methods for calculating the expected feed intake used in determining RFI. The first method is to use feeding standards, such as those set out by the NRC (2000), to predict expected feed intake based on body weight, average daily gain, and energy concentration of the diet. The second method uses the residuals from the linear regression of DMI on mid-test $BW^{0.75}$ and average daily gain (ADG) within a contemporary group of animals (Arthur et al., 1996). Disadvantages to the feeding standards model can be seen in a study conducted by Liu et al. (2000). They found that

NRC equations predicted, on average, higher intakes than were actually measured, indicating that NRC predictions overestimated energy requirements. They also found that when these standards were used, RFI was correlated with ADG (r = -0.55, P< 0.01) and BW (r = -0.26, P < 0.01). In contrast, when linear regression models were used to estimate expected feed intake, RFI was not correlated with ADG or BW in these animals. Arthur et al. (2001a) had similar results, finding that when RFI was calculated using a standard requirement model, RFI was correlated with ADG (r = -0.38, P < 0.01) and BW (r = -0.35, P < 0.01), whereas when computed from a linear regression model RFI was independent of these traits. From these studies, it appears that linear regression models are more appropriate measures of feed efficiency than NRC models. Therefore, it would be more appropriate to calculate expected feed intake by modeling actual data instead of using NRC prediction equations. If the linear regression method is used, genetic improvement of feed efficiency can be made through selection for low RFI without significant effects on growth traits (Arthur et al., 2001a).

Residual feed intake is measured by recording individual feed intakes over a period of at least 70 days (Wang et al., 2006) while simultaneously recording body weight gain. Cattle that deviate from the expected intake can be identified as more or less efficient. Cattle with a numerically higher RFI (positive value) consume more feed than expected for their body size and level of production, and be considered less efficient. Cattle with a numerically lower RFI (negative value) consume less feed than expected (as determined using the aforementioned methods) for their body size and level of production, and be considered more efficient. Arthur et al. (1996) found that animals with the lowest RFI consumed an average of 13.5% less feed than expected, while the animals with the highest RFI consumed 14% more than expected. Several studies have shown RFI to be moderately heritable, ranging from 0.26 (Crews et al., 2003) to 0.28 (Koch et al., 1963) to 0.39 (Arthur et al., 2001a), while independent of component growth traits such as average daily gain and body weight. This implies that selection for low RFI is not likely to result in changes in the two component traits. Therefore, selecting for it would not be expected to cause increases in cow size and hence, feed cost (Arthur et al., 2001a). Selection for RFI would be expected, therefore, to result in genetic change relatively comparable to that obtained with other moderately heritable traits, given enough phenotypic data and selection intensity. Feed intake has been found to be more highly correlated with RFI than with FCR (Arthur et al., 2001). Based on results reported by Archer et al. (2002), the RFI of growing heifers was highly correlated with the RFI of mature cattle fed a similar type of ration. This suggests that selecting for low RFI in growing calves would improve efficiency in the herd without increasing mature cow size. In their study, the correlation between the growing and mature cattle RFI ($r = 0.98$) was higher than that observed for FCR ($r = 0.20$), suggesting that RFI may be the more appropriate trait to assess feed efficiency across various production phases. These results emphasize the economic potential for genetic improvement in efficiency of feed utilization in beef cattle.

One limitation to applying selection pressure against RFI is that measuring feed intake in cattle is expensive. The best way to improve efficiency of beef production would be to improve feed utilization of breeding cows, but the feasibility of measuring intake on mature animals is low (Archer et al., 1999). Measuring the feed intake and efficiency of growing calves and then basing selection on these traits is more practical than measuring these traits on mature animals (Archer et al., 1999). Because of the expense of measuring feed efficiency, Archer and Bergh (2000) demonstrated that the duration of performance testing could be decreased from 112 days to 70 days with minimal impact on the accuracy of measurements of feed intake, RFI, ADG and FCR.

Feeding Behavior

Monitoring the effect of feeding behaviors on efficiency traits such as RFI and FCR in cattle has led to a great deal of debate. Past research suggests that a direct relationship exists between an animal's behavior and performance-related traits (Lancaster et al., 2005a; Schwartzkopf-Genswein et al., 2002, Streeter et al., 1999). This type of research has commonly used direct visual observation for a specified period of time to establish these relationships. The primary advantage of this technique is that it allows a variety of different behaviors to be observed and analyzed. However, because these techniques are very time and labor intensive, the data that can be collected tends to be very limited in duration. The total amount of time which can be dedicated to direct observation typically represent only a window in time and may not be representative of the long-term behavior patterns that an animal or group of animals may exhibit (Sowell et al., 1999). Calan gate systems can be used in conjunction with direct observation for studies that need to assess intake as well as feeding behavior because Calan gates have the advantage of allowing for the measurement of individual animal feed intake. In addition, several different diets can be fed to animals in the same pen with a high level of accuracy. There are several disadvantages of Calan gate systems which include large labor costs and the requirement for a training / equipment adaptation period for the animals before the research trial can begin (Cole, 1995). Some researchers have also found that the social interaction of the animals related to feeding behavior may be disrupted by these systems (Sowell et al., 1998).

Over the past decade, electronic monitoring systems have become a popular means of behavior measurement for cattle. These systems have the advantages of automated monitoring and intake measurement. One such system is the GrowSafe system (GrowSafe Systems Ltd, Airdrie, AB). It is an electronic monitoring system using radio frequency technology which allows for documentation of bunk attendance patterns by individual cattle in large groups, such as in a commercial feedlot setting. It consists of an antenna that emits an electromagnetic field encased in a rubber mat that lines the outer wall of the feed bunk, a data-logging reader panel connected to the antenna, passive transponders encased in plastic ear tags, and a computer to which data are uploaded for analysis. The antenna detects the transponders attached to the cattle when they come within 50 cm of the feed bunk. The reader panel logs the presence of the animal at specified time intervals (usually every 5-6 seconds, depending on the version of the system) while it is within range. The system enables researchers to track the number of visits by an animal to the feed bunk each day, the location along the bunk selected by the animal, and the length of time the animal remains at the bunk. This system makes it possible to relate measures of feeding behavior with feed intake.

Devries et al. (2003) compared feeding behavior data obtained using the GrowSafe system with video recordings of the same period of time for 12 Holstein cows. They found that meal duration as estimated by the GrowSafe system was highly correlated with that obtained from analysis of the video (R^2 = 0.98). However, they found that for individual cows, there were instances when a cow was present in the video but not detected by the GrowSafe system (12.6% of observations) and instances (3.5% of observations) when the animal was detected by the GrowSafe system, but was not present at the feed bunk in the video. Schwartzkopf-Genswein et al. (1999) performed a similar but more comprehensive study to validate the feeding behavior (duration and frequency) data generated by the GrowSafe system using a direct comparison with a video surveillance system. In this study, the animals were separated into individual pens in order to facilitate collection of video data on each of the individual animals. They found that the feeding duration for all animals differed significantly ($P < 0.0001$) between the GrowSafe system and the recorded video, with the GrowSafe system measurements being consistently higher than the video data (85.5 ± 2.2 and 69.8 ± 2.2 min/per day respectively). Feeding frequency also differed significantly ($P < 0.0001$) between the 2 methods. The GrowSafe system recorded the presence of the animal when it was not really at the bunk 3.6% of the time. The GrowSafe system failed to record the presence of the animal at the bunk 2.4% of the time when it was present in the video. However, they concluded that the GrowSafe system was highly effective with an accuracy of greater than 90 percent. In a 2002 study, Schwartzkopf-Genswein et al. evaluated feeding behavior traits in twelve cattle over a period of 54 days using the GrowSafe system. They found a significant positive correlation ($r = 0.38$; $P < 0.001$) between feeding duration and intake. However, feeding frequency was not related to intake ($r = 0.09$; $P > 0.10$).

The feeding behavior patterns of cattle tend to be highly repeatable whether they are kept on pasture or in a feedlot setting (Streeter et al., 1999). In addition to the diurnal feeding patterns that occur in nature, when cattle are fed in confinement, feeding activity is related to time of feeding and availability of feed. The presentation of new feed also acts as a stimulus to initiate feeding behavior (Streeter et al., 1999).

Gibb et al. (1998) found that bunk design may affect bunk attendance. Smaller calves spent an average of twice as much time (79.3 vs 33.6 ± 1.9 min/day) at the feed bunk as larger calves in the same study. They felt that this was due to the limited amount of vertical space for the head and neck to enter the bunk at their research facility. Keys et al. (1978) found that as stocking density increased, feeding duration decreased while eating rate (kg/h) increased. They found that when all calves could access the feed bunk, the average feeding duration was 288 min/d. However, as competition increased average feeding duration decreased to 213 min/d.

Some studies have found the link between feeding duration and feed intake to be weak at best (Keys, et al., 1978). In contrast, Gibb et al. (1998) found that the feeding duration of individual animals tended to be quite consistent throughout a trial. For a specific animal, feeding duration could be a very consistent indicator of differences in feed intake between days.

In one study of growing bulls, feeding behavior was not correlated with dry matter intake or average daily gain, but both feeding duration (0.41) and feeding frequency (0.17) were positively correlated with RFI (Lancaster et al., 2005a). Bulls with low RFI had lower feeding duration ($P<0.01$) and feeding frequency ($P<0.05$) than those with high RFI (Lancaster et al., 2005a). Schwartzkopf-Genswein et al. (2002) also found that feeding behavior was linked to feed intake. Their study found that feed conversion ratio (FCR) was negatively correlated with feeding duration (-0.17; $P< 0.0001$). A significant positive correlation was observed between average daily feeding duration and feed intake (0.38; $P<0.0001$), as well as a positive (though weak) correlation between average daily feeding duration and average daily gain (0.14; $P<0.001$). Feeding frequency (number of meals per day) was not significantly correlated to feed intake (0.09; $P>0.10$). Their study also determined that there was a difference in feeding behavior between heifers and steers of the same age. Heifers had significantly higher feeding durations ($P< 0.0001$) and meal frequencies ($P< 0.0001$) than their male counterparts. In a study of seventy Brahman heifers, Ribeiro et al. (2006) found that feeding duration was correlated with feed intake (0.29) and RFI (0.28) but not with FCR. However, meal frequency was not correlated with RFI or FCR. Heifers with low RFI spent significantly less time ($P<0.05$) feeding than heifers rated as high RFI, but had similar meal frequencies. Heifers with high RFI spent 20 minutes longer eating each day than heifers with low RFI. When Basarab et al. (2003) studied 176 steer calves, over a period of two years, they found that low and high RFI steers did not differ significantly in feeding frequency or in the average time spent eating each day. Small correlations between RFI and meal frequency ($r = 0.14$, $P = 0.08$) and total time spent eating each day ($r = 0.13$, $P = 0.12$) showed a small, though not statistically significant, positive trend toward high RFI steers making more visits to the feeder and spending more time eating each day. Streeter et al. (1999) found that cattle with the best average daily gains had the lowest feeding duration, followed by those with moderate rates of gain, while those with the poorest rates of gain had the highest feeding duration. They found that these differences were evident as early as day 41 on feed. Feeding frequency did not differ among the groups. This differs from the findings of Hicks et al. (1989) which suggested that feeding frequency was more highly correlated to performance than was feeding duration. Based on visual observations, Hicks et al. (1989) found that feeding frequency was related to performance of feedlot cattle, while feeding duration was associated with average daily gain. Steers that spent more time eating tended to have higher average daily gains.

Temperament

Burrow et al. (1988) proposed exit velocity as an objective measure of temperament in cattle, defining it as the time that it took the animal to cross a fixed distance while exiting a confined area. Exit velocity has been found to be a moderately heritable trait (Burrow, 2001). Voisinet et al. (1997) found that cattle that were calmer during routine handling procedures had higher average daily gains than those that were easily agitated. They also determined that heifers tended to be more excitable than steers. Their study used a more subjective temperament rating system, a chute score, assigning scores of 1 through 5 to each of the animals. Brown et al. (2004) found that exit velocity was negatively correlated with growth and intake traits (ADG and DMI) while not correlated with efficiency traits (FCR and RFI). This was similar to the results of a 2005 study

(Lancaster et al., 2005b) which suggest that heifers with calmer temperaments had decreased DMI and ADG, while RFI was not affected. Petherick et al. (2002) determined that temperament, measured as flight speed, tended to show little change over time. The found that initial flight speed measurements were correlated ($r = 0.53$ to 0.78; $P < 0.01$) with those taken at other times during the project. They also determined that flight speed was highly repeatable. Curley et al. (2006) examined both chute score and exit velocity as measures of temperament. They found that repeated measures of escape velocity were correlated ($r = 0.31$; $P < 0.05$), while chute scores were not stable over time.

OBJECTIVES

The overall objective of this research was to determine whether feeding efficiency traits are related to aspects of behavior in growing Brangus heifers.

Specific objectives of this study included:

1. Determine if feeding event duration, frequency and eating rate are important factors in predicting RFI, FCR, ADG and/or DMI.
2. Determine if meal duration, frequency and eating rate are useful for predicting RFI, FCR, ADG and/or DMI.
3. Determine whether temperament, measured as exit velocity and chute score, affects RFI, FCR, ADG and/or DMI.

MATERIALS AND METHODS

This study was conducted as part of a larger beef cattle nutrition project. The overall objectives of the larger project were to determine the value of physiological (hormone), body composition, feeding behavior and temperament traits as indicators of future performance and feed efficiency in growing Brangus heifers. During the 70-day feeding trial period, feed refusals were measured weekly to determine feed intake for the individual animals. Serum samples were collected and body weights were also measured on a weekly basis. Ultrasound measurements of body composition were obtained and blood samples were collected on days 0 and 70 of the 70-day feeding trial period. Following day 49, residual feed intakes were calculated for all animals, and heifers with the highest (n = 18) and lowest (n = 18) RFI were identified. This study focused on the feeding behavior and temperament aspects of the project.

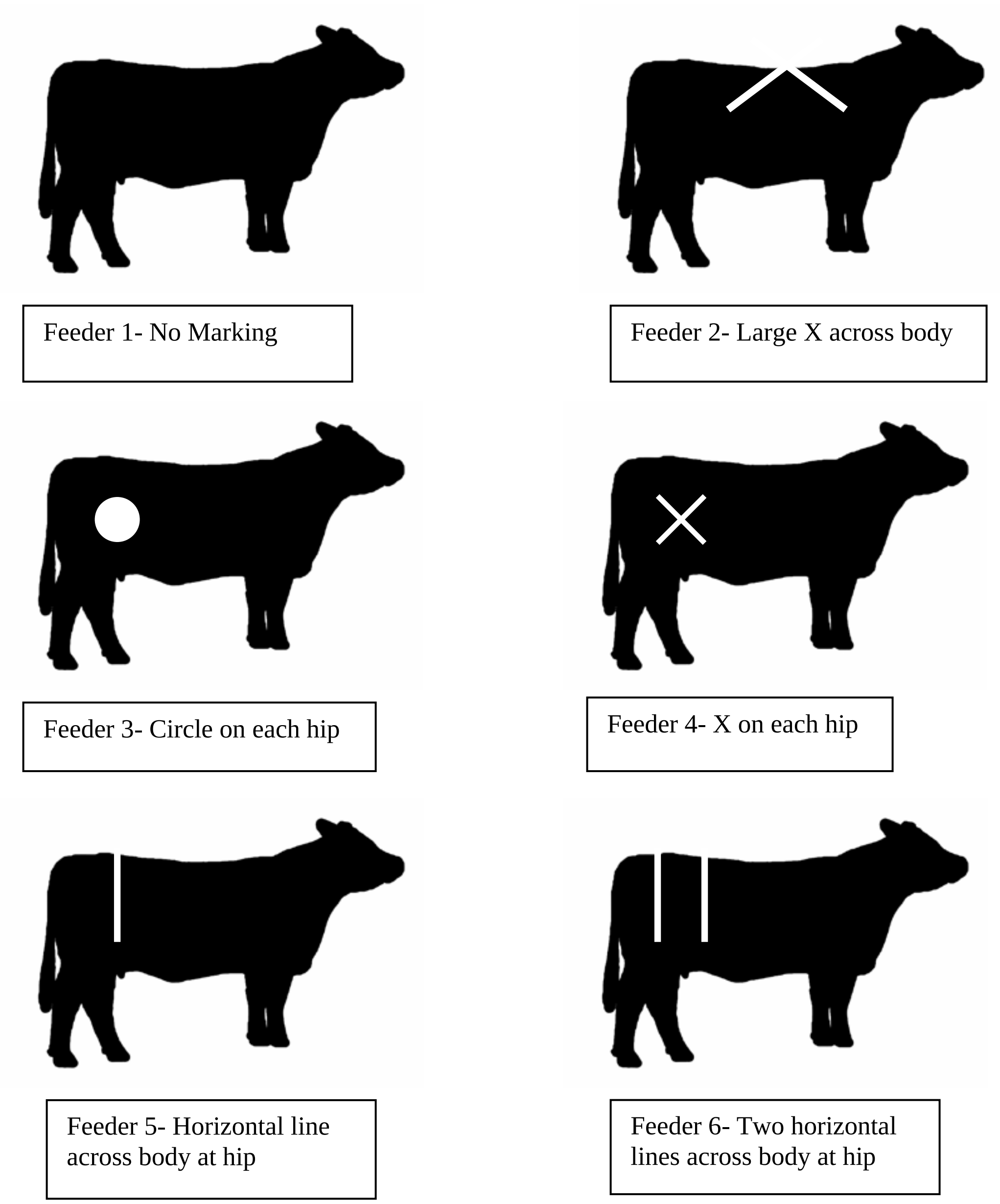
Facilities

This study was conducted in the Nutrition and Physiology Center of the Texas A&M University O.D. Butler, Jr. Animal Science Complex. The facility consisted of twenty pens (6.1 meters X 12.2 meters) constructed from open metal pipe fencing. For this project, each pen was equipped with six feeding stations, each controlled by a Calan gate (American Calan, Northwood, NH). A Calan gate is an electronically controlled door to a feed bin, capable of being opened by only one animal per pen. Each animal is fitted with a “magnetic key” that hangs from a neck cord which will open their specific gate. The apparatus enables researchers to measure the precise feed intake of individual animals while the animals are housed in groups.

Experimental Animals and Design

One hundred and fifteen embryo-transfer Brangus heifers (236 ± 10.7 days of age) obtained from Camp Cooley Ranch (Franklin, Texas) were used in this study. They were blocked by body weight and progeny group, and then randomly assigned to one of 20 pens. The animals had access to a continuous supply of fresh water. Heifers were individually fed a roughage-based diet (ME = 2.2 Mcal/kg) using Calan gate feeders. The heifers were adapted to the diet and trained to eat from the Calan gate feeders for 28 days prior to beginning the study. Residual feed intake was calculated as the difference between actual dry matter intake (DMI) and the DMI predicted from a multiple linear regression of DMI on mid-test $BW^{.75}$ and ADG. Of the 115 heifers in the project, those with the highest (n=18) and lowest (n=18) RFI (mean ± 1 SD) were identified on day 49 of the study.

Each of the animals in this study was marked with white water-based zone marking paint in order to facilitate identification during analysis of the video data. Because there were six heifers in each pen, a series of six easily distinguishable markings were used. Each animal was assigned a marking according to its designated feeder (Figure 1). These markings were reapplied while the animals were in a squeeze chute for their weekly body weight measurements.



Feeder 1- No Marking

Feeder 2- Large X across body

Feeder 3- Circle on each hip

Feeder 4- X on each hip

Feeder 5- Horizontal line across body at hip

Feeder 6- Two horizontal lines across body at hip

Figure 1. Paint Marking System for Heifers

Equipment

Ten Capture 1/3” CCD outdoor bullet cameras (Richardson Electronics, Houston, TX) were mounted on structural beams of the barn 3.35 m above the ground using metal brackets. The cameras were placed on the side of the barn opposite the pen they were recording. They were placed in such a way as to record the entire pen with particular emphasis on the feeder area. After each week, the cameras were moved laterally to record the adjacent pens. The cameras fed to one ten-channel multiplexer recorder (GE-Interlogix Kalatel Division, Corvallis, Oregon), housed in the center aisle of the building, using siamese RG-59 18/2 CCTV cable (Richardson Electronics Security Systems Division, Houston, Texas) for camera power and video feed. The multiplexer was placed in a cabinet that provided forced air ventilation with filtration for dust. This cabinet also contained a 12-volt DC power supply to power the cameras and recorder. A second ten-channel multiplexer was used to replace the full multiplexer every three days due to limited data storage capacity of the multiplexers. The data were transferred from the multiplexer to DVDs by linking the multiplexer recorder to a PC computer. The recorded video was viewed using WaveReader 3.0 S (GE Security, Corvallis, OR) for analysis. One 150 watt halogen flood light was added to each pen in order to increase visibility and to facilitate videotaping near the feeders during nighttime hours.

Feeding Behavior

The recording of video data began on day 28 of the 70 day study and continued for 28 days. After RFI was determined (day 49) and the animals with the highest and lowest RFI were identified, the video data were analyzed for each of the focal animals. Continuous video data were analyzed from the first four days of each week that the focal animal's behavior was recorded. A total of eight days (two four day periods) were analyzed for each focal animal (n = 36).

A feeding event (FE) began when the animal's head entered the Calan gate feeder and ended when the animal removed its head and the gate closed. Feeding event duration was the number of minutes the animal spent with its head in the feeder during a particular feeding event. Total daily FE duration was the amount of time the focal animal spent eating per day (min/d), not including time the animal spent with its head outside of the feeder. Feeding event frequency was the number of FE per day. Feeding event eating rate was the rate (g/min) at which the focal animal consumed feed during a FE, computed as DMI ÷ total daily FE duration. Feed refusals were measured weekly, therefore intake was divided over 7 days to calculate daily DMI. As feeding behavior was measured in 4 day intervals, weekly FE durations had to be divided by 4 to obtain total daily FE durations.

A meal included all visits an animal made to the feeder that were separated by less than 5 minutes. Meal duration was the number of minutes the focal animal spent consuming a particular meal, including feeding events and the time between them (if less than 5 min). Total daily meal duration was the average amount of time the focal animal spent per day (min/d) consuming meals, including time between feeding events (if less than 5 min). Meal frequency was the number of meals per day. Meal eating rate was the rate (g/min) at which the focal animal consumed feed during meals, calculated as DMI ÷ total daily meal duration. Because feed refusals were measured weekly, intake measurements had to be divided by 7 days to calculate daily DMI. Given that feeding behavior was measured in 4 day intervals, weekly meal durations had to be divided by 4 to obtain total daily meal durations.

Temperament

Temperament of the heifers was evaluated using chute scores and exit velocities. Chute scores were assigned while the heifers were confined but not restrained in the squeeze chute used for weekly weight measurements on days 0 and 70 of the study using the method described by Grandin (1993). Chute scores were based on a 1 to 5 scale, with a score of 1 representing a completely docile animal and a score of 5 representing a very aggressive animal. Temperament of the animals was also evaluated using an exit velocity measurement obtained on days 0 and 70 of the study following the method of Burrow et al. (1988). Exit velocity was measured as the speed (m/sec) at which the heifers crossed a fixed distance of 1.83 m upon exiting the squeeze chute using two infrared sensors.

Experimenter Reliability

The intra-observer variability (a measure of precision) of the investigator who analyzed the video was determined by reanalyzing one 30 minute segment of video from each of days 1, 5 and 8. These video segments were reanalyzed at the end of the study without knowledge of the previous data. Periods of high activity were used in order to have the greatest probability of variation. A comparison of the original and reanalyzed data was performed using the Pearson correlation procedure. This method is commonly used to measure intra-observer reliability (Lehner, 1998). Reports of an event with high intra-observer variability are considered less reliable than those with low variation.

Statistical Analysis

In order to minimize measurement errors of animal growth due to fluctuations in gut fill, growth rates of individual heifers were modeled by linear regression of weekly body weight (BW) against day on test using the regression procedure of SAS (SAS Institute Inc., Cary, NC). These regression coefficients were used to derive initial (day 0) and final (day 70) BW, mid-test metabolic BW ($BW^{0.75}$) and ADG for each animal for the 70 day RFI trial. Feed conversion ratio was calculated as kg DM feed/kg BW gain. Residual feed intake was calculated as the difference between actual and expected feed intake using the residuals from the linear regression of DMI on mid-test $BW^{0.75}$ and ADG. To further characterize RFI, heifers were ranked by RFI and separated into low and high RFI groups that were > 1 SD below and > 1 SD above the mean RFI, respectively. Data were analyzed for RFI group, week and RFI group-by week effects on performance, feed efficiency and feeding behavior traits using analysis of variance (PROC GLM of SAS). Additionally, Pearson correlations were computed using the Proc CORR procedure of SAS (SAS 9.1 for Windows, SAS Institute Inc., Cary, NC) to determine significant relationships between feed efficiency, performance, feeding behavior and temperament traits. A correlation for determining intra-observer reliability was computed. A series of t-tests were performed in order to be certain that results were not affected by side of the barn or pen.

RESULTS

Feed Efficiency Traits

During the 70 day feeding trial period, the overall daily DMI (mean ± SE) was 9.73 ± 0.08 kg/d, ranging from a minimum of 7.07 kg/d to a maximum of 11.97 kg/d (Table 1). The overall ADG was 1.07 ± 0.01 kg/d and ranged from 0.70 to 1.47 kg/d. Residual feed intake averaged -0.01 ± 0.06 kg/d with a range of -1.50 to 1.69 kg/d. Feed conversion ratio averaged 9.04 ± 0.10 kg DMI/ kg of gain, ranging from 6.43 to 14.62.

Table 1. Summary of the performance and feed efficiency traits (mean ± SE) of all focal heifers

Trait[a]	Mean[b]
Number of Heifers	36
Initial BW, kg	269.05 ± 23.50
Final BW, kg	344.14 ± 29.41
DMI, kg/d	9.73 ± 1.35
ADG, kg/d	1.07 ± 0.18
RFI, kg/d	-0.01 ± 1.06
FCR, kg of DMI/kg of gain	9.04 ± 1.67

[a] RFI = residual feed intake, FCR = feed conversion ratio
[b] Overall trait mean

When comparisons based on RFI group were made using analysis of variance, it was determined that high RFI animals consumed substantially more feed than those in the low RFI group without any difference in gain or BW (Table 2). The high RFI group had an average daily DMI of 10.69 ± 0.08 kg/d while the low RFI group had an average daily DMI of 8.77 ± 0.08 kg/d. Therefore, the high RFI heifers consumed an average of 1.92 kg/d (21.9%) more feed than the low RFI heifers. The average daily gain of the high RFI group was 1.07 ± 0.02 kg/d while that of the low RFI group was 1.08 ± 0.01 kg/d. The average RFI for the heifers in the high RFI group was 1.00 ± 0.03 while that of the individuals in the low RFI group was -1.03 ± 0.02 kg/d. The FCR for the heifers in the high RFI group was 10.05 ± 0.13 while the low RFI heifers had a FCR of 8.02 ± 0.07 kg DMI/ kg of gain. Dry matter intake and FCR were significantly (P < 0.0001) affected by RFI group, with the low RFI heifers being substantially more efficient, while there was not an effect of RFI group on initial or final BW or ADG (Table 2).

Table 2. The effect of RFI group on performance and feed efficiency traits (mean ± SE) in growing Brangus heifers

	RFI Group[1]		
Trait[2]	High	Low	*P*-value[3]
Number of Heifers	18	18	
Initial BW, kg	267.34 ± 5.67	270.76 ± 5.54	0.68
Final BW, kg	342.13 ± 7.36	346.15 ± 6.65	0.69
DMI, kg/d	10.69 ± 0.08	8.77 ± 0.08	<0.0001
ADG, kg/d	1.07 ± 0.02	1.08 ± 0.01	0.89
RFI, kg/d	1.00 ± 0.03	-1.03 ± 0.02	<0.0001
FCR, kg of DMI/kg of gain	10.05 ± 0.13	8.02 ± 0.07	<0.0001

[1] Groups were defined as high = RFI > 1 SD above the mean and low = RFI < -1 SD below the mean

[2] RFI = residual feed intake, FCR = feed conversion ratio

[3] *P*-values from overall *F*-test

Correlation analysis determined that DMI was moderately correlated with ADG (r = 0.40, P < 0.001) and initial (r = 0.48, P < 0.01) and final BW (r = 0.56, P < 0.001), the measures of performance used in this study (Table 3). In addition, DMI was correlated with FCR (r = 0.37, P < 0.05) and RFI (r = 0.77, *P* < 0.0001), the efficiency traits measured in this study. Average daily gain was positively correlated with final BW (r = 0.63, P < 0.0001) and DMI while negatively correlated with FCR (r = -0.68, P < 0.0001). Residual feed intake was strongly correlated (*P* < 0.0001) with DMI and FCR (r = 0.77 and 0.70, respectively), but was not correlated with ADG or initial or final BW. High RFI heifers did not differ from low RFI heifers in initial or final BW or ADG. However, the animals in the high RFI group consumed an average of 21.9% (P < 0.0001) more feed per day than individuals in the low RFI group.

Table 3. Correlations between performance traits and measures of feed efficiency in focal heifers

Trait[1]	Final BW	DMI	ADG	FCR	RFI
Initial BW	**0.91**	0.48**	0.25	0.11	-0.05
Final BW		0.56***	**0.63**	-0.20	-0.09
DMI			0.40***	0.37*	**0.77**
ADG				**-0.68**	-0.10
FCR					**0.70**

[1] RFI = residual feed intake, FCR = feed conversion ratio

Correlations in bold are different from zero at P < 0.0001.

***Correlations are different from zero at P< .001.

**Correlations are different from zero at P <0.01.

* Correlations are different from zero at P <0.05.

Feeding Behavior

Feeding event duration for all focal animals ranged from 0.02 to 61.68 min with a mean of 1.76 ± 0.10 min (Table 4). The average FE duration ranged from 0.02 to 61.68 min with a mean of 1.48 ± 0.11 min for the high RFI animals, while it ranged from 0.02 to 30.42 min with a mean of 2.03 ± 0.10 min for those in the low RFI group. The total daily FE duration for all focal animals ranged from 26.5 to 283.83 minutes/d with a mean of 138.1 ± 4.02 min/d (Table 4). The high RFI heifers' total daily FE duration ranged from 26.5 to 245.02 min/d, with a mean of 124.53 ± 4.26 min/d. The total daily FE duration for the low RFI animals ranged from 52.22 to 283.83 min/d, with a mean of 151.73 ± 3.79 min/d. The FE frequency for all focal animals ranged from 30 to 221 FE/d, with a mean of 104.8 ± 3.47 FE/d (Table 4). The FE frequency ranged from 30 to 221 FE/d with a mean of 119.1 ± 3.94 FE/d for the high RFI heifers, while the FE frequency ranged from 32 to 180 FE/d with a mean of 90.52 ± 3.00 FE/d for those in the low RFI group. The daily FE eating rate ranged from 33.24 to 183.2 g/min with a mean of 81.17 ± 2.52 g/min for all focal animals. The FE eating rate for the high RFI animals ranged from 50.14 to 183.2 g/min with a mean of 99.56 ± 3.28 g/min while the rate for animals in the low RFI group ranged from 33.24 to 117.78 g/min with a mean of 62.78 ± 1.76 g/min. When data were analyzed using analysis of variance, this study found that total daily FE duration, FE frequency and FE eating rate were affected by RFI ($P < 0.0001$) (Table 4).

In addition, the maximum and minimum FE duration were also impacted by RFI (P < 0.05).

Table 4. Summary of feeding event (FE) data (mean ± SE) for high RFI and low RFI heifers

	RFI Group[1]			
Trait	High	Low	Mean[2]	*P*-value[3]
FE Duration, min/FE	1.48 ± 0.11	2.03 ± 0.10	1.76 ± 0.10	0.06
Min. FE Duration, min/FE	0.14 ± 0.01	0.17 ± 0.01	0.15 ± 0.01	0.03
Max. FE Duration, min/FE	7.85 ± 0.75	9.85 ± 0.44	8.84 ± 0.60	0.02
Total FE Duration, min/d	124.53 ± 4.26	151.73 ± 3.79	138.1 ± 4.02	< 0.0001
FE Frequency, events/d	119.1 ± 3.94	90.52 ± 3.00	104.8 ± 3.47	< 0.0001
FE Eating Rate, g/min	99.56 ± 3.28	62.78 ± 1.76	81.17 ± 2.52	< 0.0001

[1] Groups were defined as high = RFI > 1 SD above the mean and low = RFI < -1 SD below the mean

[2] Overall trait mean

[3] *P*-values from overall *F*- test

The meal duration for all focal animals ranged from 5.67 to 47.27 min/meal with a mean of 15.72 ± 0.45 min/meal (Table 5). The meal duration for high RFI animals ranged from 5.67 to 30.6 min/meal with a mean of 15.48 ± 0.38 min/meal while animals in the low RFI group ranged from 6.62 to 47.27 min/meal with a mean of 15.95 ± 0.52 min/meal. The total daily meal duration for all focal animals ranged from 106.6 to 346.05 min/d with a mean of 220.13 ± 4.47 min/d. The total daily meal duration of the high RFI animals ranged from 121.47 to 321.97 min/d with a mean of 220.63 ± 3.48 min/d while the low RFI animals had daily meal durations that ranged from 106.6 to 346.05 min/d with a mean of 219.64 ± 5.46 min/d. The meal frequency for all focal animals ranged from 2 to 29 meals/d with a mean of 14.91 ± 0.34 meals/d. The meal frequency of the high RFI animals ranged from 2 to 29 meals/d with a mean of 15.06 ± 0.34 meals/d, while the animals in the low RFI group had meal frequencies that ranged from 6 to 28 meals/d with a mean of 14.75 ± 0.34 meals/d. For all focal animals, the meal eating rate ranged from 23.16 to 79.79 g/min with a mean of 45.6 ± 0.62 g/min. The heifers in the high RFI group had meal eating rates that ranged from 36.36 to 73.33 g/min with a mean of 49.33 ± 0.67 g/min while the low RFI heifers had meal eating rates that ranged from 23.16 to 79.79 g/min with a mean of 41.86 ± 0.96 g/min. Meal eating rate was affected (P < 0.0001) by RFI while measures of meal duration and frequency were not influenced (Table 5).

Table 5. Summary of meal data (mean ± SE) for high RFI and low RFI heifers

	RFI Group[1]			
Trait	High	Low	Mean[2]	*P*-value[3]
Meal Duration, min/meal	15.48 ± 0.38	15.95 ± 0.52	15.72 ± 0.45	0.63
Min. Meal Duration, min/meal	1.71 ± 0.19	1.60 ± 0.20	1.65 ± 0.19	0.69
Max. Meal Duration, min/meal	49.54 ± 1.81	57.92 ± 3.79	53.73 ± 2.80	0.05
Total Meal Duration, min/d	220.63 ± 3.48	219.64 ± 5.46	220.13 ± 4.47	0.88
Meal Frequency, events/d	15.06 ± 0.34	14.75 ± 0.34	14.91 ± 0.34	0.53
Meal Eating Rate, g/min	49.33 ± 0.67	41.86 ± 0.96	45.6 ± 0.62	< 0.0001

[1] Groups were defined as high = RFI > 1 SD above the mean and low = RFI < -1 SD below the mean

[2] Overall trait mean

[3] *P*-values from overall *F*-test

As seen in Table 6, correlation analysis determined that FE eating rate had a strong negative correlation with other FE traits such as total daily FE duration (r = -0.91, P < 0.0001), FE frequency (r = -0.71, P < 0.0001), and FE duration (r = -0.72, P < 0.0001). Feeding event eating rate was also correlated with meal traits (P < 0.05) such as total daily meal duration (-0.39) and meal duration (r = -0.39) as well as RFI (r = 0.59, P < 0.001), DMI (r = 0.45, P < 0.01) and FCR (r = 0.64, P < 0.0001). Feeding event eating rate was not significantly (P < 0.05) correlated with meal frequency, initial or final BW or ADG.

Total daily FE duration was correlated (P < 0.0001) with FE frequency (r = -0.75) and the FE duration (r = 0.84). Total daily FE duration was also correlated with total daily meal duration (r = 0.49, P < 0.005) and meal duration (r = 0.54, P < 0.001) as well as RFI (r = -0.39, P < 0.01), ADG (r = 0.33, P < 0.05) and FCR (r = -0.53, P < 0.001). Total daily FE duration was not significantly (P < 0.05) correlated with meal frequency, initial or final BW or DMI.

There was a strong significant (P < 0.0001) correlation between FE duration and FE eating rate (r = -0.72), total daily FE duration (r = 0.84) and FE frequency (r = -0.88). Feeding event duration was negatively correlated (P < 0.05) with initial BW (r = -0.39) and FCR (r = -0.39). Feeding event duration was not significantly (P > 0.05) correlated with meal eating rate, total daily meal duration, meal duration, meal frequency, RFI, final BW, DMI or ADG.

Feeding event frequency had a strong negative correlation with FE eating rate (r = -0.71, P < 0.0001), total daily FE duration (r = -0.75, P < 0.0001) and FE duration ($r = -0.88$, $P < 0.0001$). Feeding event frequency was moderately correlated with RFI ($r = 0.43$, $P < 0.01$) and FCR ($r = 0.39$, $P < 0.05$). However, FE frequency was not significantly ($P < 0.05$) correlated with any of the measured meal traits, initial or final BW, DMI or ADG.

Meal eating rate was moderately correlated with FE eating rate ($r = 0.62$, $P < 0.0001$) and total daily FE duration ($r = -0.55$, $P < 0.001$). In addition, meal eating rate was correlated with total daily meal duration ($r = -0.78$, $P < 0.0001$) and meal duration ($r = -0.51$, $P < 0.005$) as well as RFI ($r = 0.41$, $P < 0.01$), initial BW ($r = 0.57$, $P < 0.001$), final BW ($r = 0.46$, $P < 0.005$), DMI ($r = 0.59$, $P < 0.001$) and FCR ($r = 0.45$, $P < 0.01$). Meal eating rate was not significantly ($P < 0.05$) correlated with FE frequency, FE duration, meal frequency or ADG.

Table 6. Correlations between feeding behavior and feed efficiency and performance traits

Trait[1]	TFE Dur	FE Freq	FE Dur	M Rate	TM Dur	M Dur	M Freq	RFI	IBW	FBW	DMI	ADG	FCR
FE Rate	**-0.91**	**-0.71**	**-0.72**	**0.62**	-0.39[c]	-0.39[c]	0.16	0.59*	0.13	0.00	0.45[b]	-0.24	**0.64**
TFE Dur		**-0.75**	**0.84**	-0.55*	0.49[a]	0.54*	-0.24	-0.39[b]	-0.08	-0.08	-0.23	0.33[c]	-0.53*
FE Freq			**-0.88**	0.05	0.13	-0.08	0.29	0.43[b]	-0.19	-0.25	0.19	-0.24	0.39[c]
FE Dur				-0.25	0.14	0.14	-0.28	-0.32	-0.39[c]	0.14	-0.15	0.27	-0.39[c]
M Rate					**-0.78**	-0.51[a]	-0.18	0.41[b]	0.57*	0.46[a]	0.59*	0.01	0.45[b]
TM Dur						**0.70**	**0.07**	0.00	-0.39[c]	-0.19	-0.06	0.27	-0.30
M Dur							**-0.63**	-0.07	-0.14	0.05	0.03	0.38[c]	-0.38[c]
M Freq								0.04	-0.29	-0.38[c]	-0.22	-0.34[c]	0.22
RFI_p									-0.05	-0.09	**0.77**	-0.10	**0.70**
IBW										**0.91**	0.48[a]	0.25	0.11
FBW											0.56*	**0.63**	-0.20
DMI												0.41[c]	0.37[c]
ADG													**-0.68**

Correlations in bold are different from zero at $P < 0.0001$.

*Correlations are different from zero at $P < .001$.

[a] Correlations are different from zero at $P < 0.005$.

[b] Correlations are different from zero at $P < 0.01$.

[c] Correlations are different from zero at $P < 0.05$.

[1] FE Rate = feeding event eating rate, TFE Dur = total daily feeding event duration, FE Freq = number of feeding events per day, FE Dur = average duration of individual feeding event, M Rate = meal eating rate, TM Dur = total daily meal duration, M Dur = average duration of individual meal, M Freq = number of meals per day, RFI = residual feed intake, IBW = initial body weight, FBW = final body weight, DMI = dry matter intake, ADG = average daily gain, FCR = feed conversion ratio.

Total daily meal duration was correlated with total daily FE duration ($r = 0.49$, $P < 0.005$) and meal duration ($r = 0.70$, $P < 0.0001$). Total daily meal duration was negatively correlated to both FE eating rate ($r = -0.39$, $P < 0.05$) and meal eating rate ($r = -0.78$, $P < 0.0001$). Total daily meal duration was not significantly ($P < 0.05$) correlated with FE frequency, FE duration, meal frequency, or any of the measured performance or efficiency traits.

Meal duration was negatively correlated with FE eating rate ($r = -0.39$, $P < 0.05$), meal eating rate ($r = -0.51$, $P < 0.005$) and meal frequency ($r = -0.63$, $P < 0.0001$) while positively correlated with total daily FE duration ($r = 0.54$, $P < 0.001$) and total daily meal duration ($r = 0.70$, $P < 0.0001$). Meal duration was also correlated ($P < 0.05$) with ADG ($r = 0.38$) and FCR ($r = -0.38$). Individual meal duration was not significantly ($P < 0.05$) correlated with FE frequency, FE duration, RFI, initial or final BW or DMI.

Meal frequency was negatively correlated with meal duration ($r = -0.63$, $P < 0.0001$), final BW ($r = -0.38$, $P < 0.05$) and ADG ($r = -0.34$, $P < 0.05$) while not significantly ($P < 0.05$) correlated with any of the other feeding event, meal, efficiency or performance traits.

Temperament

Initial exit velocity was positively correlated with FE frequency ($r = 0.37$, $P < 0.05$). Initial exit velocity was negatively correlated with daily FE duration ($r = -0.36$, $P < 0.05$) as well as the duration of individual feeding events ($r = -0.47$, $P <$

0.005). Initial exit velocity was negatively correlated ($P < 0.05$) with initial ($r = -0.34$) and final BW ($r = -0.42$) as well as ADG ($r = -0.35$) while not significantly correlated with any meal traits, RFI, DMI or FCR.

Final exit velocity was negatively correlated ($P < 0.05$) with daily FE duration ($r = -0.35$), individual FE duration ($r = -0.40$) and individual meal duration ($r = -0.35$) while not correlated with FE or meal eating rates, FE or meal frequency or daily meal duration. Final exit velocity was not correlated with any of the feed efficiency or performance traits measured by this study.

Initial chute score was not correlated with any of the factors measured in this study. Final chute score was correlated ($r = 0.51$, $P < 0.005$) with meal frequency but was not correlated with any of the other behavioral, feed efficiency or performance traits measured in this study.

DISCUSSION

As expected, the heifers in the low RFI group did not differ from those in the high RFI group in initial or final BW or ADG, as the model for determining RFI adjusts for these traits. These findings are consistent with several previous studies that have shown RFI to be independent of growth and body size (Arthur et al., 2001a, 2001b; Herd and Bishop, 2000). The correlation between DMI and FCR found in this study (0.37) is similar to that found by others, including two studies in which Arthur et al. (2001a, 2001b) found correlations of 0.23 and 0.48. The correlation between FCR and ADG of -0.68 in the present study was also very similar to results that other researchers have seen. Carstens et al. (2002) found this correlation to be -0.72 while Arthur et al. (2001a) found a correlation of -0.74. This study found a similar, though slightly higher, correlation between RFI and FCR (0.70) to that of other research (Herd and Bishop, 2000; Arthur et al., 2001b; Ribeiro et al., 2006). The correlation (0.77) between RFI and DMI in this study is similar to that found by others (Carstens et al., 2002; Ribeiro et al., 2006). In this study, the low RFI heifers consumed considerably less (21.9%) feed than high RFI heifers. Likewise, Carstens et al. (2002) found that low RFI steers consumed 21% less DMI than steers with high RFI even though ADG and BW were similar between the two groups. This is comparable to the findings of Lancaster et al. (2005a) and Ribeiro et al. (2006), which reported that low RFI calves consumed 15% and 24.5% less feed than high RFI calves, respectively. The low RFI heifers in this study had a FCR that was 25% lower than that of the high RFI heifers. The difference in FCR could produce a great deal of economic benefit for beef cattle producers.

Feeding Behavior

This study found that low RFI heifers spent more time eating than their high RFI counterparts. The total daily FE duration for the low RFI animals was 151.73 ± 3.79 min/d, while that of the high RFI group was 124.53 ± 4.26 min/d. Total daily FE duration was negatively correlated (-0.39) with RFI, indicating that the most efficient animals spent more time eating than the least efficient animals. This differs from the findings of Lancaster et al. (2005a) which concluded that RFI was positively correlated (0.41) with bunk attendance. This difference could be due to their study using an RFID system instead of video surveillance of the animals. The RFID system reports whether the animal is in the vicinity of the bunk, not necessarily that they are eating. Schwartzkopf-Genswein et al. (2002) had similar results using a similar system, finding that average daily intake and bunk attendance duration were positively correlated (0.38). Their mean bunk attendance durations were somewhat lower than those of this study. This could be due to their study using fewer animals or a different method of measurement. They found that the most efficient animals spent less time at the feed bunk. Ribiero et al. (2006) also found that feeding duration was positively correlated (0.28) with RFI, with low RFI heifers eating for 160 min/d while high RFI heifers spent 177 min/d eating. A 2006 study by Nkrumah et al., using an RFID system found that the most efficient cattle (low RFI) spent less time eating than their less efficient counterparts. High RFI cattle spent 73.95 min/day eating while the low RFI cattle spent 47.76 min/day eating. In addition to the limitations of the RFID system, heifers have been reported to have longer daily feeding durations and greater feeding frequencies than bull or steer calves (Schwartzkopf-Genswein et al., 2002).

In the present study, total daily FE duration was moderately correlated with ADG (0.33) but not with DMI. Lancaster et al. (2005a) found that feeding duration was not correlated with either ADG or DMI. Schwartzkopf-Genswein et al. (2002) reported a moderate correlation between feeding duration and DMI (0.38) and a very small correlation with ADG (0.14). Gibb et al. (1998) reported a strong correlation (0.57) between feeding duration and DMI in growing steers. Streeter et al. (1999) found that when calves were separated into groups based on ADG, the animals with the highest ADG had the lowest feeding durations, while those with the lowest ADG had the longest feeding durations. They concluded that as ADG increased, feeding duration decreased. Hicks et al. (1989) found a weak positive correlation between time spent eating and ADG.

All of these correlations of feeding duration with other traits are dependent upon the type of methods used to calculate duration. There are several fundamental differences between data collected using an RFID system, such as the GrowSafe system, and data collected using video surveillance (Table 7). Time spent eating (feeding duration) can be calculated as simply time spent near the feeder or as time spent actually eating. This study measured feeding duration as time spent eating while studies that use RFID systems of measurement often record feeding duration as time spent within a certain distance of the feed bunk.

Table 7. General comparison between the GrowSafe system and video surveillance research

GrowSafe	Video Surveillance
The meal is the only available unit of measurement for feeding duration and frequency at this time	Feeding events and/or meals can be used as the unit of measurement for feeding duration and frequency
Pens are generally large (up to 100 calves per pen)	Pens are small (6 calves per pen)
Only 1 calf can eat at a time from each feed bunk	All calves can eat at the same time
Competition - 7-9 calves compete for each feed bunk	No competition - each calf has its own feed bunk

There was a moderate positive correlation between FE frequency and RFI (0.43). The animals in the low RFI group had a much lower FE frequency than those in the high RFI group (90.52 ± 35.93 vs 119.1 ± 47.24). It must be kept in mind that the FE in this study was an “in-to-out” event. In most studies, the frequency of visits is comparable to the meal frequency in this study due to their use of RFID systems of measurement (Table 7). There was no correlation between meal frequency and other traits of interest in this study, which is consistent with the findings of others (Streeter et al., 1999; Lancaster et al., 2005a; Ribeiro et al., 2006). Schwartzkopf-Genswein et al. (2002) also concluded that meal frequency was not related to intake or gain in cattle. Hicks et al. (1989) found feeding frequency to be more related to animal performance than feeding duration. They found that as feeding frequency increased, performance increased, but they did not present a mechanism for this relationship. The reason for their findings differing could be that they only visually observed animals every 30 min for one 24-hour period. Their results may have been different if observations had been obtained more frequently or over a longer period of time.

Differences in eating rate could strongly affect the relationship between feeding duration and intake. This could provide a viable explanation for the inconsistency between studies. It has been assumed that cattle that spend more time at the feed bunk consume more feed and gain more quickly. If eating rate is playing a larger role than expected, this assumption could be completely incorrect. In the present study, the high RFI heifers consumed more feed during each FE than the low RFI heifers with FE eating rates of 99.56 ± 3.28 g/min and 62.78 ± 1.76 g/min, respectively. Feeding event eating rate was moderately correlated with RFI (0.59) for the focal animals in this study. Lancaster et al. (2005a) did not find a significant correlation between eating rate and RFI. In the

2002 Schwartzkopf-Genswein et al. study, eating rates of more than 200g/min were reported. The reason for this substantial difference was probably due to their study measuring eating rate for only the first 3 hours after feeding in only a few animals. Cattle have been shown to eat more rapidly immediately after feed is provided to them (Streeter et al., 1999). Lancaster et al. (2005a) found that eating rate was moderately correlated ($P < 0.05$) with both ADG (0.29) and DMI (0.47). The present study did not find FE eating rate and ADG to be correlated. However, DMI ($r = 0.45$, $P < 0.01$) and FCR ($r = 0.64$, $P < 0.0001$) were correlated with FE eating rate. The reason for this difference could be that FE eating rate was correlated with RFI in this study and RFI is not correlated with growth traits such as ADG. Feed conversion ratio is known to have a strong negative correlation with ADG (Carstens et al., 2002; Arthur et al., 2001a).

With the exception of meal eating rate, meal traits as they were evaluated in this study did not differ between the high and low RFI groups. Meal eating rate was moderately correlated with RFI. Heifers in the low RFI group had a lower meal eating rate than high RFI heifers (41.86 ± 0.96 g/min vs 49.43 ± 0.67 g/min).

Temperament

There is some evidence that the excitability or temperament of an animal could affect its efficiency or performance. Objective as well as subjective techniques have been used to measure temperament in cattle. Exit velocity has been proposed as an objective measure of temperament (Burrow et al., 1988) while chute scores are more subjective. Initial and final chute scores were assigned and exit velocities assessed for each heifer in this study. In the present study, initial and final chute scores were moderately correlated ($r = 0.34$, $P < 0.05$) with each other. However, initial and final chute scores were not correlated with any of the measured performance or efficiency traits. Final chute score was moderately correlated with meal frequency. There was a moderate correlation ($r = 0.43$, $P < 0.01$) between the initial and final exit velocities. In addition, a moderate negative correlation was found between initial exit velocity and several of the FE measures, including total daily FE duration, FE duration, and FE frequency. There was also a moderate negative correlation between initial exit velocity and initial and final BW as well as ADG. Final exit velocity was negatively correlated with total daily FE duration while not correlated with any of the measured performance or efficiency traits. Petherick et al. (2002) found that as exit velocity increased, ADG and BW decreased. Lancaster et al. (2005b) observed a weak correlation between final exit velocity and DMI ($r = -0.22$, $P < 0.05$) as well as a relationship with ADG ($r = -0.28$, $P < 0.01$). It has been found that cattle that tended to be calmer in squeeze chute or group pen conditions had higher ADG than more excitable cattle (Voisinet et al., 1997). In addition, Brown et al. (2004) found exit velocity to be negatively correlated with ADG and DMI while not correlated with RFI and FCR. Based on the results of others, exit velocity does not appear to be a reliable indicator of feed efficiency traits but may be indicative of DMI or ADG in growing cattle. The results of this study do not indicate that the measured temperament characteristics are associated with intake; however, they may be weakly associated with ADG.

SUMMARY AND CONCLUSIONS

The results of this study suggest that selecting for cattle with low RFI has the potential to produce cattle that are more efficient users of feed without increasing mature cow size and thus increasing feed expenditures. However, measuring feed intake is costly and labor intensive. In order to reduce these costs, it would be beneficial to have a predictive measure of RFI that would allow intake to be measured for a shorter period of time, while still gaining the beneficial knowledge of a longer trial.

The measurement of feeding behavior could be a useful means of trying to predict efficiency (RFI) in growing calves. In this study, FE measurements were more closely related to RFI than meal measurements. Cattle that spent a greater amount of time eating at a lower rate were more efficient (lower RFI) than cattle that ate more rapidly for a shorter period of time. Many studies have quantified meals instead of FE when studying feeding behavior. This study found that measuring the duration and frequency of FE could prove to be more useful than analyzing meals when trying to predict RFI. Feeding event frequency was correlated with RFI while meal duration and frequency were not associated with RFI. Eating rate is less frequently analyzed than other measures of feeding behavior. However, in this study, it appeared that rate of eating was more closely associated with RFI than any of the other measures of feeding behavior. Clearly, more research is needed to better determine the relationships between these factors and ultimately what they mean to livestock performance. Until the relationship between feeding behavior traits and animal efficiency and performance can be more clearly established, few conclusions can be drawn based on these factors alone. Results from this study suggest that applying selection pressure for low RFI could increase feed efficiency without detrimental effects on performance or temperament. Because low RFI cattle eat substantially less without sacrificing performance, the continued search for more conclusive evidence of an accurate predictor of RFI is needed.

LITERATURE CITED

Archer, J. A., and L. Bergh. 2000. Duration of performance tests for growth rate, feed intake and feed efficiency in four biological types of beef cattle. Livestock Production Science 65:47-55.

Archer, J. A., A. Reverter, R. M. Herd, D. J. Johnston, and P. F. Arthur. 2002. Genetic variation in feed intake and efficiency of mature beef cows and relationships with postweaning measurements. 7th World Congress on Genetic Applications to Livestock Production, Montpellier, France. p 90-93.

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, and R. M. Herd. 2004. Feed intake and efficiency in beef cattle: Overview of recent Australian research and challenges for the future. Australian Journal of Experimental Agriculture 44:361-369.

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

Arthur, P. F., R. M. Herd, J. Wright, G. Xu, K. C. Dibley, and E. C. Richardson. 1996. Net feed conversion efficiency and its relationship with other traits in beef cattle. Proceedings of the Australian Society of Animal Production, Queensland, Australia. p 107-110.

Arthur, P. F., G. Renand, and D. Krauss. 2001b. Genetic parameters for growth and feed efficiency in weaner versus yearling Charolais bulls. Australian Journal of Agricultural Research 52:471-476.

Basarab, J. A., E. K. Okine, and K. L. Lyle. 2001. Relationships between daily feed intake and feeding behaviors in feedlot steers. Journal of Animal Science 80 (Suppl. 1):81.

Basarab, J. A., M. A. Price, J. L. Aalhus, E. K. Okine, W. M. Snelling, and K. L. Lyle. 2003. Residual feed intake and body composition in young growing cattle. Canadian Journal of Animal Science 83:189-204.

Burrow, H. M. 2001. Variances and covariances between productive and adaptive traits and temperament in a composite breed of tropical beef cattle. Livestock Production Science 70:213-233.

Burrow, H. M., G. W. Seifert, and N. J. Corbet. 1988. A new technique for measuring temperament in cattle. Proceedings of the Australian Society of Animal Production, Queensland, Australia. p 154-157.

Carstens, G. E., C. M. Theis, M. B. White, T. H. Welsh, B. G. Warrington, T. D. A. Forbes, H. Lippke, L. W. Greene, and D. K. Lunt. 2002. Residual feed intake in beef steers: 1. Correlations with performance traits and ultrasound measures of body composition. Proceedings, Western Section, American Society of Animal Science. p 552-555.

Cole, N. A. 1995. Intake control systems. Symposium: Intake by Feedlot Cattle., Oklahoma State University, Stillwater, OK. p 156-161.

Crews, D. H., Jr., N. H. Shannon, B. M. A. Genswein, R. E. Crews, C. M. Johnson, and B. A. Kendrick. 2003. Genetic parameters for net feed efficiency of beef cattle measured during postweaning growing versus finishing periods. Proceedings, Western Section, American Society of Animal Science. p 125-128.

Curley, K. O., J. C. Paschal, T. H. W. Jr., and R. D. Randel. 2006. Technical note: Exit velocity as a measure of cattle temperament is repeatable and associated with serum concentration of cortisol in Brahman bulls. Journal of Animal Science 84: 3100–3103.

DeVries, T. J., M. A. G. v. Keyserlingk, D. M. Weary, and K. A. Beauchemin. 2003. Technical note: Validation of a system for monitoring feeding behavior in dairy cows. Journal of Dairy Science 86:3571-3574.

Gibb, D. J., T. A. McAllister, C. Huisma, and R. D. Wiedmeier. 1998. Bunk attendance of feedlot cattle monitored with radio frequency technology. Canadian Journal of Animal Science 78:707-710.

Grandin, T. 1993. Behavioral agitation during handling of cattle is persistent over time. Applied Animal Behavior Science 36:1-9.

Herd, R. M., and S. C. Bishop. 2000. Genetic variation in residual feed intake and its association with other production traits in British Hereford cattle. Livestock Production Science 63:111-119.

Hicks, R. B., F. N. Owens, and D. R. Gill. 1989. Behavioral patterns of feedlot steers, Oklahoma State University, Stillwater.

Keys, J. E., R. E. Pearson, and P. D. Thompson. 1978. Effect of feed bunk stocking density on weight gains and feeding behavior of yearling Holstein heifers. Journal of Dairy Science 61:448-454.

Koch, R. M., K. E. Gregory, D. Chambers, and L. A. Swiger. 1963. Efficiency of feed use in beef cattle. Journal of Animal Science 22:486-494.

Koots, K. R., J. P. Gibson, C. Smith, and J. W. Wilton. 1994. Analyses of published genetic parameter estimates for beef production traits. 1. Heritability. Animal Breeding 62:309-338.

Lancaster, P. A., G. E. Carstens, J. D.H. Crews, and S. A. Woods. 2005a. Evaluation of feed efficiency traits in growing bulls and relationships with feeding behavior and ultrasound carcass estimates. Proceedings, Western Section, American Society of Animal Science. p 461-464.

Lancaster, P. A., G. E. Carstens, E. G. Brown, R. D. Randel, T. H. Welsh, T. D. A. Forbes, D. T. Dean, and A. D. Herring. 2005b. Relationships between residual feed intake, ultrasound, and temperament traits in Brangus heifers. Journal of Animal Science 83 (Suppl. 1):325.

Lehner P.N. 1998. Handbook of Ethological Methods. 2nd ed. Cambridge, UK: Cambridge University Press, 213-214.

Liu, M. F., L. A. Goonewardene, D. R. C. Bailey, J. A. Basarab, R. A. Kemp, P. F. Arthur, E. K. Okine, and M. Makarechian. 2000. A study on the variation of feed efficiency in station tested beef bulls. Canadian Journal of Animal Science 80: 435-441.

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. Journal of Animal Science 84:145-153.

NRC. 2000. Nutrient requirements of beef cattle. 7th ed. National Academy Press, Washington, DC.

Petherick, J. C., R. G. Holroyd, V. J. Doogan, and B. K. Venus. 2002. Productivity, carcass and meat quality of lot-fed bos indicus cross steers grouped according to temperament. Australian Journal of Experimental Agriculture 42:389-398.

Ribeiro, F. R. B., G. E. Carstens, P. A. Lancaster, L. O. Tedeschi, and M. H. M. R. Fernandes. 2006. Evaluation of feed efficiency traits and their relationships with carcass ultrasound and feeding behavior traits in Brahman heifers. Beef Cattle Research in Texas: 91-94.

Schwartzkopf-Genswein, K. S., S. Atwood, and T. A. McAllister. 2002. Relationships between bunk attendance, intake and performance of steers and heifers on varying feeding regimes. Applied Animal Behaviour Science 76:179-188.

Schwartzkopf-Genswein, K. S., C. Huisma, and T. A. McAllister. 1999. Validation of a radio frequency identification system for monitoring the feeding patterns of feedlot cattle? Livestock Production Science 60:27-31.

Sowell, B. F., J. G. P. Bowman, M. E. Branine, and M. E. Hubbert. 1998. Radio frequency technology to measure feeding behavior and health of feedlot steers. Applied Animal Behaviour Science 59:277-284.

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

Streeter, M. N., M. Branine, E. Whitley, F. T. McCollum, B. F. Sowell, and W. F. Quimby. 1999. Feeding behavior of feedlot cattle: Does behavior change with health status, environmental conditions and performance level? Proceedings of the 60th Annual Minnesota Nutrition Conference. p 117-130.

Voisinet, B. D., T. Grandin, J. D. Tatum, S. F. O'Connor, and J. J. Struthers. 1997. Feedlot cattle with calm temperaments have higher average daily gains than cattle with excitable temperaments. Journal of Animal Science 75:892-896.

Wang, Z., J. D. Nkrumah, C. Li, J. A. Basarab, L. A. Goonewardene, E. K. Okine, D. H. Crews, and S. S. Moore. 2006. Test duration for growth, feed intake, and feed efficiency in beef cattle using the GrowSafe system. Journal of Animal Science 84: 2289-2298.

APPENDIX 1

DAILY FEEDING EVENT AND MEAL DATA

Day	Calf ID	RFIgroup	FE Dur min/event	Total FE Dur min/d	FE Freq	M Dur min/meal	Total M Dur min/d	M Freq meals/d
1	151	Low	0.642	115.617	180	18.453	276.800	15
2	151	Low	0.693	85.283	123	25.960	181.717	7
3	151	Low	0.768	128.167	167	22.833	274.000	12
4	151	Low	0.726	92.883	128	14.577	204.083	14
5	151	Low	0.636	110.050	173	15.253	274.550	18
6	151	Low	0.769	105.367	137	9.766	195.317	20
7	151	Low	0.772	108.800	141	12.915	219.550	17
8	151	Low	0.640	104.933	164	9.802	225.450	23
1	156	Low	1.700	124.100	73	11.401	148.217	13
2	156	Low	1.886	115.050	61	12.915	154.983	12
3	156	Low	1.806	160.750	89	13.657	218.517	16
4	156	Low	1.713	143.867	84	11.576	185.217	16
5	156	Low	2.163	142.733	66	11.005	176.083	16
6	156	Low	2.719	149.550	55	11.125	178.000	16
7	156	Low	2.558	166.267	65	17.102	188.117	11
8	156	Low	3.099	151.833	49	12.375	173.250	14
1	159	Low	2.123	197.400	93	16.769	251.533	15
2	159	Low	2.593	236.000	91	25.639	282.033	11
3	159	Low	2.466	221.967	90	22.222	266.667	12
4	159	Low	3.922	274.533	70	34.391	309.517	9
5	159	Low	2.572	162.050	63	35.756	214.533	6
6	159	Low	3.387	254.050	75	26.498	291.483	11
7	159	Low	2.926	283.833	97	26.619	346.050	13
8	159	Low	3.568	267.567	75	26.051	312.617	12
1	175	Low	2.603	203.017	78	11.182	268.367	24
2	175	Low	3.871	193.533	50	15.913	222.783	14
3	175	Low	3.454	214.150	62	15.346	276.233	18
4	175	Low	4.680	224.617	48	23.268	255.950	11
5	175	Low	2.787	183.933	66	47.272	756.350	16
6	175	Low	2.647	201.150	76	13.865	249.567	18
7	175	Low	2.510	210.800	84	16.200	275.400	17
8	175	Low	2.185	194.450	89	17.394	260.917	15
1	176	Low	2.369	156.367	66	13.192	197.883	15
2	176	Low	2.551	206.617	81	26.100	287.100	11
3	176	Low	1.599	145.517	91	16.503	214.533	13
4	176	Low	1.830	148.200	81	14.576	204.067	14
5	176	Low	1.445	130.083	90	13.342	186.783	14
6	176	Low	1.443	128.400	89	19.520	175.683	9
7	176	Low	2.951	209.500	71	32.042	256.333	8
8	176	Low	2.488	194.033	78	18.326	256.567	14
1	178	Low	1.204	134.900	112	21.770	217.700	10

Day	Calf ID	RFIgroup	FE Dur min/event	Total FE Dur min/d	FE Freq events/d	M Dur min/meal	Total MDur meals/d	M Freq meals/d
2	178	Low	1.008	144.183	143	15.881	269.983	17
3	178	Low	0.984	160.383	163	20.551	328.817	16
4	178	Low	0.948	146.900	155	15.361	276.500	18
1	180	Low	2.127	161.667	76	13.166	197.483	15
2	180	Low	4.619	161.650	35	22.733	181.867	8
3	180	Low	5.642	225.683	40	18.032	252.450	14
4	180	Low	2.956	162.583	55	13.060	222.017	17
5	180	Low	3.776	192.583	51	10.898	217.967	20
6	180	Low	2.185	177.017	81	13.803	234.650	17
7	180	Low	3.954	217.483	55	13.332	253.317	19
8	180	Low	2.906	206.333	71	14.396	259.133	18
1	184	Low	0.909	130.867	144	16.498	230.967	14
2	184	Low	1.502	120.183	80	21.794	174.350	8
3	184	Low	1.191	140.517	118	13.583	230.917	17
4	184	Low	1.657	155.733	94	17.076	239.067	14
5	184	Low	0.968	60.000	62	9.691	106.600	11
6	184	Low	2.800	167.983	60	25.737	231.633	9
7	184	Low	1.224	149.317	122	17.850	267.750	15
8	184	Low	1.340	146.100	109	15.404	231.067	15
1	198	Low	0.482	70.917	147	10.492	199.350	19
2	198	Low	0.690	55.217	80	8.140	113.967	14
3	198	Low	0.573	102.567	179	16.363	229.083	14
4	198	Low	0.641	88.450	138	8.663	181.917	21
5	198	Low	0.499	76.283	153	16.824	201.883	12
6	198	Low	0.531	69.600	131	16.665	166.650	10
7	198	Low	0.576	97.333	169	17.195	223.533	13
8	198	Low	0.938	98.450	105	12.827	166.750	13
1	200	Low	3.190	162.683	51	15.725	188.700	12
2	200	Low	4.822	197.683	41	13.749	206.233	15
3	200	Low	4.029	181.300	45	12.466	199.450	16
4	200	Low	4.380	197.117	45	14.251	213.767	15
5	200	Low	4.982	179.367	36	12.316	197.050	16
6	200	Low	3.232	158.350	49	24.629	197.033	8
7	200	Low	4.040	181.817	45	23.356	210.200	9
8	200	Low	6.129	196.117	32	13.930	208.950	15
1	202	Low	1.047	121.500	116	12.012	204.200	17
2	202	Low	1.589	166.833	105	13.694	246.483	18
3	202	Low	1.601	185.717	116	14.117	268.217	19
4	202	Low	1.788	191.300	107	13.535	270.700	20
5	202	Low	1.198	105.450	88	11.773	153.050	13
6	202	Low	1.284	128.383	100	19.214	230.567	12
7	202	Low	1.332	129.217	97	15.329	183.950	12
8	202	Low	1.536	118.300	77	12.639	176.950	14
1	213	Low	1.526	105.317	69	9.997	129.967	13

Day	Calf ID	RFIgroup	FE Dur min/event	Total FE Dur min/d	FE Freq events/d	M Dur min/meal	Total MDur min/d	M Freq meals/d
2	213	Low	1.624	84.467	52	11.162	111.617	10
4	213	Low	2.145	137.267	64	11.394	159.517	14
5	213	Low	1.875	95.650	51	8.917	115.917	13
6	213	Low	1.742	104.517	60	10.713	128.550	12
7	213	Low	2.516	120.750	48	11.965	143.583	12
8	213	Low	1.899	112.067	59	16.430	147.867	9
1	221	Low	1.104	132.483	120	7.006	196.167	28
3	221	Low	1.474	200.500	136	20.907	292.700	14
4	221	Low	1.415	114.600	81	11.213	168.200	15
5	221	Low	1.037	104.700	101	7.541	165.900	22
6	221	Low	1.204	110.750	92	12.867	167.267	13
7	221	Low	1.505	138.500	92	9.248	203.450	22
8	221	Low	1.427	137.033	96	10.418	218.783	21
1	237	Low	3.090	194.700	63	17.227	223.950	13
2	237	Low	3.048	246.917	81	14.293	271.567	19
3	237	Low	3.251	214.550	66	13.273	238.917	18
4	237	Low	3.630	166.983	46	13.847	180.017	13
5	237	Low	2.946	188.517	64	18.349	220.183	12
6	237	Low	3.052	173.967	57	28.195	197.367	7
7	237	Low	3.030	218.167	72	32.056	256.450	8
8	237	Low	2.791	192.550	69	21.745	217.450	10
1	244	Low	0.958	139.867	146	14.518	261.317	18
2	244	Low	0.859	135.800	158	24.652	246.517	10
3	244	Low	1.014	149.050	147	19.645	275.033	14
4	244	Low	0.957	103.383	108	13.456	188.383	14
5	244	Low	0.984	125.950	128	16.554	248.317	15
6	244	Low	0.974	147.033	151	17.366	277.850	16
7	244	Low	0.922	116.167	126	12.116	230.200	19
8	244	Low	0.700	97.983	140	17.453	209.433	12
1	259	Low	0.914	80.417	88	18.854	150.833	8
2	259	Low	1.267	119.117	94	21.229	254.750	12
3	259	Low	0.992	109.167	110	11.394	193.700	17
4	259	Low	1.177	114.200	97	10.329	196.250	19
5	259	Low	1.088	90.283	83	11.008	143.100	13
6	259	Low	0.932	95.983	103	14.460	173.517	12
7	259	Low	1.178	140.133	119	11.839	236.783	20
8	259	Low	1.165	117.667	101	10.266	195.050	19
1	269	Low	2.075	134.900	65	9.136	182.717	20
2	269	Low	2.435	189.917	78	11.048	254.100	23
3	269	Low	1.887	167.917	89	10.918	218.350	20
4	269	Low	1.679	136.017	81	8.470	186.333	22
5	269	Low	1.807	99.367	55	6.621	125.800	19
6	269	Low	1.351	116.217	86	11.159	178.550	16
7	269	Low	1.779	160.133	90	12.816	217.867	17

Day	Calf ID	RFIgroup	FE Dur min/event	Total FE Dur min/d	FE Freq events/d	M Dur min/meal	Total M Dur min/d	M Freq meals/d
8	269	Low	2.006	162.483	81	11.772	211.900	18
1	276	Low	2.255	164.617	73	10.746	204.167	19
4	276	Low	3.028	211.967	70	8.674	234.200	27
5	276	Low	2.395	158.083	66	16.665	216.650	13
6	276	Low	2.576	144.267	56	16.376	180.133	11
7	276	Low	3.028	166.517	55	17.835	214.017	12
8	276	Low	2.655	151.317	57	11.062	188.050	17
1	157	High	0.510	75.533	148	8.505	187.100	22
2	157	High	0.616	113.417	184	11.876	273.150	23
3	157	High	0.615	99.683	162	16.129	241.933	15
4	157	High	0.680	119.750	176	16.263	260.200	16
5	157	High	1.720	77.000	132	16.524	191.433	18
6	157	High	0.702	115.850	165	16.484	247.267	15
7	157	High	0.659	110.767	168	13.733	260.933	19
8	157	High	0.558	61.383	110	15.180	151.800	10
1	161	High	0.241	26.500	110	6.806	122.517	18
2	161	High	0.357	71.733	201	9.549	229.167	24
3	161	High	0.318	66.783	210	12.398	235.567	19
4	161	High	0.303	55.700	184	9.671	203.100	21
5	161	High	0.324	47.917	148	5.670	164.433	29
6	161	High	0.312	62.950	202	14.435	274.267	19
7	161	High	0.369	77.800	211	11.818	260.000	22
8	161	High	0.341	65.883	193	13.837	262.900	19
1	172	High	1.766	220.800	125	19.954	299.317	15
2	172	High	1.380	126.967	92	12.751	178.517	14
3	172	High	1.553	170.800	110	11.659	233.183	20
4	172	High	1.755	173.717	99	21.076	231.833	11
5	172	High	2.101	100.833	48	8.781	122.933	14
6	172	High	1.695	162.683	96	17.194	223.517	13
7	172	High	1.030	132.833	129	13.220	211.517	16
8	172	High	1.519	144.350	95	13.238	211.800	16
1	182	High	0.415	70.100	169	14.513	203.183	14
2	182	High	0.511	102.650	201	19.338	251.400	13
3	182	High	0.487	91.050	187	22.445	246.900	11
4	182	High	0.534	74.817	140	16.497	197.967	12
5	182	High	0.568	86.900	153	20.647	206.467	10
6	182	High	0.620	92.450	149	20.820	208.200	10
7	182	High	0.699	117.500	168	23.773	237.733	10
8	182	High	0.673	107.000	159	21.732	239.050	11
1	205	High	4.537	245.017	54	16.197	275.350	17
2	205	High	4.624	180.333	39	30.600	214.200	7
3	205	High	7.937	238.100	30	21.489	257.867	12
4	205	High	5.547	194.133	35	12.702	215.933	17
5	205	High	3.633	217.983	60	16.761	251.417	15

Day	Calf ID	RFIgroup	FE Dur min/event	Total FE Dur min/d	FE Freq events/d	M Dur min/meal	Total M Dur min/d	M Freq meals/d
6	205	High	4.270	213.517	50	21.415	235.567	11
7	205	High	3.663	241.750	66	15.245	274.417	18
2	206	High	1.151	108.233	94	15.756	173.317	11
3	206	High	1.074	126.783	118	14.726	220.883	15
4	206	High	1.175	95.150	81	11.080	166.200	15
5	206	High	3.965	150.683	38	14.656	175.867	12
6	206	High	4.881	156.200	32	13.463	175.017	13
7	206	High	4.556	209.583	46	14.094	239.600	17
8	206	High	3.266	189.433	58	11.019	220.383	20
1	211	High	0.877	99.967	114	8.780	193.150	22
2	211	High	1.077	118.517	110	19.223	192.233	10
3	211	High	1.039	150.583	145	16.061	273.033	17
4	211	High	1.255	134.267	107	11.782	188.517	16
5	211	High	0.769	123.000	160	12.858	244.300	19
6	211	High	1.384	157.800	114	19.354	232.250	12
7	211	High	1.358	180.567	133	16.360	261.767	16
8	211	High	1.404	169.917	121	12.277	245.533	20
1	212	High	0.847	126.133	149	13.177	210.833	16
2	212	High	0.501	89.683	179	13.211	224.583	17
3	212	High	0.428	88.633	207	10.748	279.450	26
4	212	High	0.419	56.150	134	11.448	183.167	16
5	212	High	0.985	111.283	113	12.876	193.133	15
6	212	High	0.728	108.417	149	21.732	217.317	10
7	212	High	0.639	89.400	140	15.021	210.300	14
8	212	High	0.540	69.067	128	12.354	197.667	16
1	218	High	1.340	175.533	131	11.642	267.767	23
2	218	High	1.887	194.317	103	14.915	268.467	18
3	218	High	1.862	191.750	103	19.846	258.000	13
4	218	High	1.741	158.450	91	12.354	222.367	18
5	218	High	1.829	181.033	99	18.168	272.517	15
6	218	High	1.668	156.833	94	11.759	211.667	18
7	218	High	1.741	177.533	102	17.328	259.917	15
8	218	High	1.437	159.467	111	16.897	270.350	16
1	225	High	0.512	58.333	114	17.054	153.483	9
2	225	High	0.695	104.883	151	12.568	238.800	19
3	225	High	0.616	81.917	133	17.607	211.283	12
4	225	High	0.599	79.717	133	20.060	200.600	10
5	225	High	0.735	78.683	107	11.415	159.817	14
6	225	High	0.622	85.900	138	14.358	215.367	15
7	225	High	0.607	79.567	131	25.454	203.633	8
8	225	High	0.615	80.550	131	12.594	201.500	16
1	228	High	2.219	130.933	59	21.138	169.100	8
2	228	High	2.942	220.683	75	14.503	261.050	18
3	228	High	2.291	194.733	85	18.920	264.883	14

Day	Calf ID	RFIgroup	FE Dur min/event	Total FE Dur min/d	FE Freq events/d	M Dur min/meal	Total M Dur min/d	M Freq meals/d
4	228	High	2.047	180.133	88	15.706	251.300	16
5	228	High	2.933	143.733	49	17.622	176.217	10
8	228	High	2.421	162.217	67	9.888	197.767	20
1	235	High	2.985	191.017	64	14.677	249.517	17
2	235	High	4.838	174.183	36	17.621	211.450	12
3	235	High	3.265	146.933	45	14.165	184.150	13
4	235	High	3.582	211.333	59	16.957	271.317	16
5	235	High	3.991	139.683	35	12.745	165.683	13
6	235	High	2.313	136.467	59	15.814	189.767	12
7	235	High	3.487	153.417	44	14.491	188.383	13
8	235	High	3.783	158.900	42	14.686	220.283	15
1	239	High	0.435	60.517	139	11.446	194.583	17
2	239	High	0.440	89.683	204	19.060	266.833	14
3	239	High	0.450	85.883	191	22.211	244.317	11
4	239	High	0.513	92.800	181	16.797	251.950	15
5	239	High	0.400	71.650	179	13.421	241.583	18
6	239	High	0.365	80.733	221	25.764	283.400	11
7	239	High	0.416	89.533	215	20.927	292.983	14
8	239	High	0.417	76.333	183	26.698	240.283	9
1	241	High	0.380	48.250	127	9.699	145.483	15
2	241	High	0.630	55.433	88	8.676	121.467	14
3	241	High	0.606	67.217	111	11.299	146.883	13
4	241	High	0.470	59.233	126	10.069	161.100	16
5	241	High	0.360	61.283	170	17.609	193.700	11
6	241	High	0.521	81.217	156	12.763	191.450	15
7	241	High	1.028	93.567	91	14.874	163.617	11
8	241	High	1.036	98.467	95	9.432	169.783	18
1	249	High	1.590	198.717	125	18.348	293.567	16
2	249	High	2.403	218.633	91	17.410	278.567	16
3	249	High	1.363	158.083	116	18.960	265.433	14
4	249	High	1.754	164.850	94	12.864	244.417	19
5	249	High	1.837	134.067	73	12.384	210.533	17
6	249	High	1.947	142.150	73	12.539	200.617	16
7	249	High	1.723	167.167	97	15.616	265.467	17
8	249	High	1.733	131.683	76	13.369	200.533	15
1	256	High	1.181	148.850	126	15.295	244.717	16
2	256	High	0.935	115.000	123	14.012	252.217	18
3	256	High	1.680	195.050	138	12.462	286.617	23
4	256	High	1.455	184.800	127	20.614	267.983	13
5	256	High	1.325	159.017	120	25.968	259.683	10
6	256	High	1.393	154.667	111	24.728	247.283	10
7	256	High	1.167	145.817	125	26.070	234.633	9
8	256	High	1.185	128.017	108	21.509	193.583	2
1	260	High	0.302	41.400	137	12.902	141.917	11

Day	Calf ID	RFIgroup	FE Dur min/event	Total FE Dur min/d	FE Freq events/d	M Dur min/meal	Total M Dur min/d	M Freq meals/d
2	260	High	0.635	92.017	145	14.227	213.400	15
3	260	High	0.366	64.100	175	11.877	201.917	17
6	260	High	0.415	65.500	158	11.591	173.867	15
7	260	High	0.480	86.333	180	12.747	242.200	19
8	260	High	0.503	74.417	148	7.568	189.200	25
1	265	High	1.822	169.483	93	14.986	239.783	16
2	265	High	1.033	108.417	105	19.994	179.950	9
3	265	High	1.057	96.167	91	10.058	160.933	16
4	265	High	0.820	100.100	122	20.575	205.750	10
5	265	High	0.451	49.200	109	22.998	321.967	14
6	265	High	0.642	109.067	170	12.860	257.200	20
7	265	High	0.724	112.883	156	17.531	262.967	15
8	265	High	0.666	83.883	126	11.117	188.983	17

APPENDIX 2

FEEDING EVENT AND MEAL DATA AVERAGED OVER 8 DAYS

Day	Calf ID	RFIgroup	FE Dur min/event	Total FEDur min/d	FE Freq events/d	M Dur min/meal	Total M Dur min/d
151	Low	0.706	106.388	151.63	16.195	231.43	15.75
156	Low	2.205	144.269	67.75	12.645	177.80	14.25
159	Low	2.945	237.175	81.75	26.743	284.30	11.13
175	Low	3.092	203.206	69.13	20.055	320.70	16.63
176	Low	2.084	164.840	80.88	19.200	222.37	12.25
178	Low	1.125	156.065	141.25	17.587	274.39	16.13
180	Low	3.521	188.125	58.00	14.928	227.36	16.00
184	Low	1.449	133.838	98.63	17.204	214.04	12.88
198	Low	0.616	82.352	137.75	13.396	185.39	14.50
200	Low	4.350	181.804	43.00	16.303	202.67	13.25
202	Low	1.422	143.338	100.75	14.039	216.76	15.63
213	Low	1.912	109.738	57.88	11.375	134.06	12.00
221	Low	1.312	135.970	103.79	11.530	203.94	19.25
237	Low	3.105	199.544	64.75	19.873	225.74	12.50
244	Low	0.921	126.904	138.00	16.970	242.13	14.75
259	Low	1.089	108.371	99.38	13.672	193.00	15.00
269	Low	1.877	145.869	78.13	10.242	196.95	19.38
276	Low	2.778	163.006	59.50	14.852	200.33	14.88
157	High	0.758	115.423	155.63	14.337	239.98	17.25
161	High	0.321	59.408	182.38	10.523	218.99	21.38
172	High	1.600	154.123	99.25	14.734	214.08	14.88
182	High	0.563	92.808	165.75	19.971	223.86	11.38
205	High	4.985	214.025	45.75	18.966	239.41	13.50
206	High	2.632	142.065	71.13	13.364	194.13	14.75
211	High	1.145	141.827	125.50	14.587	228.85	16.50
212	High	0.636	92.346	149.88	13.821	214.56	16.25
218	High	1.688	174.365	104.25	15.364	253.88	17.00
225	High	0.625	81.194	129.75	16.389	198.06	12.88
228	High	2.703	169.127	64.88	17.148	214.77	13.25
235	High	3.531	163.992	48.00	15.145	210.07	13.88
239	High	0.430	80.892	189.13	19.540	251.99	13.63
241	High	0.629	70.583	120.50	11.803	161.69	14.13
249	High	1.794	164.419	93.13	15.186	244.89	16.25
256	High	1.290	153.902	122.25	20.082	248.34	12.63
260	High	0.434	67.260	155.13	11.484	186.53	17.00
265	High	0.902	103.650	121.50	16.265	227.19	14.63

APPENDIX 3

FEED EFFICIENCY AND GROWTH DATA

Calf ID	RFIgroup	RFIp	initialBW	finalBW	ADG	DMI	FCR
151	1	-0.88393	253.4906	322.5179	0.9861	8.0326	8.1458
156	1	-0.89309	321.6409	409.8433	1.2600	10.3097	8.1821
159	1	-0.98911	270.2076	347.7406	1.1076	8.6455	7.8055
175	1	-1.14899	258.1511	356.1095	1.3994	8.9995	6.4309
176	1	-1.01491	274.8102	354.6961	1.1412	8.8164	7.7254
178	1	-0.93096	256.5557	333.3483	1.0970	8.3592	7.6198
180	1	-1.49502	248.3918	311.5870	0.9028	7.0744	7.8361
184	1	-0.73971	275.4358	348.2609	1.0404	8.8327	8.4901
198	1	-1.1918	323.5155	394.3531	1.0120	9.3876	9.2766
200	1	-1.04775	260.4356	342.8581	1.1775	8.5510	7.2622
202	1	-0.919	257.2812	309.7343	0.7493	7.4406	9.9297
213	1	-1.08732	300.7477	377.4000	1.0950	9.2074	8.4083
221	1	-1.06759	265.4412	324.0384	0.8371	7.7220	9.2247
237	1	-1.07222	243.7652	325.1471	1.1626	8.0976	6.9651
244	1	-0.71183	288.2243	373.4737	1.2178	9.6317	7.9088
259	1	-0.95878	253.6404	343.0921	1.2779	8.7554	6.8515
269	1	-1.35276	254.8541	313.8357	0.8426	7.2043	8.5502
276	1	-1.02264	267.1059	342.7503	1.0806	8.4673	7.8355
157	3	1.216115	287.3454	365.9059	1.1223	11.2818	10.0525
161	3	1.011459	246.0636	294.8721	0.6973	8.9636	12.8554
172	3	0.486042	269.5777	353.5169	1.1991	10.3543	8.6348
182	3	1.336157	274.3074	345.5876	1.0183	10.8228	10.6285
205	3	0.700217	287.6916	378.9862	1.3042	11.2646	8.6371
206	3	1.143923	241.0848	304.5453	0.9066	9.5509	10.5351
211	3	0.596685	261.3251	351.5759	1.2893	10.5196	8.1592
212	3	1.693737	260.5475	322.0195	0.8782	10.4811	11.9352
218	3	1.158612	224.6596	283.1730	0.8359	8.9785	10.7410
225	3	0.694621	266.6547	352.4912	1.2262	10.5692	8.6192
228	3	0.763144	277.2158	348.9494	1.0248	10.3341	10.0844
235	3	0.875786	295.3013	369.6389	1.0620	10.9587	10.3193
239	3	1.111015	217.8694	289.2050	1.0191	9.2710	9.0974
241	3	1.620576	312.5013	366.6842	0.7740	11.3150	14.6181
249	3	0.957394	287.4200	390.5353	1.4731	11.9707	8.1263
256	3	0.736437	276.4724	357.4934	1.1574	10.6496	9.2010
260	3	0.906068	258.5926	339.4146	1.1546	10.4000	9.0075
265	3	0.948056	267.4655	343.7134	1.0893	10.4697	9.6118

VITA

Name: Glenda Marie Bingham

Permanent Address: Texas A&M University
2471 TAMU
Kleberg 245
College Station, TX 77843-2471

Email Address: glenda-norris@tamu.edu

Education: Texas A&M University
B.S. in Psychology, 2002

Texas A&M University
M.S. in Animal Science, 2007

Major Field of Specialization: Applied Animal Behavior