EFFECTS OF RESIDUAL FEED INTAKE CLASSIFICATION ON FEED EFFICIENCY, FEEDING BEHAVIOR, CARCASS TRAITS, AND NET REVENUE IN ANGUS-BASED COMPOSITE STEERS

A Thesis

by

JOEL TIMOTHY WALTER

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

December 2011

Major Subject: Animal Science

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Efficiency, Feeding Behavior, Carcass Traits, and Net Revenue in Angus-Based

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Approved by:

Chair of Committee,	Gordon E. Carstens
Committee Members,	David P. Anderson
	Jason E. Sawyer
Interim Head of Department,	H. Russell Cross

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ABSTRACT

Effects of Residual Feed Intake Classification on Feed Efficiency, Feeding Behavior, Carcass Traits, and Net Revenue in Angus-Based Composite Steers. (December 2011)

Joel Timothy Walter, B.S., Iowa State University

Chair of Advisory Committee: Dr. Gordon E. Carstens

The objectives of this study were to evaluate the effects of residual feed intake classification on performance, feed efficiency, feeding behavior and carcass traits, and to determine the relative importance of individual performance and carcass measurements on between-animal variation in net revenue of feedlot steers. Performance, feed intake and feeding behavior traits were measured in 508 Angus-based composite steers, using the GrowSafe feed-intake measurement system, while fed a high-grain diet for 70 days. Residual feed intake was computed as actual minus expected dry matter intake derived from regression of DMI on average daily gain and mid-test $BW^{0.75}$, and steers classified into low (n = 150), medium (n = 200) and high (n = 158) RFI groups. Following the feed-intake measurement periods, steers were fed the same diet in group pens and harvested at an average backfat thickness of 1.14 cm. Net revenue was calculated as carcass value minus feeder calf, yardage, and feed costs using 3-year average prices. Feed cost was based on actual feed consumed during the feed-intake measurement periods, and model-predicted intake adjusted for RFI during the group-feeding periods.

Steers with low RFI had $48/hd lower ($P < 0.0001$) feed cost, $16/hd numerically higher ($P = 0.29$) carcass value, and $62/hd more favorable ($P < 0.0001$) net revenue compared to their high-RFI counterparts. Net revenue was correlated with carcass weight, marbling score, yield grade, DMI, ADG, RFI and G:F ratio where animals that consumed more feed, had higher rates of gain and were more efficient had more favorable net returns. Models predicting net revenue from performance, carcass quality, and feed efficiency traits accounted for 74% of the between-animal variation in NR. In the base model, that included all traits performance, carcass quality and feed efficiency traits explained 24, 14 and 36%, respectively, of the variation in NR. Results from this study indicate that between-animal variation in net revenue was impacted to a great extent by performance and feed efficiency, rather than carcass quality traits, in Angus-based composite steers based on average 3-year pricing scenarios.

DEDICATION

I would like to dedicate this thesis to my parents who provided endless love and support while I have been so far from home. I would also like to dedicate this work to my grandparents, had it not been for my early experiences on their farm, I would not have become this passionate about working with cattle and agriculture.

ACKNOWLEDGEMENTS

I would like to thank my committee chair, Dr. Carstens, and my committee members, Dr. Anderson and Dr. Sawyer, for their guidance and support needed to further my education and complete this research. I especially thank my friends and co-workers for their help and support during my time here at Texas A&M University. I also need to thank the research center support staff here on campus and also at the McGregor research station for their excellent help during our numerous projects. I also want to recognize Lisa Slay and Candice Moore for their organization and help on all of our projects.

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CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

As feed prices approach record highs and feeder calf supplies reach recent historical lows, beef producers will need to adopt management strategies to improve production, and minimize market risk in order to maintain economically viable beef production systems. Net revenue is the difference between costs of production inputs and the value of production outputs. One strategy to minimize risk is to hedge prices for corn, feeder cattle and fed cattle on the Chicago Mercantile Exchange. Another strategy for reducing producer risk is to select animals that have reduced input costs without compromising product outputs or quality (e.g., improve feed efficiency).

Selecting animals that have more favorable feed efficiencies is one way of reducing feed costs and therefore the costs of inputs for a production system are reduced. Only 25-30% of total feed consumed by the breeding herd is used to support growth, gestation and lactation requirements, with other 70-75% used to support maintenance energy requirements of cows (Ferrell and Jenkins, 1985). Excluding purchase price, feed cost is the largest variable costs of beef production systems. Thus, favorable changes in feed efficiency while maintaining performance levels could significantly reduce the inputs to a production system and increase net revenue (Arthur et al., 2001a).

One method of measuring feed efficiency is gain to feed ratio, which is the ratio

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of weight gain to feed consumed. G:F has been found to be a moderately (0.24) heritable trait (Bishop et al., 1991) and is widely used to evaluate the effects of diet quality and management practices on production efficiencies in growing and finishing cattle production systems (Carstens and Tedeschi, 2006).

The disadvantage to utilizing G:F as a basis for selection is that it is known to be negatively correlated with average daily gain (ADG) and body weight (BW). Therefore, favorable selection for G:F in growing bulls would lead to an increase in mature cow size and a subsequent increase in feed requirements for the breeding herd (Arthur et al., 2001a).

Arthur et al.(2001a) concluded that the preferred selection trait for genetic improvement of postweaning feed efficiency would be residual feed intake. Residual feed intake was first proposed by Koch et al.,(1963) as an alternative way to measure feed efficiency that is independent of growth traits. Residual feed intake is calculated as the difference between the animal's actual feed intake and its expected feed intake that is needed to meet its requirements for maintenance and growth based on actual body size and ADG. Calculating RFI on individual animals requires measurement of individual animal feed intake, which is time consuming and expensive. In 1990, a Canadian company (GrowSafe®) developed a feed-intake measurement system the uses radio frequency identification (RFID) to record individual animal feeding behavior and feed intake data. Only one animal is allowed to eat from a feedbunk at a given time, and feed disappearance is measured as RFID tags are recorded during each feedbunk visit event.

Residual feed intake is calculated by subtracting the actual intake collected by GrowSafe system from the predicted intake, which is determined by the regression of feed intake on mid-test body weight (MBW) and ADG (Crews et al., 2006). Therefore, RFI is a measure of the variation in feed intake not needed for maintenance and a specific growth rate (Archer et al., 1999). Positive RFI values indicate animals that eat more than expected and are below average for feed efficiency. Negative RFI values indicate animals that eat less than expected and are above average for feed efficiency. Selecting for low RFI has the potential to decrease feed intake without compromising mature size or performance. Heritability estimates for RFI in beef cattle range from 0.16 to 0.43, which indicates that this trait is moderately heritable (Herd et al., 2003).

Selecting animals for low RFI could have a substantial impact on reducing feed costs and improving net revenue. For example, if 2 feeder calves with divergent RFI of -1 and +1 kg/d were compared while fed a ration costing $0.35/kg for 180 days, the difference in feed costs would equal $126 between the 2 steers. Assuming similar initial BW and gains during the 180-d feeding periods, the cost of gain would be substantially lower for the steers with the -1 kg/d RFI.

While RFI may be one way for producers to select for better animal performance there are many other factors that have an impact on net revenue. Net returns to producers are very volatile over time. From 1981 to 1990 monthly average returns to a yearling steer feeding program in Kansas ranged from losses of $118 to profits of $170 per head (Langemeier et al., 1992). These drastic net revenue differentials are the result of substantial variability in input costs, feeder and fed cattle prices and cattle performance.

Past investigations into factors affecting profitability of feedlot cattle have evaluated 2 components of net revenue: (1) gain per head attributable to price changes from the time of purchase to the time of sale, and (2) net returns associated with the increase in weight times the difference in the sale price per pound and the feed cost per pound of gain (Heady and Jensen, 1954). Swanson and West (1963) noted that allocating returns to the animal's price margin and the feed margin provides the impression that net returns to feedlot cattle enterprises are mainly explained by these two factors. They proposed using coefficients of separate determination as defined by (Wright, 1921) to statistically estimate the importance of the buying and selling operation versus factors affecting performance of the feeding operation. Using this method and data from the Illinois Farm Bureau Farm Management Service records, they determined that 82% of the total variation in net returns to cattle feeding enterprises, could be accounted for, with 38 and 44% of the variation attributed to the price margins and costs per pound of gain, respectively.

Edwards et al. (1989) conducted a similar study explaining the effects of facility, feed, labor, operating and health costs, sale prices and reproductive performance on net returns to farrow-to-finish hog operations in Iowa. They determined that facility and feed costs were the 2 most critical factors affecting variation in net returns between operations. These authors also concluded that most of the factors evaluated in their studies can have a significant impact on net returns to an operation.

In a study conducted by Langemeier et al. (1992), data from 2600 pens (540,000 head) of steers and 700 pens (132,000 head) of heifers were analyzed to estimate the quantitative impacts of price and performance variables on net returns to feedlot cattle enterprises. Price of fed steers had the largest effect on net returns, with feeder calf and corn prices having the next largest effects on net returns. These authors concluded that interest rates, feed conversion and ADG had considerably less influence on net returns per head compared to fed cattle, feeder calf and corn prices. Langemeier et al. (1992), demonstrated that as placement weights increased the impact of ADG on profit also increased. When comparing heifers and steers, differences in sale prices, feeder prices, G:F, and ADG explained 86 and 87% of the variability in net returns, respectively. Fed cattle price was found to explain the most variation in net returns, followed by G:F and feeder calf price.

Closeout data for over 14,000 pens of cattle finished in western Kansas from January 1980 through March 1997 were examined to determine how profitability varied across sex, placement weight and placement month (Mark et al., 2000). Standardized beta coefficients provide useful comparisons of the impact of variability of the independent variables (feeder price, fed price, corn price, interest rate, feed conversion, and ADG) on the dependant variable (net returns per head). This study found similar results as Langemeier et al. (1992) in that fed cattle and feeder steer price had the largest impact to variation in net returns. Corn price, interest rate, feed conversion, and ADG all had smaller effects on net returns. In order to minimize market risk exposure Mark et al. (2000) concluded that producers should focus on managing fed and feeder cattle prices; the two factors that have historically contributed most to variation in net returns to cattle feeding operations. While G:F affects profitability more in fed heifers than steers, ADG had slightly more influence on profitability in steers than heifers (Mark et al., 2000). This finding agrees with Langemeier et al.(1992).

Schroeder and Gaff, (2000) compared the impact of live weight, dressing percentage and grid pricing on carcass value using a data set involving almost 12,000 carcasses. In comparing live weight and dress weight pricing with grid-formula based prices, high-quality cattle subsidized low-quality cattle by almost $30 dollars per head. As a general rule: (1) low quality cattle with low dressing percentage will receive a higher price with live weight pricing, (2) low quality but heavy cattle should receive a better price if sold on a dressed basis and (3) grid pricing will provide the best price recognition for high quality cattle that are not excessively heavy or light (Schroeder and Graff, 2000).

Pyatt et al. (2005b) evaluated factors affecting carcass value and profitability in early-weaned Simmental steers, considering dressed-beef price, choice-select spread, and feed costs. The variation in choice-select spread, feeder calf and fed cattle prices, corn price, interest rate, G:F, and ADG explained 90% of the variation in net returns per head. Pricing factors alone accounted for almost 80% of the variation (Mark et al., 2000). Pyatt et al.(2005b) concluded that variation in G:F and DMI accounted for only 2-3% more variation in net returns than feeder calf, fed cattle and corn prices. However, the authors suggested that biological cattle type may affect the variation in net returns explained by differences in G:F and DMI. When evaluations across all dressed beef price levels were considered, ADG, DMI and G:F responded in a modest nonlinear manner when accounting for profit variation as feed prices increase (Pyatt et al., 2005b).

The objectives of this study were to evaluate the effects of residual feed intake classification on performance, feed efficiency, feeding behavior and carcass traits, and to determine the relative importance of individual performance and carcass measurements on between-animal variation in net revenue of feedlot steers. We will also look at the sensitivity of carcass and performance traits in explaining net revenue as dressed beef price, choice-select spread and ration costs change.

CHAPTER II

CHARACTERIZATION OF FEED EFFICIENCY TRAITS IN ANGUS-BASED COMPOSITE STEERS AND RELATIONSHIPS WITH PERFORMANCE, ULTRASOUD CARCASS COMPOSITION, AND FEEDING BEHAVIOR TRAITS

Introduction

Excluding purchase price, feed cost is the largest variable cost of beef production systems. Thus, favorable changes in feed efficiency could significantly reduce the costs of inputs, and consequently increase net revenue returns to beef production systems (Arthur et al., 2001a). The traditional method of measuring feed efficiency has been G:F. However, selection for G:F leads to an increase in mature body size and an increase in feed requirements of the cow-calf herd as this trait is highly correlated genetically to growth traits (Arthur et al., 2001a). Efficiency traits that will improve feed utilization without increasing mature size or negatively impacting carcass quality or reproductive traits are needed to use for selection parameters in the beef cattle industry.

Residual feed intake (RFI) has been used recently as an alternative measure of feed efficiency in growing cattle. Advantages to RFI are that it is moderately heritable (Arthur et al., 2001a; Crowley et al., 2010; Herd et al., 2003) and independent of both body weight and gain, which are included in the regression model to estimate RFI (Koch et al., 1963). Steers with low-RFI have been shown to consume 15-20% less feed than high-RFI steers despite having similar body weights and growth rates (Carstens and Tedeschi, 2006). Several studies have evaluated relationships between RFI and carcass composition traits in growing cattle (Arthur et al., 2001a; Lancaster et al., 2009; Nkrumah et al., 2004). These studies demonstrated that residual feed intake was weekly correlated (0.14 to 0.25) with measures of 12^{th} rib fat thickness, but not with LMA or intramuscular fat measurements. Residual gain efficiency is calculated by regressing ADG on feed intake and body weight (Crowley et al., 2010), thus, improved RGE is, on average, associated with faster growth rates, but is not associated with differences in feed intake. In principal it is similar to the calculation for RFI.

Several studies, (Basarab et al., 2007; Bingham et al., 2009; Nkrumah et al., 2007) have evaluated the relationships between feeding behavior traits and feed efficiency in beef cattle. Objective measurement of feeding behavior traits in large groups of animals has become easier with advancements in radio frequency identification (RFID) based technologies. Feeding behavior traits (e.g., bunk visit; frequency and duration) have been found to be weakly to moderately correlated with RFI (Lancaster et al., 2009; Nkrumah et al., 2007) and accounted for 35% of the variation in feed intake that was not accounted for by ADG and MBW (Lancaster et al., 2009). The use of feeding behavior traits as an indicator of efficiency could provide insight to the biological variation in RFI, as well as, lower the cost associated with measuring feed efficiency.

The objectives of this study were to characterize feed efficiency traits and examine the phenotypic correlations with performance, ultrasound carcass composition and feeding behavior traits in growing Angus-based composite steers.

Materials and Methods

Animals and Experimental Design

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

Five-hundred-eight Angus cross steers from the Rex Ranch (Ashby, NE), with an initial BW of 310 ± 56 kg and age of 290 ± 16 d were used in this study. Data was collected during 3 trials, with each trial occurring in the late winter for 3 consecutive years. Upon arrival, cattle were fitted with passive, half-duplex transponder ear tags (Allflex USA Inc., Dallas, TX) and randomly assigned to 2 pens equipped with 10 electronic feedbunks (GrowSafe System LTD., Airdrie, AB, Canada), at the McGregor Research Center (McGregor, TX). Prior to each trial, calves were adapted to a high grain diet (Table 2.1) for 28 d. Thereafter, steers were fed ad libitum for 70, 70, and 77 d, respectively, and individual feed intake and feeding behavior data was collected.

The GrowSafe System

The GrowSafe system (DAQ 4000E) used in this study consisted of feedbunks equipped with load bars to measure feed disappearance, and stanchions with neck bars to prevent more than one animal from eating from the feedbunk at a given time. Antenna within each feedbunk detected animal presence by recording the radio-frequency identification tags upon entry to a feedbunk. Feed intake was allocated to each individual animal based on continuous recordings of feed disappearance during each BV event. Along with individual feed intake data, the system also recorded each bunk visit, the

Table 2.1. Steer diet ingredient and chemical analysis.

Item	
Ingredient	*As-fed basis %*
Dry rolled corn	73.7
Chopped sorgum-sudan hay	6.0
Cottonseed meal	6.0
Cottonseed hulls	6.0
Molasses	5.0
Mineral Premix[a]	2.5
Urea	0.8
Chemical Composition	*Dry matter basis*
Dry matter %	90.2
CP, %DM	12.6
NDF, %DM	20.3
ME, Mcal/kg DM	3.0

[a]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 Tylan.

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 3 s.

Data Collection

A subroutine of the GrowSafe 4000E 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, with the exception of the parameter setting for maximum duration of time between consecutive EID recordings to end an uninterrupted BV event. For this study, the parameter setting of 100 s was used as recommended by Mendes et al. (2011). Feeding behavior data from a total of 9, 3, and 15 d for trials 1, 2, and 3 respectively were omitted from all analyses due to system failure (power outage, equipment malfunction), system maintenance, or when the proportion of daily feed supply assigned to individual animals (average feed disappearance) was less than 95%. Average feed disappearance for the three trials was 98.5%, 98.7%, and 97.3%, respectively.

Cattle were weighed at 14-d intervals and ultrasound measurements of subcutaneous fat depth, intramuscular fat, and LMA were collected on days 0 and 70 of the trial by a certified technician who used an Aloka 500-V instrument with a 17-cm, 3.5-MHz transducer (Corometrics Medical Systems Inc., Wallingford, CT). Images were then sent to the Centralized Ultrasound Processing laboratory (Ames, IA) for estimation of 12th rib fat thickness (**BF**), longissimus muscle area and percent intramuscular fat (**IMF)**.

Diet samples were collected weekly and composited by weight at the end of each trial. Moisture analysis was conducted by drying in a forced-air oven for 48 h at 105°C and chemical analysis was conducted by an independent laboratory (Cumberland Valley

Analytical Services Inc., Hagerstown, MD). Metabolizable energy concentration of the experimental diet was computed using the Large Ruminant Nutrition System (http://nutritionmodels.tamu.edu/lrns.htm) which is based on the Cornell Net Carbohydrate and Protein System.

Computations

Growth rates of individual steers were modeled by linear regression of BW on day of test using the general linear model of SAS (SAS Inst., Cary, NC). These regression coefficients were used to compute initial and final BW and ADG. Metabolic BW (MBW; mid-test $BW^{.75}$) was then computed as the average of initial and final BW raised to the 0.75 power. Moisture analyses of the diet ingredient samples were used to compute average daily DMI from feed intake data.

Gain:feed ratio was calculated as the ratio of daily DMI to ADG. Residual feed intake was computed as actual DMI minus expected DMI to meet growth and maintenance energy requirements (Koch et al., 1963). Expected DMI was derived from linear regression of DMI on MBW and ADG using the mixed procedure of SAS with year as a random effect. Residual gain efficiency was assumed to represent the residual from a multiple regression model regressing ADG on DMI and MBW with year as a random effect, as proposed by Koch et al.(1963).

Feeding behavior data were based on in-to-out events to the feedbunk (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., 2011).

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 frequency, meal duration, and meal size (Figures 2.1 and 2.2).

Statistical Analysis

All performance, feed efficiency, ultrasound measurements, and feeding behavior traits were adjusted to remove the random effect of trial by using the mixed procedure in SAS. Dependent variables were analyzed using a one-way random-effect treatment structure with trial as a random effect and an adjusted variable computed as the overall mean plus the residual. Phenotypic Pearson correlation coefficients using the PROC CORR command of SAS were generated among the adjusted performance, feed efficiency, ultrasound measurements and feeding behavior traits.

Stepwise regression (PROC REG; SAS Inst., Cary, NC) was used to determine the order of inclusion of ultrasound carcass composition traits in the base model which includes ADG and MBW. To evaluate the relationship between feeding behavior traits and RFI, all feeding behavior traits were added to the carcass-adjusted regression that included ADG, MBW and ultrasound traits. To characterize RFI, steers were ranked into three classification groups: low (< 0.5 SD), medium (± 0.5 SD), and high (> 0.5 SD). Data were analyzed using the PROC MIXED command in SAS. Least squares means comparisons between RFI groups were generated using the Tukey post hoc test.

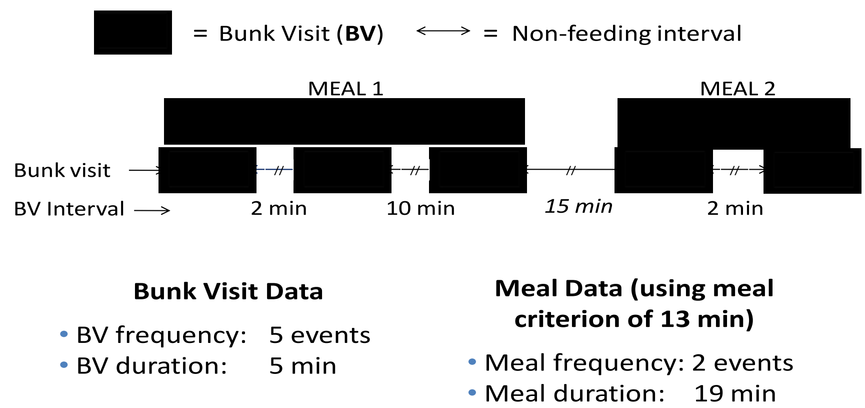

Figure 2.1. Feeding behavior definitions scheme

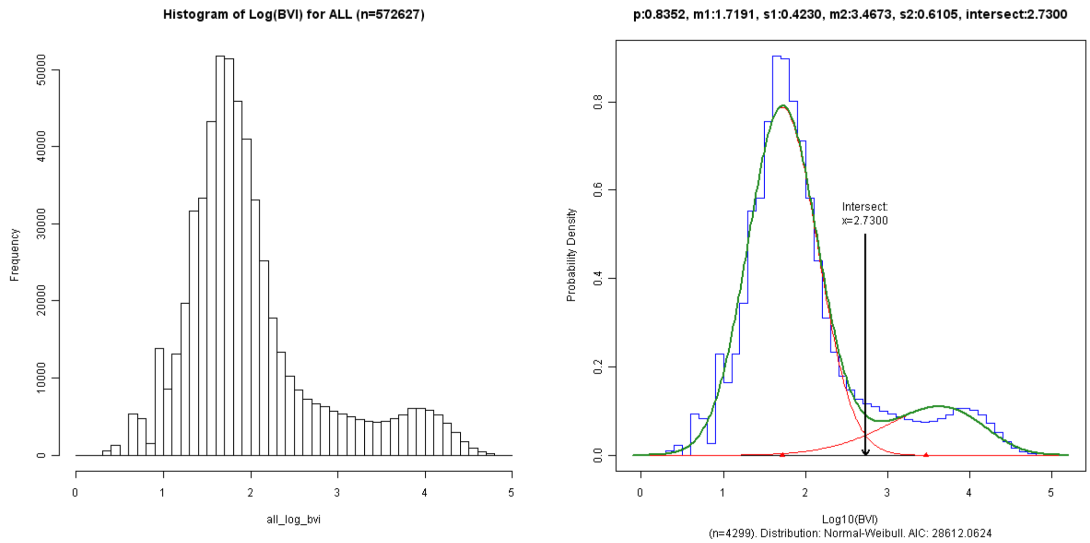

Figure 2.2. a) Histogram of $\log_{10}$-transformed non-feeding intervals. Intervals less than 2 s have been removed. *b*) Graphical representation of the G-W combination with a bin width of 0.1 $\log_{10}$ units. Intervals less than 2 s have been removed.

Results and Discussion

Summary statistics are presented in Table 2.2 for the 3 performance studies. The initial age of the steers averaged 290 ± 16 d across the 3 studies and ranged from 277 d in year 3 to 307 d in year 1. Three-year averages for ADG, DMI, G:F, and RFI were; 1.69 ± 0.25 kg/d, 10.5 ± 1.30 kg/d, 6.36 ± 1.35, and 0.00 ±0.80 kg/d, respectively. The average DMI was slightly higher for steers in year 1 than in the other 2 years, most likely due to the higher initial age and initial BW of steers in year 1. However, the variation in ADG (CV = 10 to 15%), DMI (CV = 9 to 10%), and G:F (CV = 10 to 14%) were similar across the 3 tests. Similar to the 3- year means found in this study, Herd et al. (2003) reported similar means and SD for DMI (9.2 ± 0.2kg/d) and Feed:gain (7.0 ± 0.2 kg/d) in Angus feedlot cattle. In addition, Schenkel et al.(2004) reported overall means and SD of 1.74 ± 0.26 kg/d, 10.95 ± 1.77 kg/d, 6.11 ± 1.02 kg/d, and 0.00 ± 1.47 kg/d for ADG, DMI, Feed:gain, and RFI, respectively, of growing purebred bulls, which were similar to this study. Overall summary statistics for performance, feed efficiency, carcass ultrasound and feeding behavior traits are given in Table 2.3.

Step-wise regression analysis determined the order of inclusion of ultrasound carcass composition traits which included, initial and final, BF, LMA, and IMF. In this study, the RFI base model (RFIp) was adjusted for final BF carcass ultrasound trait (RFIc) which accounted for the largest increase in variation in DMI beyond ADG and MBW (0.42 to 0.46; Table 2.4). Inclusion of carcass fat traits as independent variables has been reported to account for more variation in DMI by Basarab et al. (2003) and Lancaster et al. (2009). The additional increase in the R^2 in these studies ranged from 2 to 4%, slightly less than the

Table 2.2. Summary statistics (±SD) of performance, feed efficiency, ultrasound composition, and feeding behavior traits for Angus-based composite steers.

Trait[a]	Year 1	Year 2	Year 3
No. of steers	170	168	170
Performance traits			
Initial age, days	307.7 ± 9.6	284.4 ± 8.9	277.5 ± 9.5
Initial BW, kg	378.8 ± 29.7	273.9 ± 20.4	277.0 ± 26.9
Final BW, kg	483.7 ± 35.8	397.2 ± 33.2	416.2 ± 35.9
ADG, kg/d	1.50 ± 0.23	1.76 ± 0.22	1.81 ± 0.187
DMI, kg/d	11.60 ± 1.11	9.82 ± 1.03	10.01 ± 1.01
Feed efficiency traits			
G:F	0.13 ± 0.02	0.18 ± 0.02	0.18 ± 0.02
RFIp, kg/d	0.00 ± 0.82	0 .00± 0.780	0.00 ± 0.763
RFIc, kg/d	0.00 ± 0.82	0 .00± 0.801	0.00 ± 0.723
RGE, kg/d	0.00± 0.19	0.00 ± 0.182	0.00 ± 0.143
Carcass ultrasound traits			
Initial LMA, cm^2	58.52 ± 6.02	48.79 ± 5.43	48.33 ± 4.69
Initial BF thickness, cm	0.603 ± 0.169	0.32 ± 0.05	0.245 ± 0.093
Initial IMF, %	3.31 ± 0.511	2.81 ± 0.458	2.40 ± 0.510
Final LMA, cm^2	70.56 ± 6.91	62.71 ± 6.62	64.30 ± 7.22
Final BF thickness, cm	0.880 ± 0.223	0.612 ± .133	0.652 ± 0.236
Final IMF, %	3.60 ± 0.573	2.93 ± 0.667	2.90 ± 0.635
Bunk visit traits			
BV frequency, events/d	74.05 ± 12.49	61.15 ± 11.35	45.02 ± 8.22
BV duration, min/d	59.05 ± 12.99	61.58 ± 13.91	66.19 ± 13.3
Meal traits			
Meal frequency, events/d	5.85 ± 2.71	5.42 ± 1.73	4.31 ± 1.07
Meal duration, min/d	132.95 ± 28.15	150.32 ± 33.16	129.44 ± 21.73
Meal criterion, min	14.92 ± 7.80	20.63 ± 10.83	23.08 ± 10.20
Meal length, min/event	26.40 ± 10.65	30.71 ± 12.54	31.74 ± 9.22
Meal size, kg/event	2.24 ± 0.678	1.93 ± 0.571	2.43 ± 0.551
Eating rate, g/min	90.97 ± 20.59	68.31 ± 16.31	79.36 ± 14.92
BV per meal, events/meal	14.15 ± 4.40	12.08 ± 3.57	10.87 ± 2.66

[a]RFIp = residual feed intake from base model; RFIc = residual feed intake from carcass adjusted model; RGE = residual gain efficiency; BF = 12th-rib fat thickness; IMF = intra muscular fat; BV = bunk visit; Meal data was derived from meal criterion calculated from individual data and applying a Gaussian-Weibull bimodal model.

Table 2.3. Summary statistics for performance, feed efficiency, ultrasound composition, and feeding behavior traits in Angus-based composite steers.(n = 508)

Trait[a]	Mean	SD	Min	Max
Performance traits				
Initial age, days	290	16	251	326
Initial BW, kg	310.1	56.1	219.1	451.8
Final BW, kg	432.5	51.0	326.7	591.8
ADG, kg/d	1.69	0.25	0.66	2.43
DMI, kg/d	10.5	1.3	6.6	14.0
Feed efficiency traits				
G:F	0.16	0.03	0.08	0.27
RFIp, kg/d	0.00	0.80	-3.36	2.38
RFIc, kg/d	0.00	0.77	-2.97	2.48
RGE, kg/d	0.00	0.17	-0.53	0.56
Carcass ultrasound traits				
Initial LMA, cm^2	51.9	7.16	32.9	76.1
Initial BF thickness, cm	0.39	0.19	0.13	1.14
Initial IMF, %	2.84	0.62	1.25	5.26
Final LMA, cm^2	65.9	7.70	46.4	96.1
Final BF thickness, cm	0.72	0.23	0.23	1.68
Final IMF, %	3.15	0.70	1.35	5.14
Bunk Visit traits				
BV frequency, events/d	60.1	16.1	19.3	105.9
BV duration, min/d	62.2	13.7	27.6	105.8
Meal traits				
Meal frequency, events/d	5.19	2.06	2.41	21.9
Meal duration, min/d	137.5	29.4	70.2	240.6
Meal criterion, min	19.5	10.3	0.89	82.6
Meal length, min/event	29.6	11.1	4.97	91.8
Meal size, kg/event	1.44	0.50	0.55	4.64
Eating rate, g/min	79.6	19.7	41.4	179.5
BV per meal, events/meal	12.4	3.85	3.06	29.1

[a]RFIp = residual feed intake from base model; RFIc = residual feed intake from carcass adjusted model; RGE = residual gain efficiency; BF = 12^{th}-rib fat thickness; IMF = intra muscular fat; BV = bunk visit; Meal data was derived from meal criterion calculated from individual data and applying a Gaussian-Weibull bimodal model.

Table 2.4. Variation in residual feed intake (RFI) base model (BM) R^2 with additional carcass ultrasound and feeding behavior traits for Angus-based composite steers.

Trait[a]	R^2	Additional Increase
RFIp Base Model (BM; ADG and MBW)	0.42	
Ultrasound		
RFI BM + Final LMA	0.42	0.00%
RFI BM + Final IMF	0.42	0.00%
RFI BM + Final BF	0.46	6.89%
Feeding Behavior		
RFI BM + BV frequency	0.53	18.97%
RFI BM + BV duration	0.60	31.03%
RFI BM + BV frequency and duration	0.63	36.20%

[a]RFIp = residual feed intake from base model; RFIc = residual feed intake from carcass adjusted model; BF = 12th-rib fat thickness; IMF = intramuscular fat; BV = bunk visit.

current study, which found an increase of 6.9%. The reduction in SD of RFI after inclusion of the ultrasound traits in this study (0.80 vs. 0.77 kg/d for RFIp and RFIc, respectively) was similar to previous studies by Basarab et al. (2003; 0.66 vs. 0.62 kg/d) in growing steers and Schenkel et al. (2004; 1.47 vs. 1.45 kg/d) in growing bulls. Lancaster et al. (2009) reported a larger (0.78 vs. 0.72 kg/d) reduction in SD of RFI than what was observed in this study.

Results from earlier studies done by (Basarab et al., 2003; Lancaster et al., 2005) reported rank correlations of 0.87 and 0.92 respectively between the phenotypic RFI base model and the base RFI model adjusted for carcass traits in finishing steers. In the current study Pearson and Spearman rank correlation coefficients between RFI p and RFIc were 0.96 and 0.98, respectively. More recently, Lancaster et al. (2009) reported rank correlations of 0.92 and 0.91 between the phenotypic RFI base model and a carcass-fat adjusted RFI model in growing Angus bulls.

Phenotypic Correlations between Performance, Feed Intake and Feed Efficiency Traits

The phenotypic correlations between growth and feed efficiency traits are presented in Table 2.5. Dry matter intake was strongly (P <0.50) correlated with ADG (0.49), initial BW (0.53) , and final BW (0.62); while theses correlations were numerically lower compared with previous studies (Lancaster et al., 2009; Nkrumah et al., 2007), moderate to strong correlations were found among all 5 efficiency traits measured in this study. Dry matter intake was strongly correlated with both RFIp and RFIc traits, 0.76 and 0.73 respectively, and RFIp and RFIc were independent of ADG and initial BW, such that steers with a lower RFIp consumed 16% less (P < 0.01) DMI than steers with higher RFIp,

Table 2.5. Phenotypic Pearson correlations between performance, feed intake, and feed efficiency traits in Angus-based composite steers. (n = 508)

Trait[a]	ADG	DMI	G:F	RGE	RFIp	RFIc
Initial BW	0.27[b]	0.53[b]	-0.17[b]	-0.22[b]	-0.02	-0.01
ADG		0.49[b]	0.64[b]	0.83[b]	0.00	0.00
DMI			-0.35[b]	0.00	0.76[b]	0.73[b]
G:F				0.88[b]	-0.66[b]	-0.64[b]
RGE					-0.27[b]	-0.26[b]
RFI_p						0.96[b]

[a]; RGE = residual gain efficiency; RFIp = residual feed intake from base model; RFIc = residual feed intake from carcass adjusted model.
[b]Correlations are different from zero at $P < 0.05$

even though ADG is similar across RFI classification groups (Table 2.6). This result is expected because the use of linear regression to compute RFI forces the trait to be phenotypically independent of its component traits. A recent study by Lancaster et al. (2005) reported low-RFI calves consumed 15% less feed than high-RFI calves. Several previous studies also found RFI to be positively correlated with DMI but independent of growth and body size (Arthur et al., 2001a; Arthur et al., 2001b; Herd et al., 2003; Lancaster et al., 2009; Nkrumah et al., 2007). Both RFIp and RFIc were moderately correlated in a negative manner with RGE, -0.27 and -0.26 respectively; steers with lower RFIp had greater ($P < 0.01$) residual gain compared to steers with higher RFIp. Average daily gain and G:F showed a strong correlation (0.65) which is consistent with correlations reported previously (Arthur et al., 2001a; Lancaster et al., 2009; Nkrumah et al., 2004). These correlations suggest that applying selection pressure against G:F will increase mature body size and growth rate, causing an increase in feed requirement. Lancaster et al. (2009) reported slightly weaker correlations with Feed:gain, RFIp and RFIc of 0.49 and 0.45 respectively, and an 18.1% difference in Feed:gain between low and high RFI animals. Likewise, in the current study G:F had a strong negative correlation with both RFIp and RFIc, -0.66 and -0.64, respectively; low-RFI steers had a 15% more favorable G:F when compared to high-RFI steers. This compared well with Nkrumah et al. (2004), who reported a correlation of 0.62 between RFIp and Feed:gain. RGE showed a strong correlation (0.88) with G:F such that selection against both RFI traits and RGE would be beneficial to improving feed efficiency and gain of animals with minimal effect on growth traits.

Table 2.6. Effects of RFI classification on performance, feed efficiency, and carcass ultrasound traits in Angus-based composite steers.

Trait*	Low RFI	Medium RFI	High RFI	SE	P-value
No. of steers	150	200	158	-	-
Performance traits					
Initial age, days	290	290	289	9	0.39
Initial BW, kg	310.6	310.9	307.9	34.6	0.53
Final BW, kg	433.0	433.7	429.9	26.3	0.58
ADG, kg/d	1.69	1.69	1.68	0.09	0.90
DMI, kg/d	9.55[a]	10.5[b]	11.3[c]	0.57	0.0001
Feed efficiency traits					
G:F	0.18[a]	0.16[b]	0.15[c]	0.02	0.0001
RFIp, kg/d	-0.931[a]	-0.007[b]	0.903[c]	0.031	0.0001
RFIc, kg/d	-0.854[a]	-0.019[b]	0.852[c]	0.03	0.0001
RGE, kg/d	0.054[a]	0.001[b]	-0.053[c]	0.018	0.0001
Carcass ultrasound traits					
Initial LMA, cm^2	52.3	52.0	51.2	3.34	0.19
Initial BF thickness, cm	0.372	0.396	0.400	0.110	0.04
Initial IMF, %	2.86	2.83	2.84	0.26	0.80
Final LMA, cm^2	66.5	65.9	65.2	2.4	0.22
Final BF thickness, cm	0.648[a]	0.73[b]	0.76[b]	0.085	0.0001
Final IMF, %	3.03[a]	3.15[ab]	3.25[b]	0.23	0.01
Bunk Visit traits					
BV frequency, events/d	54.0[a]	61.8[b]	70.8[c]	2.0	0.0001
BV duration, min/d	54.7[a]	59.6[b]	65.9[c]	8.4	0.0001
Meal traits					
Meal criterion, min	21.3[a]	19.3[ab]	18.2[b]	2.5	0.02
Meal frequency, events/d	4.86[a]	5.25[ab]	5.44[b]	0.48	0.03
Meal duration, min/d	129.0[a]	136.27[b]	147.6[c]	6.8	0.0001
Meal length, min/event	29.2	29.1	30.7	1.3	0.33
Meal size, kg/event	2.12[a]	2.2[ab]	2.31[a]	0.14	0.02
Eating rate, g/min	77.4	80.7	80.1	6.6	0.120
Ratio traits					
BV per meal, events/meal	11.9[a]	12.2[a]	13.1[b]	0.97	0.007

*RFIp = residual feed intake from base model; RFIc = residual feed intake from carcass adjusted model; RGE = residual gain efficiency; BF = 12^{th}-rib fat thickness; IMF = intra muscular fat; BV = bunk visit; Meal data was derived from meal criterion calculated from individual data and applying a Gaussian-Weibull bimodal model.

[a,b,c] Means within a row without a common superscript differ ($P < 0.05$).

Phenotypic Correlations between Feed Efficiency and Ultrasound Carcass Composition Traits

In this study, LMA and BF ultrasound traits were weakly to moderately correlated with both ADG and DMI (Table 2.7). Nkrumah et al. (2004) and Schenkel et al. (2004) reported weak to moderate correlations of BF and LMA with ADG and DMI in finishing steers and growing bulls, respectively. Lancaster et al. (2009) conducted a study with growing bulls and found LMA and BF to be moderately correlated (> 0.35) with ADG and DMI. Final BF was weakly correlated with G:F RGE and RFIp (-0.19, -0.09 and 0.26, respectively) such that more efficient steers were leaner. Gain in BF was weakly correlated with RFIp (0.24) such that steers with low RFIp gained 23% less ($P < 0.05$) BF during the test than steers with high RFIp. Lancaster et al. (2009) reported a slightly stronger correlation with gain in BF and RFIp (0.30) in his study with growing bulls, and found low RFIp bulls gained 34% less BF than their high-RFI counterparts. Other research in growing bulls (Arthur et al., 2001a; Lancaster et al., 2009; Schenkel et al., 2004) and steers (Basarab et al., 2003; Nkrumah et al., 2004) also reported weak correlations between ultrasound carcass fat traits, Feed:gain, and RFIp. The current study showed similar results to a study performed by Basarab et al. (2003), who reported that inclusion of change in carcass fat traits during the test in an adjusted model to compute expected DMI (RFIc) resulted in a lack of correlation between final carcass fat and RFIc. Lancaster et al. (2009) also reported no correlation with carcass ultrasound traits and RFIc.

Table 2.7. Phenotypic correlations between performance, feed efficiency, and carcass ultrasound composition traits in Angus-based composite steers (n = 508).

Traits[a]	ADG	DMI	G:F	RGE	RFIp	RFIc
Initial composition trait						
12th-rib fat thickness, cm	-0.09[b]	0.16[b]	-0.24[b]	-0.22[b]	0.14[b]	-0.03
LMA, cm^2	0.04	0.18[b]	-0.12[b]	0.16[b]	-0.04	-0.05
Intramuscular fat, %	0.08[b]	-0.02	0.10[b]	0.10[b]	-0.05	-0.05
Final composition trait						
12th-rib fat thickness, cm	0.11[b]	0.35[b]	-0.19[b]	-0.09[b]	0.26[b]	-0.00
LMA, cm^2	0.26[b]	0.28[b]	0.02	0.00	-0.07	-0.05
Intramuscular fat, %	0.08	0.17[b]	-0.06	-0.01	0.13[b]	0.05
Gain in composition trait						
12th-rib fat thickness, cm	0.20[b]	0.34[b]	-0.08	0.03	0.24[b]	0.01
LMA, cm^2	0.30[b]	0.18[b]	0.16[b]	0.17[b]	-0.05	-0.01
Intramuscular fat, %	0.01	0.19[b]	-0.14[b]	-0.09[b]	0.16[b]	0.01

[a]F:G = feed to gain ratio; RGE = residual gain efficiency; RFIp = residual feed intake from base model; RFIc = residual feed intake from carcass adjusted model.
[b]Correlations are different from zero at ($P < 0.05$).

Final LMA showed no significant correlation with G:F, REG, or RFIp. These results agree with previous research that reported non-significant correlations (-0.10 to 0.09) between final LMA and RFIp (Arthur et al., 2001a; Lancaster et al., 2009; Nkrumah et al., 2004; Schenkel et al., 2004). Gain in LMA was weakly correlated with G:F and RGE such that more efficient steers had higher gains in carcass ultrasound LMA. A lack of correlation between gain in ultrasound LMA and RFIp in finishing steers was reported by Basarab et al. (2003). In this study, steers with low RFIp had similar final LMA and gain in LMA during the test compared to steers with high RFIp.

Final IMF was weakly correlated (0.13) with RFIp, but not G:F or RGE such that more efficient steers had less IMF, additionally, gain in IMF was weakly correlated with G:F, REG, and RFIp (-0.14, -0.09, and 0.16, respectively), with more efficient animals gaining less IMF during the study. Studies done by Nkrumah et al. (2004) and Schenkel et al. (2004) reported no significant correlation of final IMF with Feed:gain or RFIp in growing steers or bulls, respectively. However, Basarab et al.(2003) and Nkrumah et al. (2007) did find positive correlations between carcass ultrasound IMF and RFIp in growing steers, which is similar to the current study.

Feeding Behavior Phenotypic Correlations and RFI Classification Evaluation

Phenotypic correlations between performance, feed efficiency, and feeding behavior traits are summarized in Table 2.8 and the differences in feeding behavior traits between steers with divergent RFI phenotypes are presented in Table 2.6.

Table 2.8. Phenotypic correlations between performance, feed efficiency, and feeding behavior traits in Angus-based composite steers (n = 508).

Traits[a]	ADG	DMI	G:F	RGE	RFIp	RFIc
Bunk visit traits						
BV frequency, events/d	-0.02	0.25[a]	-0.23[a]	-0.05	0.44[a]	0.41[a]
BV duration, min/d	0.06	0.41[a]	-0.30[a]	-0.06	0.56[a]	0.55[a]
Meal traits						
Meal criterion, min/d	0.18[a]	0.09[a]	0.19[a]	0.16[a]	-0.14[a]	-0.10[a]
Meal frequency, events/d	-0.03	0.04	-0.07	-0.03	0.12[a]	0.09[a]
Meal duration, min/d	0.15[a]	0.24[a]	-0.04	0.11[a]	0.28[a]	0.28[a]
Meal length, min/d	0.09[a]	0.10[a]	0.00	0.05	0.06	0.09[a]
Meal size, kg/event	0.20[a]	0.32[a]	0.08	0.00	0.15[a]	0.18[a]
Eating rate, g/min	0.08	0.25[a]	-0.13[a]	-0.10[a]	0.10[a]	0.08
BV per meal, events/meal	0.01	0.11[a]	-0.10[a]	-0.03	0.15[a]	0.16[a]

[a] RGE = residual gain efficiency; RFIp = residual feed intake from base model; RFIc = residual feed intake from carcass adjusted model; BV = bunk visit; Meal data was derived from meal criterion calculated from individual data and applying a Gaussian-Weibull bimodal model.
[b]Correlations are different from zero at ($P < 0.05$).

Bunk visit frequency and duration were both similarly correlated with RFIp and RFIc such that steers classified as low RFI visited the feed bunk 24% less frequently and spent 17% less time at the bunk than high RFI steers. Nkrumah et al. (2007) also found that more efficient animals spent 24% less time at the feedbunk and visited the feedbunk 14% less than their lees efficient counterparts. Bunk visit frequency was moderately correlated with RFIp and RFIc (.44 and .41 respectively), this is a stronger relationship than reported by Nkrumah et al. (2007; 0.18), but similar to Montanholi et al.(2010) and Kelly et al. (2010) who reported correlations of 0.35 and 0.45, respectively. Bunk visit duration was correlated 0.56 and 0.55, with RFIp and RFIc, respectively. This is higher than reported by Montanholi et al. (2010; 0.24) but similar to Nkrumah et al. (2007; 0.49). It has been reported that pigs classified for low RFI visited the feeder less frequently than high RFI pigs (de Haer et al., 1993). Bunk visit frequency was weakly correlated (0.24) with DMI in this study, while, bunk visit duration was found to be moderately correlated (0.41) with DMI.

In the current study bunk visit frequency (60.1 events/d) was higher than previous studies (Basarab et al., 2007; Nkrumah et al., 2006), but similar to Kelly et al. (2010) who reported ranges of 53.4 to 68.1 bunk visits per day. Bunk visit duration (62.2 min/d) was similar with Nkrumah et al. (2007; 2006) but much lower than results reported by Kelly et al. (2010; 116min/d). This indicates that bunk visit duration is a better predictor of intake than bunk visit frequency.

Evaluation of Meal Traits and RFI Classification

System and methodology differences used to calculate behavioral traits and meal data make comparisons between studies difficult (Tolkamp et al., 2000). Wide variation in meal frequencies and duration found throughout literature, (Bach et al., 2006; Bingham et al., 2009; DeVries et al., 2003) could be explained by the large variation in meal criterion, of 2 to 58.6 min, that was reported by Tolkamp et al. (2000). Variances in meal data could also be caused by differences in diet, bunk management or breed types of cattle.

Meal criterion work done previously in dairy cattle (Bach et al., 2006; DeVries et al., 2003; Tolkamp et al., 2000) applied a 2- population Gaussian distribution model to the non-feeding interval data and reported meal criterion data ranging from 27.7 to 58.6 min. In the current study, a Gaussian-Weibull mixed bimodal distribution model was chosen to fit the non- feeding interval data based on a previous recommendation by Yeates et al. (2001) in dairy cattle. The average meal criterion of 19.54 was lower than studies in dairy cattle which have used the Gaussian-Weibull methodology for meal criterion calculation. Nutrient composition, palatability and physical characteristics of a ration can affect individual animal intake and also affect the short-term feeding behavior of animals (Allen, 2000), this may help explain observed meal criterion differences between beef and dairy cattle.

Meal duration (137.5 ± 29.4 min/d) was slightly longer than reported by Lancaster et al. (2009; 99.5 min/d) in growing bulls, but similar to data reported by De Vries et al. (2009) in growing dairy heifers. Meal frequency (5.19 ± 2.1 events/d) was slightly shorter than frequencies reported in previous literature (DeVries et al., 2003; Lancaster et al., 2009; Tolkamp et al., 2000), this could be due impart to differences in diet and cattle type. While meal frequency was not correlated with ADG or DMI meal duration showed weak to moderate correlation with ADG and DMI (0.16 and 0.24, respectively), eating rate also showed a moderate correlation (0.25) with DMI, corresponding with findings by Lancaster et al. (2009). These relationships indicate that steers with increased ADG and DMI spent more time at the feed bunk and consumed feed at a higher rate.

Meal eating rate in this study (80 g/m) was similar to eating rates reported by Lancaster et al. (2009; 97 g/min) and Bach et al. (2006; 89 to 91 g/min), but higher than results found by Bingham et al. (2009; 42 to 50 g/min) and De Vries et al. (2009; 45 to 57 g/min). Eating rate differences could be due to variation in diet and animal breed type between studies. In this study steers with low-RFI consumed feed at the same rate as steers with high-RFI (Table 2.6) which agrees with Lancaster et al. (2009) but is different from others (Bingham et al., 2009; and Kelly et al., 2010) who found significant ($P < 0.01$) differences in eating rate between low and high RFI phenotypes.

Meal frequency and duration were not correlated with G:F but meal eating rate showed a week correlation (-0.13) with G:F such that less efficient animals consumed feed at a higher rate. Meal duration, meal criterion and meal eating rate were all correlated with REG 0.11, 0.16 and -0.10, restively, such that more efficient steers had greater amounts of time between meals and consumed feed at a slower rate than high-RFI steers. Steers with low RFIp phenotype spent 13% less ($p < 0.01$) total time consuming meals and ate 8% less ($P < 0.05$) feed per meal, while having similar meal lengths and eating rates as steers with high RFIp phenotypes.

In agreement with this study, meal eating rate was not correlated with RFI in cattle (Golden et al., 2008) or pigs (de Haer et al., 1993). Meal duration in calves fed a high-grain diet was positively correlated with RFI (0.29) as well as in dams fed high roughage rations (0.36; Basarab et al., 2007). Phenotypic correlations between RFI and eating rate (0.14), eating time (0.16), and feeding frequency (0.18) were reported by Robinson and Oddy (2004). Correlations in the current study, between RFI, meal frequency and meal duration (0.12 and 0.28, respectively) higher than the correlation between these feeding behavior traits and their relationship with ADG and DMI. This trend corresponds to the study done by Lancaster et al. (2009) in growing bulls. This suggests that the between animal variation in feed intake is more associated with RFI than growth or performance traits, conversely, meal length, meal size and eating rate show stronger relationships with growth and performance traits than with RFI. Both RFIp and RFIc were weakly correlated with the bunk visit per meal ratio trait (0.15 and 0.16, respectively) such that low RFI steers had 9% fewer bunk visits per meal compared to high RFI steers. This is opposite of what was found by de Haer et al. (1993), who found bunk visits per meal to be negatively (-0.33) correlated with RFI in pigs.

Implications

Finding a strategy to identify cattle that require fewer feed inputs without impacting growth or reducing value-determining traits (e.g., carcass composition) could greatly improve the profitability and sustainability of beef production. This study has demonstrated that steers with low RFI phenotype consumed 15% less feed while maintaining similar ADG and final BW compared with high-RFI phenotyped steers. Compared with other feed efficiency traits examined, RFI has considerable potential for use in selection programs due to the fact that this trait is genetically independent of level of production. Although, RFI remains a relatively expensive trait to measure it has been shown to be correlated with feeding behavior. With the advancement of new technologies, like active RFID, to cost-effectively enable measurement of feeding behavior traits, novel strategies to identify more efficient cattle based on between-animal differences in feeding behavior patterns may be developed. Furthermore, these strategies will provide opportunities to explain the relationships between RFI and net returns, to optimize production system profitability.

CHAPTER III

EFFECTS OF RESIDUAL FEED INTAKE CLASSIFICATION ON FEEDLOT PERFORMANCE, FEED EFFICENCY, CARCASS TRAITS AND NET REVENUE ANGUS-BASED COMPOSITE STEERS

Introduction

Profitability in beef cattle production is a function of both inputs and outputs, and as ration and calf costs continue to climb it is important to improve efficiency of input utilization to maintain or increase profitability. Net returns realized by the cattle producer are affected by gender, genetics, growth promotants, health, BW, days on feed, performance, feedstuff and grid prices, end carcass composition, and weather (Mark et al., 2000; Pritchard, 1999). The positive and negative relationships between animal performance and carcass traits result in economic trade-offs that vary across input costs, grid discounts and premiums. As a producer, it is important to understand the relative risk factors that contribute to differences in profit; this understanding will help a producer make more cost-effective decisions regarding management and marketing (Schroeder, 1993).

Residual feed intake first proposed by Koch et al. (1963) is becoming an increasingly more popular way to identify animals for increase efficiency of feed utilization. Steers with low-RFI have been shown to consume 15-20% less feed than high-RFI steers despite having similar body weights and growth rates (Carstens and Tedeschi, 2006), as RFI is a feed efficiency trait that is independent of growth. Residual feed intake has also been shown to have little impact on carcass composition (Arthur et al., 2001a; Lancaster et al., 2009), thus, effectively reducing the inputs without affecting the outputs.

Previous research indicates that price factors outweigh performance and carcass trait variables in explaining between-animal variation in feedlot profit (Lawrence et al., 1999). Mark et al. (2000) reported on results from a model that included, feeder calf, fed cattle, and feed costs, and found that these price factors accounted for more than 90% of the between-pen variation in net revenue of feedlot cattle. Forristall et al. (2002) noted that increasing Choice-Select spread results in increased marbling score influence on net returns. Changing feed costs (±10%) altered the importance of carcass weight on net returns. Coefficients for HCW increased 6.6% at lower prices and decreased 10.7% at higher prices, yet marbling and performance parameters exhibited non-linear changes (Forristall et al., 2002). Few studies have examined the effects of both carcass and performance traits when accounting for between-animal variation in NR of feedlot cattle.

The experimental objectives were 1) to look at the effect of RFI classification on carcass quality and NR, 2) to determine the relative importance of performance, feed efficiency, and carcass merit in explaining variation in profitability using 3-yr average pricing, and 3) evaluate the influence of dressed beef price, Choice-select spread, ration cost, on variation in NR.

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.

Five-hundred-eight Angus cross steers from the Rex Ranch (Ashby, NE), with an initial BW of 310 ± 56 kg and age of 290 ± 16 d were used in this study. Data was collected during 3 trials, with each trial occurring in the late winter for 3 consecutive years. Upon arrival, cattle were fitted with passive, half-duplex transponder ear tags (Allflex USA Inc., Dallas, TX) and randomly assigned to 2 pens equipped with 10 electronic feedbunks (GrowSafe System LTD., Airdrie, AB, Canada), at the McGregor Research Center (McGregor, TX). Prior to each trial, steers were adapted to a high grain diet (Table 2.1) for 28 d. Steers were weighed at 14-d intervals and ultrasound measurements of subcutaneous fat depth, intramuscular fat, and LMA collected on days 0 and 70 of the trial by a certified technician who used an Aloka 500-V instrument with a 17-cm, 3.5-MHz transducer (Corometrics Medical Systems Inc., Wallingford, CT). Thereafter, steers were fed ad libitum for 70, 70, and 77 d, respectively, and individual feed intake and feeding behavior data was collected using an electronic feed intake measurement system (GrowSafe System LTD., Airdrie, AB, Canada). A subroutine of the GrowSafe 4000E software, Process Feed Intakes was used to compute feed intake and feeding behavior data.

Group-Feeding Phase

Following the individual-animal intake-measurement period, steers were moved to pens with concrete fence-line feedbunks. During the group-feeding phase, steers were fed the same diet and weighed at 28-d intervals. Within each year, steers were fed until they reached an estimated backfat depth of approximately 1.14 cm in 2 slaughter groups. Overall, steers were fed for an average of 150 ± 29 d on feed, and harvested at 440 ± 23 d of age.

Carcass Data Collection

Steers were harvested at Sam Kane Beef (Corpus Christi, TX). Animals were stunned via captive bolt pistol, exanguinated, and hot carcass weight measured. Following a 48-h chill (4° C), 12-13th rib fat thickness, longissimus muscle area, kidney, pelvic, and heart fat, and marbling score (**MS**) measurements were obtained by trained university personnel, and used to determine quality grade (**QG**) and calculate yield grade (**YG**).

Prediction of Feed Intake

The Cattle Value Discovery System (**CVDS**) was used to predict individual-animal feed intakes during the group-feeding phase. For each pen, inputs for the model included dietary ME concentration, days on feed, number of animals per pen and pen feed delivery weights. Individual animal performance and carcass data used for model prediction included: sex, breed type (beef or dairy), hide thickness, initial date of feeding period, age, BCS, initial and final BW, yield grade, HCW, BF, marbling class and percentile and LMA. The dynamic iterative growth model of CVDS as described by (Tedeschi et al., 2004) was used to calculate individual animal predicted intakes (DMR).

Weather data, during the months steers were on feed, including temperature, relative humidity, wind speed, and precipitation, were used by the CVDS model to adjust DMR for heat or cold stress.

Model-predicted intakes during the group-feeding periods were adjusted for RFI based on the assumption that relative rank for RFI determined during the 70-day feed-intake measurement period was maintained during the entire feeding period. Arthur et al. (2001b) 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 the length of the measurement period.

Economic Analysis

Three-year average price data were used to determine ration and feeder calf costs, and carcass values to standardize economic factors across years. Ration costs were based on the 3-year (2008-2010) average price for corn, hay, cottonseed meal, cottonseed hulls, urea, mineral premix and molasses of $165, $123, $339, $110, $499, $1009, and $215 /tonne, respectively. The 3-year average ration cost was $220/tonne. All feed ingredient prices were obtained from the USDA NASS Ag. Price Report, except for the premix, which was based on the actual 3-year (2008-2010) price. Carcass value was based on 3-year average dressed beef price of $142/ 45.5 kg and 3-year average grid-formula discounts and premiums for carcass weights, yield grades and quality grades (Table 3.1).

Feeder calf prices were derived from a 3-yr average price slide that was split by 22.7 kg increments and applied to individual initial BW (USDA NASS). Net revenue was determined as carcass value minus costs for feeder calf, yardage ($0.30/day), and feed. Feed cost was based on actual feed consumed during the feed-intake measurement periods, and model-predicted intake adjusted for RFI during the group-feeding periods.

Statistical Analysis

All performance, feed efficiency, ultrasound measurements, feeding behavior, carcass and NR traits were adjusted to remove the random effect of trial by using the mixed procedure in SAS. Dependent variables were analyzed using a one-way random-effect treatment structure with trial as a random effect and an adjusted variable computed as the overall mean plus the residual. Phenotypic Pearson correlation coefficients using the PROC CORR command of SAS were generated among the adjusted performance, feed efficiency, ultrasound measurements, feeding behavior, carcass measurements and NR traits. To characterize RFI, steers were ranked into three classification groups: low (< 0.5 SD), medium (± 0.5 SD), and high (> 0.5 SD). Data were analyzed using the PROC MIXED command in SAS. Least squares means comparisons between RFI groups were generated using the Tukey post hoc test.

The stepwise option of PROC REG in SAS was used to determine between-animal variation in NR attributed to carcass and performance traits. Independent variables used in the models included year, initial BW, DMI, ADG, RFI, G:F, HCW, MS, and YG. Both linear and quadratic terms were evaluated for performance and carcass measurements. The dependent variable was NR per steer.

Table **3.1.** Three year average[a] grid yield and quality grade premiums and discounts ($/45.4 kg)[b].

	Yield grade						
Item	1	2A[c]	2B[c]	3A[d]	3B[d]	4	5
Prime	15.74	14.06	13.96	11.94	11.94	-0.80	-10.35
Choice	3.77	2.09	1.99	-0.01	-0.01	-12.75	-22.30
Select	-2.46	-4.14	-4.24	-6.26	-6.26	-19.00	-28.55
Standard	-10.88	-12.56	-12.66	-14.68	-14.68	-27.42	-36.97

[a]From 2008 to 2010: dressed price = $142.00/45.4 kg (USDA, 2011).
[b]Weight discounts: 181 to 226 kg, -$36.84; 227 to 250 kg, -$23.49; 251 to 272 kg, -$1.00; 273 to 408 kg, $0.00; and 409 to 431kg, -$0.06.
[c]Refers to yield grades between 2.00 and 2.49; B refers to yield grades between 2.50 and 2.99.
[d]Refers to yield grades between 3.00 and 3.49; B refers to yield grades between 3.50 and 3.99.

Results and Discussion

Summary statistics for performance, efficiency, carcass quality and NR traits during the total feeding period (Intake-measurement and group-feeding periods) are presented in Table 3.2. The steers consumed 9.98 ± 1.21 kg DM/d, and gained 1.34 ± 0.21 kg/d during the entire feeding period. Average BF depth and hot carcass weights were 1.21 ± 0.36 cm and 309.3 ± 24.1 kg, respectively. The mean carcass value, feed cost, and NR was $951.86, $363.55, and $-134.98 per head, respectively.

Phenotypic Correlations between Independent Variables and Net Revenue

The phenotypic correlations among the independent variables used to estimate NR are shown in Table 3.3. Average daily gain was correlated (0.34) with NR such that steers with a higher ADG have a greater NR, Pyatt et al. (2005a) reported a slightly lower correlation of 0.22 between ADG and NR that used 5-year average pricing to determine NR in early weaned Simmental steers. Average daily gain was also positively correlated (0.57 and 0.44) with DMI and HCW, respectively, with higher rates of gain being associated with higher DMI and heavier carcasses. Gain to feed ratio and RFI had strong ($P < 0.05$) correlations (0.55 and -0.53) with NR, respectively, demonstrating that more efficient steers had more favorable NR. Similarly, Pyatt et al. (2005a) reported that G:F was positively correlated (0.45; $P < 0.001$) with NR. Hot carcass weight was highly correlated (0.47; $P < 0.05$) with NR. Marbling score was positively correlated (0.24) with NR, such that higher marbled carcasses had a higher NR. Pyatt et al. (2005a) reported a higher correlation (0.50) between marbling score and NR, which likely reflects the higher average marbling score of 581 ± 93 for early weaned Simmental

Table 3.2. Summary statistics for performance, efficiency, carcass quality and net revenue traits in Angus-based composite steers (3 Studies; n = 508).

Trait	Mean	SD	Min	Max
Total feeding period[a]				
Initial BW, kg	310.1	56.1	219.1	451.8
Final BW, kg	513.7	36.9	376.8	631.8
ADG, kg/d	1.34	0.21	0.71	2.03
DMI, kg/d	9.98	1.21	6.21	13.7
G:F	0.14	0.03	0.07	0.22
RFI, kg/d[b]	0.00	0.76	-3.17	2.31
Carcass traits				
Hot carcass weight, kg	309.3	24.1	220.0	379.4
12^{th} rib-fat thickness, cm	1.21	0.36	0.20	2.54
KPH %	2.09	0.45	1.00	4.00
LMA, cm^2	75.6	6.61	51.0	96.1
Yield grade	3.19	0.35	2.20	4.50
Marbling Score[c]	414.9	65.6	300.0	720.0
Profitability[d]				
Total days on feed, days	150.6	29.4	107.0	193.0
Carcass value, $/hd[e]	951.86	85.60	481.10	1,187.66
Feed cost, $/hd[f]	363.55	66.75	220.15	539.79
Net revenue, $/hd[g]	-134.98	53.77	-417.43	54.51

[a]All traits are calculated over the total feeding period.
[b]RFI = Sum of RFI from individual feeding plus adjusted RFI calculated during group feeding.
[c]Marbling score= [b]300 = Slight^0, 400 = Small^0, 500 = Modest^0, and 600 = Moderate^0.
[d]Carcass value, Feed cost and Net revenue are base on 3yr average prices (2008 to 2010, USDA)
[e]Carcass value = actual individual carcass weight ± associated premiums and discounts.
[f]Feed cost = (actual feed during 70-d intake measurement period + predicted intake during group-feeding period adjusted for RFI) x $220/tonne.
[g]Net Revenue = Carcass value – (feed + yardage +feeder calf costs)

Table 3.3. Pearson correlation coefficients between performance, feed efficiency traits and Net revenue in Angus-based composite steers during the total feeding period.

Trait[a]	ADG	DMI	G:F	RFI	HCW	MS	YG	NR
Initial BW	0.27[b]	0.42[b]	-0.13[b]	-0.02	0.74[b]	0.17[b]	0.11[b]	0.26[b]
ADG		0.57[b]	0.50[b]	0.00	0.44[b]	0.00	0.09 [b]	0.34[b]
DMI			-0.41 [b]	0.67[b]	0.47[b]	0.16[b]	0.30[b]	-0.17[b]
G:F				-0.70[b]	0.00	-0.17 [b]	-0.22 [b]	0.55 [b]
RFI					-0.07	0.11[b]	0.26 [b]	-0.53[b]
HCW						0.13[b]	0.04	0.47 [b]
MS							0.16[b]	0.24[b]
YG								-0.29[b]

[a] RFI = residual feed intake; MS = Marbling score; YG= Yield grade; NR = net revenue.
[b]Correlations are different from zero at $P < 0.05$.

steers and greater choice-select spread of $8.90, compared to the average marbling score of 415 ± 66 and choice-select spread of $6.25 for the current study. Yield grade was negatively correlated (-0.29) with NR, which is expected because of carcass value discounts associated with higher YG carcasses.

Evaluation RFI Classification on Performance, Efficiency and Net Revenue

Steers with low RFI consumed 16% less ($P < 0.001$) feed and had 15% more favorable ($P < 0.001$) G:F ratios than high-RFI steers. Initial age, initial BW, and final BW were not different between low and high-RFI steers. On average, low-RFI steers had 6 more days on feed due to the fact that more of the low-RFI steers were harvested during the second slaughter group, as they were leaner ($P < 0.0001$) relative to steers with high-RFI phenotypes (1.09 vs. 1.27 cm BF). Therefore, the feed cost during the entire feeding period was 13% lower for steers with low-RFI compared to steers with high-RFI. Although not statistically different, the carcass value for low-RFI steers was $15/head numerically higher ($P < 0.28$) compared to the steers with high-RFI. Consequently, NR favored the low-RFI steers by $62/head relative to their high-RFI counterparts (Table 3.4).

Explaining Net Revenue Using 3-Year Average Pricing

Results from a single-variable regression analysis of carcass measurements, performance and feed efficiency on NR is shown in Table 3.5. Independently, G:F accounted for a high ($r^2 = 0.54$) amount of variation in NR, whereas HCW and ADG accounted for a moderate ($r^2 = 0.37$ and 0.33, respectively) amount of variation. Residual feed intake, QG, and DMI all accounted for a low amount ($r^2 = 0.26$, 0.15 and 0.12,

Table 3.4. Effects of RFI classification on performance, efficiency, and net revenue in Angus-based composite steers (3 Studies; n = 508).

Trait	Low RFI	Medium RFI	High RFI	SE	P-value
Total feeding period[a]					
Initial BW, kg	432.2	432.8	432.0	26.4	0.98
Final BW, kg	519.0	512.2	510.5	3.35	0.09
ADG, kg/d	1.34	1.33	1.34	0.10	0.79
DMI, kg/d	9.14[a]	9.94[b]	10.8[c]	0.40	0.0001
G:F	0.15[a]	0.14[b]	0.13[c]	0.01	0.0001
RFI, kg/d[b]	-0.88[a]	0.01[b]	0.85[c]	0.03	0.0001
Carcass traits					
Hot carcass weight, kg	312.3	308.6	307.5	2.75	0.19
12th rib-fat thickness, cm	1.09[a]	1.24[b]	1.27[b]	0.09	0.0001
KPH %	2.07	2.08	2.11	0.07	0.71
LMA, cm^2	77.1[a]	75.4[ab]	74.4[b]	0.54	0.0011
Yield grade	3.07[a]	3.22[b]	3.25[b]	0.09	0.0001
Marbling score[c]	405.7	414.4	423.5	6.04	0.061
Net Revenue[d]					
Total days on feed, days	154.0[a]	149.9[b]	148.1[b]	18.1	0.0014
Carcass value, $/hd[e]	959.83	952.12	944.40	10.2	0.28
Feed cost, $/hd[f]	339.84[a]	361.20[b]	388.69[c]	32.0	0.0001
Net revenue, $/hd[g]	-104.20[a]	-133.09[b]	-166.84[c]	9.70	0.0001

[a]All traits are calculated over the total feeding period.
[b]RFI = Sum of RFI from individual feeding plus adjusted RFI calculated during group feeding.
[c]Marbling score= [b]300 = Slight^0, 400 = Small^0, 500 = Modest^0, and 600 = Moderate^0.
[d]Carcass value, Feed cost and Net revenue are base on 3yr average prices (2008 to 2010, USDA).
[e]Carcass value = actual individual carcass weight ± associated premiums and discounts.
[f]Feed cost = (actual feed during 70-d intake measurement period + predicted intake during group-feeding period adjusted for RFI) x $220/tonne.
[g]Net Revenue = Carcass value – (feed + yardage +feeder calf costs).

Table 3.5. Regression of net revenue with performance and carcass measurements of Angus based steers using 3-year average pricing.

Item	Intercept	Slope	RMSE[a]	R^2
Initial BW, kg	-114.2	-0.07	53.7	0.00
Initial BW, kg^2 [b]	-124.2	-0.00	53.7	0.01
ADG, kg/d[c]	-271.8	102.0	49.3	0.16
ADG,kg/d^2 [b]	-206.3	38.7	49.1	0.17
Hot carcass weight, kg	-433.7	0.97	48.6	0.19
Hot carcass weight,kg^2 [b]	-282.3	0.00	48.7	0.18
Marbling score[d]	-214.7	0.19	52.3	0.05
Marbling score[b]	-168.5	0.00	52.6	0.04
Quality grade	-287.9	0.39	51.7	0.08
Quality grade[b]	-210.0	0.00	51.8	0.07
Yield grade	-47.5	-27.4	52.9	0.03
Yield grade[b]	-90.7	-4.30	52.9	0.04
12^{th} rib fat thickness, cm	-102.4	-27.0	52.9	0.03
12^{th} rib fat thickness,cm^2 [b]	-117.7	-10.9	52.8	0.04
REA, cm^2	-340.3	2.71	50.7	0.11
KPH%	-143.1	3.91	53.8	0.00
KPH%[b]	-140.2	1.15	53.8	0.00
Dry matter intake, kg/d[e]	-25.0	-11.0	52.1	0.06
Dry matter intake, kg/d^2 [b]	-78.0	-0.56	52.1	0.06
RFI, kg/d[f]	-134.9	-36.3	46.2	0.26
G:F[g]	-281.1	1073.0	46.4	0.26
G:F [b]	-215.3	4185.1	45.6	0.28

[a]Root mean square error.
[b]Quadratic term.
[c]Average daily gain during total feeding period.
[d]300 = $Slight^0$, 400 = $Small^0$, 500 = $Modest^0$, and 600 = $Modest^0$.
[e]Actual intake from individual feeding plus CVDS predicted intake adjusted for RFI from group feeding.
[f]Sum of RFI from individual feeding plus adjusted RFI calculated during group feeding.
[g]G:F ratio calculated during the total feeding period.

respectively) while all other variables were minor ($r^2 < 0.11$) contributors to differences in NR.

Results from multiple-variable stepwise regression analysis of NR on performance, carcass, and efficiency traits are shown in Table 3.6. The base model that included year, initial BW, ADG, HCW, MS, YG, DMI, RFI and G:F ratio accounted for 74.0% of the variation in NR with performance (BW, ADG, and HCW), carcass quality (MS and YG), and efficiency traits (DMI, RFI, and G:F) contributing 24, 13, and 36%, respectively, of the total NR variation. Year had minimal contribution (0.21%) to the variation in NR in this model. Of the performance traits, BW, ADG and HCW explained 0.3, 0.2 and 24% of NR, respectively, carcass quality traits, MS, and YG explained 8 and 6% of NR, respectively, and efficiency traits, DMI, RFI, and G:F explained 0.9, 7, and 28% of NR variation, respectively. The model that included year, initial BW, ADG, HCW, MS, YG, DMI, and G:F ratio, as the efficiency trait (G:F model), accounted for 73.9% of the variation in NR with performance (BW, ADG, and HCW), carcass quality (MS and YG), and efficiency traits (DMI and G:F) contributing 26, 17, and 31%, respectively, of the total NR variation. Year had minimal contribution (0.23%) in the G:F model when explaining the variation in NR. Of the performance traits, BW, ADG and HCW explained, 3, 0.2 and 23% of NR, respectively, carcass quality traits, MS and YG explained 9 and 8% of NR, respectively, and efficiency traits, DMI and G:F explained 2 and 28% of NR, respectively. The model that included year, initial BW, ADG, HCW, MS, YG, DMI, and RFI, as the efficiency trait (RFI model), accounted for 72.7% of the variation in NR with performance (BW, ADG, and HCW), carcass quality

Table 3.6. Regression of net revenue on carcass and live-animal performance traits in Angus-based composite steers (3-year average price).

	Partial R^2		
Trait	Base model	G:F model	RFI model
Year	0.21	0.23	0.13
Initial BW, kg	-	2.83	-
Initial BW, $kg^{2\,a}$	0.33	-	0.88
ADG, kg/d	-	-	-
ADG, $kg/d^{2\,a}$	0.24	0.19	16.37
Hot carcass weight, kg	21.0	21.0	8.72
Hot carcass weight, $kg^{2\,a}$	2.68	2.18	2.40
Marbling score[b]	6.47	8.00	6.02
Marbling score[a]	0.97	0.96	0.98
Yield grade	0.78	0.84	0.64
Yield grade[a]	5.14	7.00	4.53
Dry matter intake, kg/d	-	-	0.61
Dry matter intake, $kg/d^{2\,a}$	0.89	2.43	5.42
RFI, kg/d[c]	6.96	-	26.1
G:F	0.21	0.15	-
G:F[a]	28.2	28.2	-
Model R^2	74.02	73.98	72.77

[a]Quadratic term.
[b]300 = Slight^0, 400 = Small^0, 500 = Modest^0, and 600 = Modest^0.
[c]RFI = Sum of RFI from individual feeding plus adjusted RFI calculated during group feeding.

(MS and YG), and efficiency traits (DMI and RFI) contributing 28, 12, and 32%, respectively, of the total NR variation. The effect of year explained 0.13% of the variation in NR in the RFI model. Of the performance traits, BW, ADG and HCW explained, 1, 16 and 11% of NR, respectively, while carcass quality traits, MS and YG explained 7 and 5% of NR, respectively, and efficiency traits, DMI and RFI explained 6 and 26% of NR, respectively.

Pyatt et al. (2005a) conducted a similar study with early-weaned Simmental steers (n = 192) using 5-year average pricing. Their model (r^2 = 78%) included expected progeny differences for yearling weight, carcass weight, percent retail cuts and marbling, as well as performance (DMI, ADG, and gain:feed ratio) and carcass (HCW,YG, and MS) traits. Carcass traits, year and performance traits accounted for 51, 24, and 3% of the between-animal variation in NR, respectively. In their study, G:F, ADG, and expected progeny differences in yearling weight, carcass weight, percent retail cuts and marbling, were not significant sources of variation in NR.

Previous studies that have examined sources of variation NR using group-fed data have shown that price variables accounted for the majority of the variation in NR compared to production-related variables (Lawrence et al., 1999; Pritchard, 1999; Schroeder, 1993). However, these studies did not include pen average DMI or feed efficiency traits in assessing the effects of variation in performance traits on NR. Models that included effects of feeder-calf price, fed-cattle price, and feed cost have been shown to account for more than 90% of the variation in NR between feedlot pens (Mark et al., 2000; Mintert et al., 1993). Although, Mintert et al. (1993) did not evaluate carcass traits, they reported that performance traits in group fed cattle accounted for only 5 to 10% of the variation in NR, while ADG and interest costs explained 2 to 4% of net returns when input and output prices were included in the model. In the current study, ADG explained approximately 3% of the variation in NR. The relatively low contribution of ADG in explaining variation in NR likely reflects its high correlation with HCW. Gardner et al. (1996) examined factors affecting profitability in high-risk newly weaned Continental-sired steers, and found that medical cost, dressing percentage, marbling score, DMI, ADG, days on feed, BF, and initial BW explained 82% of the variation in net returns. In the current study, morbidity rate of steers was less than 1%, resulting in performance, carcass, and efficiency traits explaining over 74% of the variation in NR of Angus-based composite steers.

Effect of Dressed Beef Price on Net Revenue

Comparisons of regression models estimating profit with increasing dressed beef prices are exhibited in Table 3.7. Models accounted for 71 to 78% of the variability of NR among steers. As dressed beef price increased the total amount of variation in NR explained by the independent variables also increased. Year-to-year variation remained relatively low ($r^2 < 0.25$) as dressed beef price increases from \$132 to \$162/45.4 kg Gain:feed accounted for the most variability in NR as dressed beef price rises, however decreased as dressed price is increased. Hot carcass weight had the most variation across models, for every \$10 increase in dressed beef price the r^2 of HCW increased by 6%, which agreed with Williams and Bennett (1995), who reported a 10% reduction in base carcass price would result in lower target HCW to optimize profits. Marbling score and

Table 3.7. Comparison of variation (partial R^2) for models estimating net revenue at various dressed beef prices ($/45.4kg) in Angus-Based composite steers.

Trait	$132	$142	$152	$162
Year	0.25	0.21	0.19	0.17
Initial BW, kg	15.4	-	-	-
Initial BW, kg^2 [a]	-	0.33	0.30	0.28
ADG, kg/d	-	-	-	-
ADG, kg/d^2 [a]	0.21	0.24	0.22	0.20
Hot carcass weight, kg	4.03	21.0	25.7	32.7
Hot carcass weight, kg^2 [a]	2.36	2.68	2.45	2.22
Marbling score[b]	7.73	6.47	5.91	5.35
Marbling score[a]	1.04	0.97	0.88	0.80
Yield grade	0.91	0.78	0.71	0.65
Yield grade[a]	5.65	5.14	4.69	4.25
Dry matter intake, kg/d	-	-	-	-
Dry matter intake, kg/d^2 [a]	3.11	0.89	0.81	0.73
RFI, kg/d[c]	-	6.96	6.35	5.28
G:F	0.16	0.21	0.15	0.14
G:F[a]	31.1	28.2	27.9	25.2
Model R^2	71.86	74.02	76.27	78.51

[a]Quadratic term.
[b]300 = Slight^0, 400 = Small^0, 500 = Modest^0, and 600 = Moderate^0.
[c]RFI = Sum of RFI from individual feeding plus adjusted RFI calculated during group feeding.

YG both declined in relative importance as dressed carcass price increased, this is because at higher beef prices additional weight is more important than carcass composition.

At a carcass base price of $132/45.4 kg, DMI and RFI accounted for 3.11 and 0.00 % of the variation in NR, respectively. Above the $142/45.4 kg price DMI and RFI importance decreased as dressed price increased because as the carcass becomes more valuable the consumption of inputs becomes less important. Average daily gain accounts for minimal (< 0.24) variation in NR at all dressed beef prices. Pyatt et al. (2005b) conducted a similar study on early weaned Simmental steers, and HCW was the most significant variable, just above year, when dressed beef price was above $108. While feed efficiency was not significant in the models above $108, the trend of HCW, marbling score, and YG were similar to what was found in the current study. DMI accounted for 2 to 3% of the variation in NR and ADG was not reported.

Effect of Choice-select Spread on Net Revenue

Comparisons of regression models estimating profit at increasing Choice-select spread are exhibited in Table 3.8. Models accounted for at least 74% of the NR differences among steers. Accountability of variation in profit decreased with increasing spread. Similar to dressed price models G:F, although decreasing, was the most important variable in estimating NR at all Choice-select spreads, similar to Forristall et al. (2002), who also reported feed conversion decreased in relative importance as the Choice-select spread widened. Hot carcass weight remained mostly constant (r^2 = ~24%) at Choice-select spread of $4.25, $6.25, and $8.25 but drops to 20% at the $10.25

Table 3.8. Comparison of variation (partial R^2) for models estimating net revenue at various Choice-Select spreads ($/45.4kg) in Angus-based composite steers.

Trait	$4.25	$6.25	$8.25	$10.25
Year	0.25	0.21	0.17	0.12
Initial BW, kg	-	-	0.28	0.24
Initial BW, kg^2 [a]	0.41	0.33	-	-
ADG, kg/d	-	-	-	-
ADG, kg/d^2 [a]	0.26	0.24	0.16	0.14
Hot carcass weight, kg	21.6	21.0	19.9	18.5
Hot carcass weight, kg^2 [a]	3.23	2.68	2.16	1.70
Marbling score[b]	4.08	6.47	9.52	13.8
Marbling score[a]	0.21	0.97	2.04	3.22
Yield grade	0.92	0.78	0.67	0.57
Yield grade[a]	8.09	5.14	8.89	8.21
Dry matter intake, kg/d	-	-	-	-
Dry matter intake, kg/d^2 [a]	0.83	0.89	0.91	0.90
RFI, kg/d[c]	3.94	6.96	3.20	2.89
G:F	0.23	0.21	-	-
G:F[a]	30.8	28.2	25.2	22.2
Model R^2	74.86	74.02	73.13	72.52

[a]Quadratic term.
[b]300 = Slight^0, 400 = Small^0, 500 = Modest^0, and 600 = Moderate^0.
[c]RFI = Sum of RFI from individual feeding plus adjusted RFI calculated during group feeding.

spread. Marbling score increased from explaining 4% of the variation in NR in the $4.25 model to explaining > 17% of the variation in NR when Choice-select spread reaches $10.25. Greer and Trapp (2000) concluded that cattle sold with a narrow Choice-select carcass value spread would require fewer days on feed to maximize profits, suggesting that performance traits accounted for more variation in net revenue than QG traits. Yield grade explained about 6-10% of the variation in NR as Choice-select spread widened, and variation attributed to DMI remained constant as Choice-select spread increased from $4.25 to $10.25. Residual feed intake explained 3-7% of the variation in NR with changing Choice-select spreads.

Effects of Ration Cost on Net Revenue

Comparisons of regression models estimating variation in NR as ration costs changed are shown in Table 3.9. The models accounted for at least 67% of the variation in NR. In contrast to, Pyatt et al. (2005b) who reported an increase in the accountability of total variation in NR as feed cost increased, the current model decreased from 78% to 67% in total r^2. As ration cost increased from $175/tonne to $265/tonne, the variation attributed to G:F and HCW decreased at an increasing rate. At the $265/tonne, MS becomes the second most important variable, behind RFI, in explaining NR. At the highest ration cost of $310/tonne, RFI is the most important variable when accounting for variation in NR, marbling score becomes more important than HCW and YG at higher ration costs. Variation in NR attributed to ADG increased as the ration cost reaches $310/tonne. When ration costs reach $310/tonne HCW becomes insignificant in explaining between animal variation in NR and initial BW explains over 4% of the

Table 3.9. Comparison of variation (partial R^2) for models estimating net revenue at various ration prices ($/tonne) in Angus-based composite steers.

Trait	$175	$220	$265	$310
Year	-	0.21	0.33	0.55
Initial BW, kg	-	-	4.05	4.10
Initial BW, kg^2 [a]	-	0.33	-	-
ADG, kg/d	-	-	-	5.50
ADG, kg/d^2 [a]	0.13	0.24	0.23	-
Hot carcass weight, kg	28.5	21.0	9.04	-
Hot carcass weight, kg^2 [a]	1.81	2.68	2.87	-
Marbling score[b]	6.04	6.47	5.77	5.44
Marbling score[a]	0.93	0.97	0.88	0.64
Yield grade	0.85	0.78	0.75	0.67
Yield grade[a]	5.91	5.14	5.50	3.31
Dry matter intake, kg/d	-	-	-	0.64
Dry matter intake, kg/d^2 [a]	1.70	0.89	1.06	0.73
RFI, kg/d[c]	-	6.96	33.9	38.5
G:F	0.09	0.21	0.19	7.30
G:F[a]	33.0	28.2	6.17	0.53
Model R^2	78.98	74.02	70.71	67.87

[a]Quadratic term.
[b]300 = Slight^0, 400 = Small^0, 500 = Modest^0, and 600 = Moderate^0.
[c]RFI = Sum of RFI from individual feeding plus adjusted RFI calculated during group feeding.

varation. With high ration costs carcass quality traits become more important than HCW. Residual feed intake explained more of the variation in NR when ration costs reach $265/tonne than G:F; because RFI focuses on decreased inputs while remaining independent of BW and gain.

Using Feeding Behavior to Explain Net Revenue

As novel EID technologies are developed to enable collection of feeding behavior data in a cost-effective manner, the use of individual animal data to predict variation between animal intake, morbidity and efficiency traits beef cattle increases. Results from this study and previous research (Montanholi et al., 2010; Nkrumah et al., 2007) have shown that feeding behavior traits are moderately correlated with feed efficiency and intake. A study conducted by Sowell et al. (1999) examined the differences in feeding behavior between healthy and morbid steers, it was reported that healthy steers had more frequent feeding bouts when compared to morbid steers. In Table 3.10, the results of a stepwise regression equation to predict NR when applying predicted intake (DMR) and feeding behavior traits to the base model, which includes carcass characteristics, and ADG. The inclusion of DMR to the base model increased the model r^2 from 45.5 to 51.6. This low increase in r^2 can be explained by the correlation (0.55) between DMR and HCW. When feeding behavior traits were included in the model with DMR the r^2 increased to 58.0, and BV frequency makes up 11% of the increase in r^2. These results indicate that the majority of NR can be predicted without collecting individual feed intake.

Implications

As feed prices increase the value of cattle with superior genetics for efficiency of feed utilization become more important. In this study, steers with low-RFI had \$48/hd lower feed cost, \$16/hd numerically higher carcass value, and \$62/hd more favorable ($P < 0.0001$) NR compared to steers with high-RFI phenotypes. Models with non-price factors accounted for a majority of the variation among Angus-based composite steers in estimating NR. In the base model using 3-year average prices G:F ratio, HCW, DMI, MS, YG, ADG, and RFI were the major determinants of profitability, accounting for 74% of the variation among steers. As dressed beef prices increased the importance of HCW increased while MS, DMI, and G:F ratio decreased. With expanding Choice-select spread, MS importance increased while DMI, HCW, and G:F ratio decreased. As ration costs increased HCW and YG decreased in importance. At costs above \$265/tonne initial BW becomes significant, and RFI replaces G:F and becomes the most significant variable that accounts for variation in NR. Grid prices and feed costs alter target composition and marketing date of feed-lot cattle. Factors explaining variation in NR would be expected to change with different biological cattle types, management strategies, and future marketing conditions.

Table 3.10. Regression of net revenue on carcass, live-animal performance, and feeding behavior traits in Angus-based composite steers (3 year average price).

	Partial R^2		
Trait[a]	Base model	DMR model	FB model[b]
Year	2.71	0.00	0.29
Initial BW, kg	0.37	-	-
Initial BW, kg^2 [c]	0.28	0.44	-
ADG, kg/d	8.73	8.71	5.51
ADG, kg/d^2 [c]	-	0.25	-
Hot carcass weight, kg	18.7	18.7	18.4
Hot carcass weight, kg^2 [c]	1.41	0.77	1.58
Marbling score[d]	6.12	6.12	5.45
Marbling score[c]	0.91	0.94	0.79
Yield grade	0.69	0.38	0.38
Yield grade[c]	8.67	8.67	6.37
Dry matter required, kg/d[e]	-	6.08	4.19
Dry matter required, kg/d^2 [c]	-	0.64	0.80
BV duration, min/d	-	-	2.95
BV frequency, events/d	-	-	10.8
BV frequency, events /d[c]	-	-	0.50
Model R^2	48.54	51.66	58.03

[a]FB Model = Feeding Behavior model; includes the addition of feeding behavior traits over the base model.
[b]BV = Bunk visit; Meal data was derived from meal criterion calculated from individual data and applying a Gaussian-Weibull bimodal model.
[c]Quadratic term.
[d]300 = Slight^0, 400 = Small^0, 500 = Modest^0, and 600 = Modest^0.
[e]Intake individually predicted by CVDS for the total feeding period.

CHAPTER IV

SUMMARY

Identifying cattle that reduce input costs, e.g. consume less feed, without impacting outputs, e.g. carcass quality or reproductive efficiency is important to improve net revenue of beef cattle producers. The results of this thesis show that RFI was correlated with feed intake and G:F ratio, while remaining independent of growth and body size. Additionally, RFI can be calculated to account for the differences in ultrasound carcass composition. Selection for improved RFI has the potential to improve gross feed efficiency with minimal affects on growth and carcass composition. Although, RFI remains a relatively expensive trait to measure, it has been shown to be correlated with feeding behavior. Feeding behavior can be used to identify more efficient group-fed cattle without the costs associated with collecting individual intake and calculating RFI.

Angus-based composite steers selected for low-RFI were shown to have lower feed costs, higher carcass values and more favorable net revenue when compared with high-RFI steers. Models with non-price factors accounted for the majority of the variation in NR between Angus-based composite steers when three-year average prices were used. In the current study G:F ratio accounted for the most variation in NR as dressed beef price, choice-select spread and ration costs changed. Hot carcass weight, RFI, DMI, and MS also explained moderate amounts of variation in NR as input and output prices changed. With future research and new technologies identifying cattle with a more favorable net return may become more cost-effective, by monitoring feeding behavior data and by using models to predict animal intake.

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