THE RELATIONSHIP BETWEEN PERFORMANCE, RESIDUAL FEED INTAKE, AND TEMPERAMENT ASSESSED IN GROWING HEIFERS AND SUBSEQUENTLY AS THREE-YEAR OLD SUCKLED BEEF COWS

By

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A THESIS PRESENTED TO THE GRADUATE SCHOOL OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE

UNIVERSITY OF FLORIDA

2011
To my parents, Mike and Charlene Loyd
ACKNOWLEDGMENTS

First and foremost, I thank God for the abilities, knowledge, and opportunities He has granted me, as well as the everlasting strength that has allowed me to persevere in achieving my goals. I also thank my parents for their endless encouragement, support, and love. To Dad, who taught me the value of hard work, and Mom, who taught me how to find enjoyment and happiness throughout all of life’s journeys. I cannot imagine who I would be without them. I thank my older sister, Andrea Loyd, who has been the best role model a girl could ask for, both in school and out. Her dedication, persistence, and intelligence never fail to amaze me. I also thank the Blacks, my new family, for all their love and support during our stay in Florida.

I would like to express my deepest gratitude to Dr. Cliff Lamb for granting me the opportunity of a lifetime as a student. He is an incredible teacher, role model, and a great friend who is constantly finding the best in every situation and whose happiness is contagious. Because of his mentorship, I will depart here with a variety of invaluable skills which I will utilize for many years to come. I also thank his family: Margo, Jordan, Dante, and Jack, for making us feel right at home here in Marianna. In addition, I am lucky to have been guided by such a supportive supervisory committee, as Dr. Chad Chase and Dr. Nicolas DiLorenzo are always willing to answer my questions and expose me to unfamiliar facets of the beef industry and research. I am also grateful to have had the continuous guidance of Dr. Mike Smith during my time here. He ignited a fire within me for research and education, and for that I will be forever thankful.

To Kalyn Bischoff, little Montana, my colleague and best friend here, the girl I can always count on, and someone with whom I have shared a number of embarrassing moments with, I cannot express how thankful I am for her friendship. We have shared so many memories that I will forever treasure and she has inspired me in so many ways. I am also extremely grateful for
the wonderful times I have shared with Vitor and Paula Mercadante, as well as Guilherme and Fernanda Marquezini. I will always cherish their stories, friendship, and the beautiful culture they have so kindly shared with me.

I wish to thank the NFREC beef crew: David, Olivia, Mary, Mark, Don, Harvey, Butch, and Pete for all their assistance with my trial. Milking *Bos indicus* cows was an experience I will never forget! Words cannot describe my appreciation for the tireless hours they put in to make my research trial a success. In addition, I am grateful for their understanding, guidance, and patience if things went a little differently than planned. I also thank Dr. Travis Maddock, who helped get me started with my trial, for his willingness to answer questions along the way. I am grateful for our secretaries, Tina and Gina, not only for keeping us grad students in line and on task, but for also having someone to share a good laugh with.

And finally, to the one person who knows me better than anyone else, my husband Seth, I cannot thank him enough. It takes a special person and a special kind of love to move across the country to support me in the fulfillment of my goals and dreams. Even on the worst of days, he always had the ability to make me smile and chuckle. I am grateful for the faith we share together and for the opportunity to have his love and support for the rest of my life.
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THE RELATIONSHIP BETWEEN PERFORMANCE, RESIDUAL FEED INTAKE, AND TEMPERAMENT ASSESSED IN GROWING HEIFERS AND SUBSEQUENTLY AS THREE-YEAR OLD SUCKLED BEEF COWS

By

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May 2011

Chair: Dr. Graham Cliff Lamb
Major: Animal Science

We determined the relationship between performance, residual feed intake (RFI), and temperament measured in weaned, growing heifers (Phase I) and subsequently measured in lactating beef cows (Phase II) of the same cohort. Individual performance and daily dry matter intakes (DMI) were evaluated in 74 yearling heifers of diverse breedtypes and were subsequently reevaluated for those females upon the birth (± 3.5 d) of their second calf. A 21-d acclimation period (Phase I) or 14-d acclimation period (Phase II) preceded a 70 d test, where individual feed intakes of a forage-based diet were recorded by the GrowSafe System (© GrowSafe Systems Ltd., Alberta, Canada, 2011). Cattle were weighed every 14 d (Phase I) or 7 d (Phase II) and a linear regression of body weight (BW) against day on test was used to derive average daily gain (ADG). For both phases, chute scores (CS) and exit velocities (EV) were recorded every 14 d. Pen scores (PS) were recorded on d 56 (Phase I) or d 49 (Phase II). Cows were milked to determine individual energy corrected milk (ECM) production on d 14 (lactation d 28 ± 3.5; ECM14) and 70 (lactation d 84 ± 3.5; ECM70) of Phase II, and were ultrasounded on d 0 and 70 for carcass backfat (BF0, BF70) and ribeye area (REA0, REA70). Heifer RFI was calculated by regressing DMI on ADG and midtest BW^{0.75} (MBW). Individual RFI values ranged from -2.27
(most efficient) to 2.01 (least efficient). Heifers were ranked by RFI and placed into Low (most efficient; <0.5 SD; n = 24), Med (<0.5 SD>; n = 24), and High (least efficient; >0.5 SD; n = 26) RFI groups. Initial BW, final BW and ADG were similar among groups. However, daily DMI differed for all groups ($P < 0.0001$) and was greatest (10.82 ± 0.23 kg/d) for High; intermediate (9.63 ± 0.24 kg/d) for Med; and lowest (8.47 ± 0.24 kg/d) for Low RFI heifers. The cow RFI model included ECM14, ECM70, and BF70, which represented significant variation ($P < 0.2$) from stepwise regression analysis. Individual cow RFI values ranged from -5.79 to 8.51. Cows which were most efficient as heifers (Low) had decreased ($P < 0.05$) daily DMI and RFI values (13.6 ± 0.6; -1.17 ± 0.50 kg/d, respectively) than cows ranked as Med (15.5 ± 0.6; 0.80 ± 0.50 kg/d) or High (15.7 ± 0.6; 0.20 ± 0.46 kg/d) as heifers. In addition, cows which were least efficient as heifers (High) had the greatest d 14 and 70 ECM (6.27 ± 0.36 and 5.40 ± 0.31 kg/d) compared to cows that were more efficient heifers (4.66 ± 0.38 and 4.58 ± 0.33 kg/d for Low and 4.66 ± 0.38 and 4.00 ± 0.33 kg/d for Med). Pearson correlations between heifer and cow RFI were not significant; however, heifer RFI rank tended to be correlated with cow RFI ($r = 0.227; P = 0.059$). Temperament traits (CS, EV, PS) were correlated ($P < 0.05$) with one another within phases, and were also correlated with performance traits. We conclude that milk production and backfat were important sources of variation affecting evaluation of RFI in lactating beef cows. In addition, selecting for the most efficient heifers may result in reduced feed consumption for similar performance as mature cows.
CHAPTER 1
INTRODUCTION

In the livestock industry, profit may be determined as a function of inputs and outputs. Because the goal of most production systems is to improve profitability, it is important to consider the balance of inputs and outputs, especially in our current beef cattle industry. Traditionally, genetic selection pressure has been focused on optimization of output traits such as growth rate, carcass characteristics, and reproductive performance. However, in recent years many producers have widened their selection criteria to include input traits. This is a result of increasing prices for fuel, feed, and fertilizer, as well as the fact that feed provision represents the largest proportion of variable expenses incurred by a beef cattle enterprise (Arthur et al., 2001b; Moore et al., 2009; Kelly et al., 2010a). Improving the efficiency of feed utilization in beef cattle has emerged as a viable option to curtail feed inputs and reduce the cost of production.

Economically relevant traits which quantify an individual’s ability to utilize feed consumed for growth, maintenance, or production (feed efficiency) have been a topic of renewed interest within the past decade. Considering that maintenance requirements of the cowherd alone consume 60 to 65% of total energetic inputs, it would be both economically and biologically ideal to improve the energetic efficiency of feed utilization in beef cattle (Arthur 2001b).

Incorporation of feed efficiency traits into a selection program may not only be economically advantageous, but also may have significant positive environmental implications. Growing concerns about the environmental impacts of gas and nutrient excretion by livestock species has challenged researchers to develop technologies and strategies to improve production efficiency, thereby reducing potentially harmful emissions (Eckard et al., 2010). In a review of the literature, Moore et al. (2009) summarized the advantage that more efficient cattle have over their counterparts due to decreased DMI, reduced manure production, and lower methane
emissions (Nkrumah et al., 2006; Hegarty et al., 2007). These results provide evidence that increased feed efficiency in cattle may mitigate the negative impacts production has on the environment.

By selecting individuals with superior feed efficiency traits, improvements may be observed in the efficiency of production, reduction of feed costs and emissions, and improvement in profitability. Considerable progress has been made in identifying feed efficient animals, and current selection strategies often focus on the utilization of more efficient breeding sires to make genetic improvements in efficiency of their offspring (Moore et al., 2009; Wood et al., 2004). While feed efficiency is a useful tool, it is important to acknowledge that as a single trait, selection may be undesirable (Moore et al., 2009). There are many complex biological processes responsible for the variation in feed intake and efficiency among individual cattle, many of which have not yet been identified (Arthur and Herd 2005; Herd and Arthur, 2009; Moore et al., 2009). Therefore, these traits should be incorporated into already existing selection criteria to prevent the potentially negative effects single trait selection could have on other production traits.

Several studies have investigated feed efficiency in young cattle, but few have determined how residual feed intake (RFI) may be related to subsequent mature animal performance (Arthur et al., 2005; Basarab et al., 2007). Recent studies examined the repeatability of RFI in cattle between growing and finishing phases (Kelly et al., 2010b; Durunna et al., 2011), but there is no reported data demonstrating the relationship of feed efficiency for growing females compared to those same females once they are mature, lactating cows. Therefore, understanding the impact of selection for feed efficiency of growing cattle on
subsequent mature cattle performance is essential to completely understand the impact of feed efficiency in cattle operations.
CHAPTER 2
LITERATURE REVIEW

Quantification of Feed Efficiency

Due to underlying complexities in biological/metabolic processes and the relationship of feed intake to body size and production level, selecting cattle based on feed intake alone is rarely used (Arthur and Herd, 2005). Instead, different measures or traits of feed efficiency have been used. Approximately 70 to 75% of the total energy requirements for beef production is directed toward meeting the maintenance requirements of all cattle (Ferrell and Jenkins, 1985); however, individual animal variation in maintenance requirements exists (Johnson et al., 2003). This, coupled with inherent differences in individual animal feed intake (Richardson and Herd, 2004), are the basis for improving feed efficiency (Moore et al., 2009). Traditionally, the most common measure of feed efficiency in beef enterprises has been feed conversion ratio (FCR), also referred to as feed:gain (F:G). It is the ratio of feed consumed to the amount of weight gained over a specific period of time such as daily DMI:ADG (Brody, 1945). An animal with a low FCR consumes less feed per unit of gain compared to its counterparts with a high FCR and is classified as more feed efficient. Although FCR is frequently utilized due to its ease of measurement and calculation, it is criticized for its relationship with mature body size, as its measurement is influenced by growth rate and composition of gain (Nkrumah et al., 2004). The highly negative correlation between FCR and growth rate (Koots et al., 1994) as well as the observed increase in mature cow size resulting from lean FCR selection (Mrode et al., 1990) may amplify cow maintenance requirements and feed costs. Therefore, selection for FCR may also result in changes in undesirable traits that affect production efficiency (Nkrumah et al., 2004).

Partial efficiency of growth (PEG; Kellner, 1909), relative growth rate (RGR; Fitzhugh and Taylor, 1971), and the Kleiber Ratio (KR; Kleiber, 1947) are three determinations of feed
efficiency that have also been used to quantify feed efficiency. Measuring individual animal feed intake is required for PEG, which is calculated by dividing average daily gain (ADG) by the difference between average daily feed intake and expected dry matter intake (DMI) based on the National Research Council’s (NRC, 1996) maintenance feed requirements (Arthur et al., 2001a). Both RGR (growth relative to instantaneous size) and KR (weight gain per unit of metabolic body weight; Arthur et al., 2001a; Nkrumah et al., 2004) are indirect measures of efficiency because they require only the measurement of growth. A correlation between PEG and ADG in hybrid steers and bulls was detected, indicating that its selection may increase growth rate and mature size similarly to FCR (Nkrumah et al., 2004). These findings are in contrast to a report that demonstrated no such relationship, but also used French feeding standards for maintenance feed requirements in calculation of predicted DMI (Arthur et al., 2001b). The indirect measurements of feed efficiency (RGR and KR) have shown positive relationships with ADG (Nkrumah et al., 2004), which also appears to result in larger, faster growing cattle.

The potentially undesirable increases in maintenance requirements resulting from selection for FCR, PEG, RGR, and KR have resulted in the development of a feed efficiency trait known as residual feed intake (RFI). The concept of RFI was first proposed by Koch et al. (1963) who identified individual differences in intake existing for growing cattle at the same production level. They determined feed efficiency to be a function of gain, feed consumption, and average weight throughout the test. More specifically, RFI is the difference between an animal’s actual average daily feed intake and its predicted daily feed intake for maintenance or production (Basarab et al., 2003). The predicted daily feed intake value is obtained by regressing daily dry matter intake (DMI) on ADG and mid-metabolic body weight (MBW; [body weight at test midpoint]$^{0.75}$) or midtest BW. Cattle with more negative RFI values consume less feed than
expected (more efficient) and are therefore more desirable than their counterparts who possess more positive RFI values. Its selection does not result in heavier body weights (BW) because it is (by definition) independent of ADG (Arthur et al., 2001a; Nkrumah et al., 2004; Baker et al., 2006; Nkrumah et al., 2007; Kelly et al., 2010a).

Residual feed intake may be calculated as phenotypic RFI (RFIp) and/or genetic RFI (RFIg). The RFIg trait requires incorporation of genetic covariances of feed intake with both weight and production traits (Crews, 2005). The genetic RFI approach could alleviate any potential responses for growth rate and increased maintenance requirements resulting from RFI selection (Crews, 2005). However, RFIg was reported to be independent of ADG and BW, it was strongly correlated both genetically (0.92) and phenotypically (0.97) with RFIp, so its calculation may not be required (Nkrumah et al., 2007).

**Factors Affecting Residual Feed Intake**

In a review, Herd and Arthur (2009) acknowledged that individual variation in feed intake is due, in part, to differences in the maintenance requirements of cattle. A variety of underlying factors have also been shown to affect feed efficiency, thereby creating numerous sources of variation that need to be considered when evaluating cattle for this trait. Currently there is no standard method for calculating RFI in beef cattle, so these variables must be considered when selecting cohort groups in order to limit their impact on feed efficiency test results.

**Sex, age, and breedtype.** Total energy required for maintenance, the state at which bodily tissues have zero net loss or gain in energy, differs for cattle varying in sex, age, and breedtype (NRC, 2000). By pooling data across multiple studies, the NRC (2000) concluded that maintenance requirements of bulls are typically 15% greater than those of steers and heifers of
the same genotype, and maintenance requirements of steers and heifers appear to be similar. In addition, Carstens et al. (1989) reported that *Bos indicus* breeds have 10% lower maintenance requirements, and crossbred *Bos indicus* x *Bos taurus* cattle have 5% lower maintenance requirements, than British breeds. Contradictory data make it difficult to characterize differences in maintenance requirements for cattle of different ages (NRC, 2000). For example, Blaxter et al. (1966) did not observe an influence of age on the maintenance requirements of steers ranging from 15 to 81 weeks of age, while Carstens et al. (1989) found an 8% decrease in metabolizable energy required for maintenance as cattle went from 9 to 20 months of age.

When comparing results from studies that evaluated RFI for cattle differing in age, sex, and/or breedtype, it was evident that differential maturity patterns may produce additional variation. Sex effects have been detected and data indicates that heifers are less efficient than steers (Elzo et al., 2009), and steers are less efficient than bulls (Nkrumah et al., 2004). Significant differences in RFI for divergent breedtypes were also reported (Schenkel et al., 2004; Riley et al., 2007). Elzo et al. (2009) also observed a tendency for Brahman-influenced cattle to be more efficient than those of Angus influence in a sub-tropical environment. A moderate correlation \((r = 0.55)\) for RFI evaluated at two different ages has also been observed (Crews et al., 2003), which provides further evidence for the relationship between maturity and feed efficiency. These results validate the thesis that like-type cattle should be used when evaluating RFI (Herd and Arthur, 2009).

**Physiological status and production level.** Beef cattle within diverse physiological states (maintenance, growth, gestation, or lactation) have differing energy requirements due to the energetic constraints associated with that particular physiological state. In both growing and
The National Research Council (NRC, 2000) has reported maintenance requirements for nonlactating, mature beef cows to be approximately 20% lower than those of lactating cows. When crossbred beef cattle selected for similar growth rates and body size were characterized by milk production level (Low, Medium, or High), Low cows required 12% less energy per unit of metabolic weight than their counterparts to maintain weight throughout gestation and lactation (Montaño-Bermudez et al., 1990). In the same study, they observed an 18% increase in maintenance requirements from gestation to lactation and found that milk production differences accounted for 23% of the variation in maintenance requirements. These results indicate that maintenance requirements vary by physiological status and milk production level, and that additional variation exists beyond that associated with milk production potential.

Deposition of lean tissue and adipose tissue comes at different energetic costs due to their diverse chemical compositions (NRC, 2000). For an animal to gain weight, the net energy required is dictated by the proportion of protein and fat deposited within the empty body tissue (NRC, 2000). Because the growing and finishing phases are characterized by protein deposition and fat deposition, energetic requirements vary between the two phases. Therefore, comparing efficiencies of cattle at different growth stages could introduce additional error in the calculation of RFI.

**Body composition.** Residual feed intake and body composition differences have been characterized in young, growing cattle. Richardson et al. (2001) reported a correlation ($r = 0.43$) between whole-body chemical composition and genetic variation in RFI, as steer progeny born to high RFI parents were associated with increased fatness. In addition, there were trends for low
RFI steers to have lower amounts of dissectible carcass fat \((P = 0.08)\) and intermuscular fat \((P = 0.06)\) than medium and high RFI steers (Basarab et al., 2003). These data indicate that body composition has a potential role in quantifying energetic efficiency and adjustments for carcass composition may be necessary when evaluating cattle for RFI.

**Diet.** Dietary composition, digestibility, and level of allowed intake are additional sources of variation that may affect evaluation of RFI in beef cattle. It has been reported that dietary energy density influenced growth rates and feed efficiency traits in Angus and Hereford bulls (Fan et al., 1995). On high energy, concentrate diets (2.85 Mcal ME/kg of DM) bulls exhibited increased growth rates, higher metabolizable energy intake, and reduced feed efficiency compared to those consuming roughage cubes (1.89 Mcal ME/kg of DM). Therefore, it is important to ensure that cohorts are consuming identical diets during the feed efficiency test.

As the level of feed consumption increases, the energy expended to digest it rises, resulting in a greater loss of heat and gases (NRC, 2000). Therefore, cattle fed an *ad libitum* diet express differences in appetite and likely lose more energy for digestive processes than those consuming a restricted diet.

There also is evidence that more efficient cattle may have a greater ability to digest consumed DM. A negative correlation \((r = -0.44)\) between RFI and digestibility of cattle consuming a high grain ration has been observed, indicating that more efficient cattle have an enhanced ability to digest feed (Richardson and Herd, 2004). Although it appears that individual differences in digestibility may have an impact on feed efficiency, more research is needed to discern the magnitude of the relationship.

**Physical activity and feeding behavior.** Much like digestion, processes associated with physical activity are energy-expensive and result in heat production. Feeding situations that
require more energy for locomotion when grazing or in competition for bunk space may alter relative levels of energy expenditures. Therefore, care should be taken to ensure cohorts are exposed to the same basic feeding conditions.

It also has been reported that the level of physical activity associated with differences in animal behavior patterns affects energetic expenditures and feed efficiency (Susenbeth et al., 1998). More feed efficient (lower RFI) animals exhibited a lower duration of daily feeding activities compared to less efficient counterparts (Golden et al., 2008). In addition, positive genetic and phenotypic correlations among RFI and feeding time per day, number of eating sessions per day, and eating rate have been reported in feedlot steers (Robinson and Oddy, 2004). International research efforts (Nkrumah et al., 2006, 2007; Kelly et al., 2010a) have also demonstrated that differences in daily feeding behavior exist. Moreover, positive relationships between phenotypic RFI and daily feeding events (r = 0.45), feeding-associated events (r = 0.23), and daily eating rate have been observed (r = 0.26; Kelly et al., 2010a). Collectively, it appears that greater incidences of feeding-associated activities likely exist for less feed efficient cattle. Incorporating feeding behavior traits into the RFI model accounted for 20% (Kelly et al., 2010a) and 35% (Lancaster et al., 2009b) of the variation in intake not explained by MBW, ADG, and ultrasonic carcass measurements in heifers and bulls, respectively. Therefore, animal-to-animal variation for feeding behavior exists and may need to be considered when calculating RFI.

**Duration of feed efficiency test.** Another variable that may impact the results of an RFI evaluation is the duration of the feed efficiency test, or the total number of days individual feed intake and growth rates are measured. In North America, a 112-d test was the previous industry standard for evaluating bull performance (Kemp, 1990). However, due to increased feed and management costs associated with longer test durations, researchers established a reduced
duration for assessing feed efficiency. The optimal feed efficiency test duration for Angus, Hereford, Polled Hereford, and Shorthorn weaned calves was determined to be 70 d, as variation in RFI was barely unaltered when the test exceeded 70 d (Archer et al., 1997). In addition, accuracy of measurement for growth rate, feed conversion, and RFI was not compromised when cattle were weighed every 2 wk, rather than weekly. For young Angus, Hereford, Simmental, Bonsamara, and Afrikaner bulls, it was similarly reported that a 70-d feeding test was accurate (Archer and Bergh, 2000). Extending the test duration past 70 d appears to have no advantage; however, RFI results may be inaccurate when cattle are tested for fewer than 70 d.

**Environment and season during feed efficiency test.** The effects of ambient temperature and seasonal conditions on beef cattle performance and energy expenditures have been established (NRC, 2000). When cattle are maintained in their thermoneutral zone, heat production from tissue metabolism and digestive fermentation is determined primarily by level of feed intake and efficiency of feed usage (NRC, 2000). However, when temperatures exceed an animal’s upper critical threshold, both feed intake and production declines. High body temperatures increase metabolic rate of tissues, forcing the animal to work harder to dissipate heat and therefore increase energy requirements. Below the lower critical temperature, metabolism must increase to maintain body temperature, which also increases maintenance energy requirements (NRC, 2000). Because RFI is a measure of individual differences in intake relative to maintenance requirements, its estimation may differ under various climatic conditions (Mujibi et al., 2010).

Few studies have investigated the effect of seasonality differences on feed efficiency in beef cattle. Differences in feed efficiency and performance for steers tested in either fall and winter or winter and spring seasons were observed over three consecutive years in Canada.
Correlations between feed intake and air temperature, relative humidity, solar radiation, and wind speed were observed (-0.26, 0.23, 0.30, -0.14 for fall/winter, and 0.31, -0.04, 0.14, and 0.16 for winter/spring, respectively), but nature and magnitude differed for the correlations by season. Although these authors reported that season possibly affects feed intake and feed efficiency, more data is needed.

Selection for Residual Feed Intake

To meet specified breeding objectives and achieve success in a beef cattle enterprise, breeding decisions must be based on credible information. Genetic progress made by selecting for RFI is feasible only if the trait is somewhat heritable, or able to be successfully passed on to future generations. A variety of studies have examined heritability estimates for RFI, and values range from 0.16 (Herd and Bishop, 2000) to 0.47 (Lancaster et al., 2009a). Because most heritability estimates fall between these values, RFI has been termed ‘moderately heritable’ (Arthur et al., 2001b; Robinson and Oddy, 2004; Schenkel et al., 2004). Therefore, selecting for RFI should reduce feed costs without affecting growth rate or mature size, while maintaining the ability to produce more efficient progeny. It has been demonstrated that divergent selection for RFI results in progeny that maintain efficiency, as Angus steers born to parents selected for low RFI (more efficient) had improved feed efficiencies in the feedlot compared to steers born to high RFI parents (Richardson et al., 1998). In addition, there was no accompanied change in performance of growth or carcass characteristics for the low or high progeny. It was also reported that progeny of high RFI parents consumed 5% more feed per day than low RFI steers (Richardson et al., 2001). These results indicate that genetic selection for RFI is possible and lower RFI progeny may be economically superior to higher RFI counterparts.
Residual Feed Intake and Carcass Composition

In the past decade, the capacity of feed efficiency research has expanded, facilitating an improved understanding of RFI’s relationship to carcass characteristics. As more feed intake, comparative slaughter, and ultrasonic carcass data have been collected and analyzed, some researchers are concerned that genetically and phenotypically lower RFI cattle may be less desirable in the United States’ quality-based beef retail markets (Nkrumah et al., 2004).

Positive correlations between phenotypic RFI and backfat gain throughout the test period were detected in growing Brangus heifers ($r = 0.22$; Lancaster et al., 2009a) and hybrid Bos taurus steers and bulls ($r = 0.30$; Nkrumah et al., 2004), indicating that less efficient cattle have a greater propensity to deposit subcutaneous fat in the growing phase regardless of sex and breed type. In addition, multiple studies have observed small carcass fatness decreases (Richardson et al., 2001; Basarab et al., 2003; Kelly et al., 2010a; Shaffer et al., 2010) and increased carcass lean content (Nkrumah et al., 2004) when comparing phenotypically low RFI cattle to higher RFI counterparts. However, some researchers have reported no significant difference in hot carcass weight, carcass backfat, Longissimus dorsi muscle area, yield grade, and quality grade between low and high RFI steers (Castro-Bulle et al., 2007; Cruz et al., 2010). Relatively low numbers of cattle were used in these studies ($n = 8$ and $n = 15$ steers per group per study, respectively).

Several studies have also detected a genetic component for RFI and body composition. A negative correlation ($r = -0.43$) between RF Ig and estimated carcass lean content in Hereford bulls was reported (Herd and Bishop, 2000). In Angus steers divergently selected for RFI, genetic improvement in feed efficiency corresponded with a small shift toward greater whole-body lean content (Richardson et al., 2001). Robinson and Oddy (2004) examined records on
1,481 feedlot steers consuming a high grain diet, which were either tropically adapted or temperate breeds raised in Australia. These authors reported positive genetic correlations for RFI and rump and rib fat (r = 0.72 and r = 0.48 adjusted for age; r = 0.79 and r = 0.58 adjusted for weight) and for RFI and intramuscular fat percentage (r = 0.22 and r = 0.25 adjusted for age and weight, respectively). A reduction in post-slaughter muscle tenderness as indicated by a lower myofibril fragmentation index and increased calpastatin concentration of the *Longissimus dorsi* muscle was also observed in low RFI steers after one generation of selection (McDonagh et al., 2001). Collectively, it appears that selecting for superior RFI cattle may result in negative effects on carcass fatness and meat quality.

In order to calculate RFI independently of carcass composition, ultrasonic carcass characteristics have been included in the traditional RFI model for growing cattle. Inclusion of lumbar fat gain accounted for an additional 4% of the variation in feed intake (Kelly et al., 2010a), and inclusion of backfat gain and final ribeye area explained 9% of variation in feed intake not explained by MBW and ADG (Lancaster et al.; 2009b). These authors concluded that adjustment of RFI for ultrasonic carcass traits will alleviate the changes in carcass composition associated with improved RFI.

**Biomarkers and Indirect Indicators for Residual Feed Intake**

In order to accurately calculate RFI in cattle, precise individual feed intake data is necessary. Unfortunately, its collection is expensive, with estimates ranging from $150 to $450 cost per head on a 70-d test. Attempts to group-feed cattle and derive pen estimates of feed efficiency have been performed (Guiroy et al., 2001; Tedeschi et al., 2006; Williams et al., 2006); however, these estimates require the use of mathematical models and dilute the inherent differences in intake between individual pen-mates (Moore et al., 2009). Therefore, in an
attempt to alleviate the costs associated with accurate RFI quantification and selection, research to indirectly estimate RFI is underway.

**Relationship of feed efficiency with hormones and metabolites.** Circulating concentrations of insulin-like growth factor-1 (IGF-1), a hormone that regulates growth (Moore et al., 2009) and cellular proliferation (Kelly et al., 2010a) was reported to be genetically (Moore et al., 2005) and phenotypically (Brown et al., 2004) correlated with RFI in a positive manner. Although its application as an indirect indicator of RFI exists in Australia and the United States (Moore et al., 2009), contradictory data question its validity. No relationship between overall concentrations of plasma IGF-1 and RFI in growing beef heifers was reported (Kelly et al., 2010a), and selection for concentrations of serum IGF-1 had little effect on RFI (Lancaster et al., 2008). The moderate heritability of IGF-1 ($h^2 = 0.4$; Moore et al., 2005) and its economical measurement make it an ideal biomarker for RFI, but more consistent data are needed to validate its application.

Leptin, a regulator of feed intake, body weight, and energy expenditure, has been positively associated with body fat deposits in beef cattle (Minton et al., 1998). While it has been reported that leptin concentrations are positively correlated with phenotypic RFI (Richardson et al., 2004), other studies have observed no significant relationship between leptin and RFI (Brown et al., 2004; Kelly et al., 2010a). A single nucleotide polymorphism (SNP) located in the promoter region of the leptin gene was reported to be related to growth rate, body fatness, and feed intake, but not to feed efficiency traits (Nkrumah et al., 2005). These results indicate that leptin may not be an accurate indicator for RFI.
Insulin, beta-hydroxybutyrate, urea, non-esterified fatty acids, and creatinine (Kelly et al., 2010a; Richardson et al., 2004) are other recently studied plasma analytes. However, these have shown minimal evidence to warrant their adoption as indirect indicators of RFI.

**Single nucleotide polymorphisms.** Genetic correlations existing between RFI and previously mentioned traits indicate that regulation of intake, growth, and energy partitioning in beef cattle is controlled by a variety of genes (Sherman et al., 2008). By analyzing single nucleotide polymorphisms (SNP), it may be possible to identify candidate genes responsible for variation in RFI. A whole-genome scan of feedlot cattle with extremely high or low RFI values and diverse breedtypes identified 161 SNP that were significantly associated with RFI (Bardense et al., 2007). The 20 most significant SNP explained 76% of the genetic variation in RFI, indicating genetic markers may be more accurate biomarkers than circulating analytes (Moore et al., 2009). IGENITY® (Merial Limited, Duluth, GA) and GeneSTAR® (Pfizer Animal Health, New York, NY) are genetic tests currently available to identify individual differences in feed efficiency. Although genetic correlations between these markers and RFI are reported for both products, these tests account for less than 15% of the variation in feed intake. Therefore, precautions should be taken when using these tests to quantify relative feed efficiencies in beef cattle.

**Residual Feed Intake and Reproductive Efficiency**

Reproductive efficiency is a key component to cow-calf enterprises because it is a primary determinant of profitability. Since nutritional status has been identified as an important mediator of reproductive events (Wiltbank et al., 1969; Day et al., 1986), differences in feed intake may affect the age of puberty (AOP) for heifers as well as the length of the anestrous period for cows. It was recently reported that British-bred heifers (n = 137) with positive (POS;
0.74 kg TDN/d) RFI reached puberty at a younger age (414 ± 3.8 vs. 427 ± 4.7 d; \( P = 0.03 \)) than negative (NEG; -0.73 kg TDN/d) RFI heifers (Shaffer et al., 2010). In addition, a one unit increase in RFI resulted in a 7.5 d reduction in AOP; however, RFI had no effect on pregnancy or conception rates. Phenotypic correlations \( (P < 0.05) \) between RFI and ultrasonic measures of subcutaneous rib (initial \( r = 0.19 \); final \( r = 0.27 \)) and rump fat (initial \( r = 0.17 \); final \( r = 0.24 \)) were sustained throughout the trial, indicating that more feed efficient heifers may have delayed attainment of reproductive maturity due to decreased fatness.

In crossbred beef heifers (n = 61) between 7.6 and 9.5 mo of age, RFI adjusted for BF over a 113-d feeding test was calculated and heifers were sorted into POS and NEG RFI groups (Basarab et al., 2009). The average age at which heifers attained pubertal status were similar between POS and NEG RFI heifers; however, more POS RFI heifers tended \( (P = 0.09) \) to reach puberty by 12 \( (P = 0.09) \) and 13 \( (P = 0.06) \) mo of age compared with NEG heifers. In addition, POS heifers tended to have greater pregnancy rates at the third \( (80.7 \text{ vs. } 63.3\%; \ P = 0.13) \), fourth \( (87.1 \text{ vs. } 66.7\%; \ P = 0.06) \), and fifth week of the breeding season \( (87.1 \text{ vs. } 70.0\%; \ P = 0.10) \) compared with NEG heifers. These results are consistent with Shaffer et al. (2010) and indicate that puberty may be slightly delayed in more efficient heifers.

It has been reported that pregnancy rates for mature cows producing Low, Medium, or High RFI progeny (Basarab et al., 2007) and for mature cows divergently selected to produce Low or High RFI calves (Arthur et al., 2005) are similar. However, in both of these studies, it was reported that cows producing more efficient progeny tended to calve later than their counterparts. Therefore, it appears that RFI has no effect on overall pregnancy rates; however, more efficient females may have slightly delayed attainment of pregnancy throughout their lifetime.
As the cost of production within the beef industry continues to rise, producers are continuously searching for methods which will reduce input costs. Because feed costs are directly associated with approximately two thirds of total inputs (Arthur et al., 2001a), many producers have shifted the focus of their selection programs. Traditionally, selection pressure has centered on output traits such as growth rate, carcass composition, and reproductive efficiency. In recent years, however, producers have included traits which reduce inputs. One of these traits is feed efficiency.

Residual feed intake (RFI) is one phenotypic trait used to determine feed efficiency that measures variation in feed intake independently of body weight or growth rate, and is computed as the difference between an animal’s actual daily feed intake and the predicted daily feed intake value. Although it has been well established that RFI is a moderately heritable trait (Herd and Bishop, 2000), there have been few published studies comparing an individual’s RFI between two different physiological states, such as growth and lactation. This is important to understand in a beef production scenario, as maintenance requirements for non-lactating beef cows are approximately 20% lower than those of lactating cows (NRC, 2000). Thus, differences in maintenance requirements and the type of production (growth or lactation) that energy is partitioned toward may result in changes in individual feed efficiency.

Therefore, our objectives were: 1) to determine whether RFI evaluated as heifers has an impact on subsequent RFI, overall performance, and temperament as mature cows; 2) to determine the correlation between RFI measured in growing heifers and RFI measured as
mature, lactating cows; and 3) to identify the effect of cow and heifer feed efficiency on mature reproductive performance.

**Materials and Methods**

**Phase I animals and management.** Heifers (n = 74) of six different breedtypes (AN = Angus, n = 14; BH = Brahman, n = 11; RO = Romosinuano, n = 22; AN × BH = Angus × Brahman, n = 10; AN × RO = Angus × Romosinuano, n = 9; BH × RO = Brahman × Romosinuano, n = 8) born in Brooksville, Florida between December 2006 and March 2007 were weaned in early September, 2007. Upon weaning, heifers grazed bahaiagrass (*Paspalum notatum*) pasture before receiving a cottonseed- and soybean meal-based preconditioning diet (1.8 kg/d; 14% CP; 488 Pellet Medicated Weaning Ration, Lakeland Animal Nutrition) for 3 to 6 wk. Heifers also had *ad libitum* access to Tifton 85 bermudagrass hay and complete mineral (Southern States, Marianna, FL) while receiving the preconditioning diet. Subsequently, heifers were transported to the Feed Efficiency Facility (FEF; Marianna, FL) of the Institute of Food and Agricultural Sciences of the University of Florida in October 2007.

Upon arrival to the FEF, heifers were fitted with Electronic Identification (EID) tags (Allflex USA Inc., Dallas-Fort Worth, TX), weighed, and randomly assigned to pens (108 m² / pen) equipped with 2 GrowSafe feed bunks each (© GrowSafe Systems Ltd., Alberta, Canada, 2011). There was a mean number of 16.9 calves per pen, thus allowing 8.5 calves to feed per GrowSafe bunk (2 bunks / pen). A 21-d acclimation period to the diet and facilities preceded a 70 d feeding trial, where the GrowSafe System recorded daily feed intakes for each individual. Heifers had *ad libitum* access to water and a forage-based diet consisting of whole corn, chopped bermudagrass, corn gluten feed, cottonseed hulls, and mineral supplement (FRM, Bainbridge, GA). The diet was formulated to support growth rates of 1 kg/d (Table 2-1; NRC, 1996). Upon
initiation of the 70 d trial (d 0), heifers were weighed, body condition scored (1 to 9 scale; 1 being emaciated; 9 being extremely obese), evaluated for temperament traits every 2 wk, and assigned a pen score (PS) on d 56. After completing the trial period, the heifers were removed from the FEF and were required to successfully deliver 2 calves by the 2010 spring calving season.

**Phase II animals and management.** Beginning in January 2010, females from Phase I (n = 74) were allowed to calve in pasture as second parity, 3-yr old cows. Cows received *ad libitum* access to Tifton 85 Bermudagrass silage and mineral supplement prior to calving. Every week, cows who delivered healthy calves within the previous wk were moved from pasture to the FEF as a group. Upon entry into the facility, calves were fitted with EID tags and cows were checked to ensure their EID was intact. Cow-calf pairs within each group were then randomly assigned to pens, with no more than six pairs per pen.

A 14-d acclimation period was allowed before initiating the 70 d test. Pairs in each pen had *ad libitum* access to water and two GrowSafe feed bunks. The forage-based diet consisted of 86.7% Tifton 85 Bermudagrass silage, 12.4% dried distillers grains plus solubles, 0.7% range mineral, and 0.2% salt, suitable for lactating beef cows (Table 2-1; NRC, 1996). Individual daily feed intake values for cows and calves were determined using the GrowSafe System (GrowSafe Systems, Ltd., Alberta, Canada). Weights of cows were recorded weekly from d 0 to 70 of the test, and weights of calves were collected on d 0 and 70. Cow milk production and carcass ultrasound traits were measured on d 14 and d 70 (d 28 ± 3.5 and d 84 ± 3.5 of lactation). Cows were evaluated for body condition score (BCS) and temperament traits every 2 wk and were assigned a pen score (PS) on d 49.
**Milk production (Phase II).** On d 14 (d 28 ± 3.5 of lactation) and d 70 (d 84 ± 3.5 of lactation) of the test, cows were milked to determine individual energy corrected milk (ECM) production. On the morning of milking, cows were separated from their calves. Each cow was restrained in a hydraulic chute and received 40 I.U. of oxytocin intravenously. Cows were milked immediately as milk let-down occurred using a vacuum pump connected to a four claw milking machine. When all four quarters were dry, machine milking ceased and residual milk from all quarters was stripped by hand (procedure adapted from Marston et al., 1992). Cows were returned to their pens without their calves and were allowed *ad libitum* access to feed and water. Following a minimum separation period of 6 h, cows were milked again as previously described. Milk was weighed and daily production (kg/d) was adjusted to 24-h yield. Energy-corrected milk (kg/d) produced on d 14 and 70 were determined using the equation: (ECM = (0.327*lb of milk) + (lb of fat*12.95) + (lb of protein*7.2); Lamb et al., 1999). Fat and protein values from cows milked during a preliminary trial in 2009 were used to compute the ECM for each breedtype and were as follows: AN: 3.03, 3.35; BH: 4.22, 3.20; RO: 3.55, 3.23; AN × BH: 3.49, 2.88; AN × RO: 3.29, 3.29; BH × RO: 4.07, 3.03 (% fat and protein, respectively; Dairy One Forage Laboratory; Ithaca, NY).

**Ultrasonic carcass traits (Phase II).** On d 0 and 70, ultrasound was used to scan. *Longissimus dorsi* muscle area (REA) and fat thickness (BF) using an Aloka real-time ultrasound scanner (3.5-MHz linear array transducer, Aloka 500V, Corimetrics Medical Systems, Inc., Wallingford, CT) and image capturing software. Scanning was performed on the right side of each animal, between the 12th and 13th ribs. For both REA and BF, there were 2 measurements taken per individual at each scanning session. Final d 0 and 70 REA and BF values were calculated as the average between the 2 measurements recorded.
**Blood collection and analysis (Phase II).** Blood samples for all cows were collected via coccygeal venipuncture using Vacutainer tubes (Becton & Dickinson Vacutainer Systems, Rutherford, NJ) every wk from d 0 to 70. To determine days to first postpartum ovulation, the first increase in progesterone (evidence of first postpartum ovulation) that exceeded 1.0 ng/mL, followed by a progesterone pattern consistent with normal estrous cycles was the criteria used for assessing days to first postpartum ovulation (Perry et al., 1991). Samples were collected in 10 mL glass vials containing 143 USP units of Na heparin (BD Diagnostics, Franklin Lakes, NJ), immediately placed on ice, and centrifuged at 1,500 × g at 4°C for 15 min. The plasma was transferred by pipette into polypropylene vials (12mm × 75mm; Fisherbrand) and stored at -20°C until further analysis.

Plasma progesterone concentrations were determined by enzyme-linked immunosorbant assay (ELISA) to confirm estrous cycling status. Concentrations of plasma progesterone were determined in duplicate by enzyme-linked immunosorbant assay (ELISA) modifying the procedure previously described by Rasmussen et al. (1996). The standard curve contained 0.1, 0.2, 0.5, 1.0, 2.0, 5.0, 10.0, and 20.0 ng/tube. Assay sensitivity for a 100-µL sample was 0.1 ng/mL. Pooled samples revealed that the intra- and inter-assay coefficient of variation were 18.5% and 13.9% for 12 assays, respectively.

**Temperament traits (Phase I and II).** Temperament traits evaluated were chute score (CS), exit velocity (EV), and pen score (PS). The subjective measurement of the behavioral response to restraint within the squeeze chute (CS) was assigned on a 1 to 5 scale (1 = calm, docile, and quiet; 2 = restless; 3 = nervous; 4 = excited and flighty; 5 = aggressive) by a trained evaluator. Exit velocity was the speed (m/s) at which each cow exited the squeeze chute and passed by LED optical sensors placed at a distance of 1.83 m. Pen Score was a subjective
measurement of the animal’s behavioral response to isolation in the pen with a handler present. Three trained evaluators assigned scores on a 1 to 5 scale (1 = calm, docile, and quiet; 5 = aggressive) and were used to compute a mean score for each animal.

During Phase I, EV and CS were recorded every 2 wk (d 0, 14, 28, 42, 56, 70) and PS was evaluated on d 56. In Phase II, EV and CS were recorded every 2 wk, but milking days (d 14 and 70) were excluded to avoid confounding side effects of oxytocin administration. In Phase II, PS was evaluated on d 49.

**Calf intake.** Average DMI of calves was determined by the summation of DMI of feedstuffs (using the GrowSafe System) and the DMI of ECM from suckling. Weights of calves collected on d 0 and 70 of the feeding test were used to calculate ADG. Gain:feed (G:F) was computed as the ratio of ADG to daily DMI.

**Statistical analysis**

Average daily gain for heifers and cows was calculated by regressing BW on day of test using the SLOPE function (Microsoft EXCEL). For Phase I, predicted daily DMI was derived by regressing DMI on ADG and MBW using the REG procedure of SAS (© SAS Inst. Inc., Cary, NC, 2011). Phenotypic RFI for heifers in Phase I was calculated by subtracting expected daily DMI from the predicted daily DMI value (Koch et al., 1963; Archer et al., 1997; Arthur et al., 2001 a,b). The statistical model was:

\[ Y_j = \beta_0 + \beta_1 ADG_j + \beta_2 MBW_j + e_j \]

where:

\( Y_j \) = daily DMI of the jth animal

\( \beta_0 \) = regression intercept

\( \beta_1 \) = regression coefficient for ADG
\[ \beta_2 = \text{regression coefficient for MBW} \]

\[ e_j = \text{error associated with the jth animal} \]

Heifers were sorted and placed into Low (< 0.5 SD; \( n = 24 \)), Medium (< 0.5 SD >; \( n = 24 \)), and High (> 0.5 SD; \( n = 26 \)) feed efficiency groups based on their RFI values, with more negative values being efficient and positive values inefficient. The MIXED procedure of SAS was used to determine whether differences existed between Low, Medium, and High RFI groups for initial age, initial BW, final BW, BCS, ADG, DMI, and RFI of heifers.

For lactating cows in Phase II, an alternative RFI model was used to more appropriately adjust for differences in milk production and carcass composition among cows. The full model included ADG, MBW, ECM14 (lactation d 28 milk yield), ECM70 (lactation d 84 milk yield), ECMAVG (average of d 14 and 70 milk yield), BF0 (d 0 backfat), BF70 (d 70 backfat), BFCHG (change in backfat), REA0 (d 0 REA), REA70 (d 70 REA), and REACHG (change in REA). Stepwise regression was used to eliminate non-significant variables \( (P < 0.2) \) from the model. The final model used to calculate RFI was:

Phase II (cows)

\[ Y_j = \beta_0 + \beta_1 \text{ADG}_j + \beta_2 \text{MBW}_j + \beta_3 \text{ECM14}_j + \beta_4 \text{ECM70}_j + \beta_5 \text{BF70}_j + e_j \]

where:

\[ Y_j = \text{daily DMI of the jth animal} \]

\[ \beta_0 = \text{regression intercept} \]

\[ \beta_1 = \text{regression coefficient for ADG} \]

\[ \beta_2 = \text{regression coefficient for MBW} \]

\[ \beta_3 = \text{regression coefficient for ECM14} \]

\[ \beta_4 = \text{regression coefficient for ECM70} \]
\[ \beta_5 = \text{regression coefficient for BF70} \]
\[ e_j = \text{error associated with the jth animal} \]

The GLM procedure of SAS was used to quantify Type III (partial) sums of squares for each parameter included in the model and calculate the percentage of variation each parameter contributed. Cows were sorted and placed into Low (< 0.5 SD; \( n = 18 \)), Medium (< 0.5 SD >; \( n = 34 \)), and High (> 0.5 SD; \( n = 18 \)) feed efficiency groups based on their RFI values, with more negative values being efficient and positive values inefficient. The MIXED procedure of SAS was used to determine if differences existed between Low, Medium, and High RFI groups for initial age, initial BW, final BW, average BCS, ADG, DMI, RFI, and d 14 ECM, d 70 ECM, d 0 REA, d 70 REA, d 0 BF, d 70 BF, d to calving, and d to first postpartum ovulation for cows.

In order to assess the effect of heifer RFI rank (Low, Medium, or High) on subsequent performance as cows, the MIXED procedure of SAS was used to identify differences in initial age and BW, final BW, BCS, ADG, d 14 ECM, d 70 ECM, d 0 REA, d 70 REA, d 0 BF, d 70 BF, d to calving, and d to first postpartum ovulation for cows based on heifer rank. The PROC CORR procedure was used to detect correlations existing among RFI and performance parameters between heifers and cows. It was also used to identify correlations among temperament traits and performance traits, as well as correlations between heifer and cow temperament parameters.

Breed differences for RFI in Phase I and II, as well as d 14 and 70 ECM were analyzed using the MIXED procedure of SAS, where breed was the predictor variable. The PDIF option was used for pair-wise comparisons of least squared means.

Cows that resumed normal estrous activity by d 70 of the feed efficiency test received a value for days to estrus based on concentrations of plasma progesterone. The remaining
anestrous cows were assigned a missing value. The CORR procedure of SAS was used to establish the relationship between cycling status and heifer/cow RFI and RFI rank. The MIXED procedure of SAS was also used to identify differences in days to estrus among High, Medium, and Low RFI groups as heifers and cows. In order to investigate whether RFI or RFI rank affected time at which cows calved during the 2010 calving season, the CORR and MIXED procedures of SAS were used as previously described.

To determine whether performance and feed intake of the suckling calves was associated with feed efficiency, feed intake, and performance of their dam as a growing heifer or lactating cow, PROC CORR was used. Variables examined were calf total DMI, calf DMI from feed, calf DMI from ECM, calf G:F, dam RFI as a cow, and dam RFI as a heifer.

Significance was declared when $P < 0.05$, and a tendency was declared when $P < 0.10$.

**Results**

Heifers in Phase I had a mean initial age of 290.3 d (SD = 22.4 d), initial BW of 257.9 kg (SD = 28.3 kg), final BW of 311.5 kg (SD = 30.3 kg), daily DMI of 9.67 kg (SD = 1.50 kg), ADG of 0.82 kg/d (SD = 0.15 kg/d), and RFI of 0.00 kg/d (SD = 1.04 kg/d). As mature cows in Phase II, they had a mean initial age of 3.08 yr or 1122.7 d (SD = 0.10 or 35.0, respectively), initial BW of 428.9 kg (SD = 41.7 kg), final BW of 440.7 kg (SD = 43.3 kg), daily DMI of 16.32 kg (SD = 3.21 kg), and ADG of 0.19 kg/d (SD = 0.31 kg/d).

During Phase I, initial age, initial BW and final BW, BCS, and ADG of heifers did not differ among groups (Table 2-2) when heifers were placed into groups based on their RFI values (Low, Medium, or High RFI). Average daily DMI for Low RFI heifers (8.47 ± 0.24 kg/d) was 12% less ($P < 0.0001$) than Medium heifers (9.63 ± 0.24 kg/d) and 22% less ($P < 0.0001$) than High heifers (10.82 ± 0.23 kg/d). In addition, Medium heifers also consumed 11% less ($P <
0.0001) feed per day than High heifers. Individual heifer RFI values ranged from −2.27 kg/d DM (most efficient) to 2.01 kg/d DM (least efficient).

Similar to Phase I, initial age, initial BW, average BCS, and ADG of cows did not differ among RFI groups during Phase II; however, DMI varied significantly for all groups (Table 2-3). The most efficient cows (Low) had the lowest \( (P < 0.05) \) daily DMI \((13.76 \pm 0.56 \text{ kg/d})\), Medium cows had intermediate daily DMI \((16.43 \pm 0.43 \text{ kg/d})\) and High cows had the greatest \( (P < 0.05) \) DMI \((19.58 \pm 0.62 \text{ kg/d})\). In addition, d 14 and 70 ECM, d 0 and 70 BF, d 0 and 70 REA, d to calving, and d to first postpartum ovulation were similar for all classes of cows. A greater number of cows fell into the Medium RFI classification \((n = 34)\) than the Low \((n = 20)\) and High \((n = 16)\) groups. Individual RFI values for the cows ranged from -5.79 kg/d DM (most efficient) to 8.51 kg/d (least efficient).

Cow performance data based on heifer RFI category (Low, Medium, or High) is represented in Table 2-4. The least efficient (High) heifers were 25 d younger \( (P < 0.05) \) at the start of Phase II than the intermediate (Medium) heifers, but were similar in age to the most efficient (Low) heifers. In addition, High heifers were lighter \((417.0 \pm 8.3 \text{ kg}; P < 0.05)\) at the beginning of phase II than Medium \((444.6 \pm 8.0 \text{ kg})\) heifers, but were similar in weight to Low heifers. However, final weight and ADG of cows was not affected by RFI ranking as heifers. Cows which were most efficient as heifers (those in the Low group) had lesser \( (P < 0.05) \) daily DMI \((13.6 \pm 0.6 \text{ kg/d})\) than Medium \((15.5 \pm 0.6 \text{ kg/d})\) and High \((15.7 \pm 0.6 \text{ kg/d})\) cows that were less efficient as heifers. Cows which were classified as Low RFI as heifers also possessed RFI values that were lower \( (P < 0.05) \) than cows ranked Medium or High as heifers. In addition, heifers that were regarded as least efficient (High) produced greater \( (P < 0.05) \) quantities of ECM \((6.27 \pm 0.36 \text{ kg/d on d 14}; 5.40 \pm 0.31 \text{ kg/d on d 70})\) than the Medium \((4.66 \pm 0.38 \text{ on d})\).
14; 4.00 ± 0.33 on d 70) and Low (4.66 ± 0.38 on d 14; 4.58 ± 0.33 on d 70) groups. There were no differences in carcass composition when cows were grouped by heifer feed efficiency ranking. However, cows which were least efficient as heifers (High) tended \((P < 0.10)\) to calve 15 d earlier than cows which were Medium heifers. Number of days to first postpartum ovulation was similar for all cows when sorted by heifer RFI rank.

Table 2-5 represents correlation coefficients of various traits for heifers and cows. The relationship between RFI measured in heifers and that measured in lactating cows was not significant \((r = 0.187; P = 0.122)\) nor was the relationship between heifer and cow RFI ranks \((r = 0.175; P = 0.148)\). However, heifer RFI rank and cow RFI tended to be positively correlated \((r = 0.227; P = 0.0585)\). Heifer ADG was positively correlated with DMI \((r = 0.444; P = 0.001)\) and RFI \((r = 0.237; P = 0.048)\) and tended to be negatively correlated with both measurements of BF for cows \((r = -0.211; P = 0.081 \text{ on d 0 and } r = -0.207; P = 0.086 \text{ on d 70})\). Heifer DMI was also positively correlated with DMI, RFI, and d 70 ECM for cows, and there was a tendency for heifer DMI to be correlated with cow ADG, d 70 BF, and d 14 ECM. Heifer RFI was positively correlated with DMI \((r = 0.299; P = 0.010)\) and d 70 ECM \((r = 0.240; P = 0.040)\), and tended to be correlated with d 14 ECM \((r = 0.211; P = 0.071)\). Positive correlations also existed between heifer RFI rank and cow DMI \((r = 0.288; P = 0.0128)\) and d 0 BF \((r = 0.241; P = 0.046)\), with a tendency to be positively correlated with d 70 ECM \((r = 0.204; P = 0.081)\). Heifer age was positively correlated \((P < 0.05)\) with cow ADG, DMI, and RFI, such that older heifers had higher gains, higher intakes, and poorer feed efficiency as cows. Negative correlations were detected between heifer age and d 14 ECM \((r = -0.257; P = 0.027)\), as well as heifer age and d 70 BF \((r = -0.425; P = 0.001)\). Heifer age also tended to be negatively correlated \((r = -0.233; P = 0.054)\).
with BF on d 0. There were no correlations observed between heifer performance/feed efficiency and REA.

Pearson correlation coefficients between temperament traits (CS, EV, PS for heifers and cows) and performance traits for heifers and cows are represented in Table 2-6. Chute scores recorded during Phase I were negatively associated with ADG in Phase I ($r = -0.281; P = 0.016$) and Phase II (-0.315; $P = 0.006$), such that more excitable heifers had reduced ADG for two physiologically different states. Heifer CS was negatively correlated ($P < 0.05$) with ECM on d 14 and 70, indicating that more excitable heifers produced more ECM throughout lactation as cows. Like CS, heifer EV was negatively associated with cow ADG and positively associated with ECM 14, but only tendencies were observed. Heifer PS was not related to heifer or cow performance; however, cow PS tended ($P < 0.10$) to be negatively correlated with DMI in heifers ($r = -0.195$) and cows ($r = -0.203$) as well as d to calving ($r = -0.206$), and was also negatively correlated with d to first postpartum ovulation ($r = -0.300; P < 0.05$). In addition, cow CS was negatively associated ($P < 0.05$) with cow ADG ($r = -0.294$) and d to first postpartum ovulation ($r = -0.256$). Cow CS was positively correlated ($P < 0.01$) with ECM on d 14 ($r = 0.455$) and d 70 ($r = 0.328$). Average exit velocity recorded for cows in Phase II was not related to heifer or cow performance traits.

Pearson correlation coefficients among temperament parameters and RFI/RFI rank for heifers and cows showed no association between heifer RFI/RFI rank and temperament parameters evaluated in both phases. Cow rank was negatively correlated with heifer PS ($r = -0.283; P = 0.018$) but not cow PS ($r = -0.133; P = 0.272$), and was unrelated to remaining temperament parameters. Mean CS, mean EV, and PS were positively correlated with one
another within each phase (Table 2-7). In addition, all temperament parameters were positively correlated between the heifer and cow phases.

Differences in breed composition for heifer RFI (Figure 1-3) were established. Angus (AN), Brahman (BH), and Romosinuano (RO) heifers had lower ($P < 0.05$) RFI values than Brahman-Romosinuano crossbred (BH × RO) heifers. Brahman heifers were also more efficient ($P < 0.05$) than Angus-Brahman crossbred (AN × BH) heifers and Angus-Romosinuano (AN × RO) crossbred heifers. When RFI was evaluated in mature cows (Figure 1-4), BH cows were most efficient, possessing the lowest RFI values ($P < 0.05$) compared to all other breeds.

Breed differences for milk production on d 14 and d 70 were observed and are presented in Figures 1-5 (d 14) and 1-6 (d 70). On d 14, AN × BH cows produced greater quantities of ECM ($P < 0.05$) than AN, BH, and RO cows; however, ECM was similar among AN × BH, AN × RO, and BH × RO crossbred cows. Milk production on d 14 was lowest ($P < 0.05$) for RO cows. On d 70, RO cows continued to yield less ECM ($P < 0.05$) compared to all other breeds. The BH × RO cows had greater d 70 ECM production ($P < 0.05$) than AN, AN × RO, BH, and RO cows. On d 70, ECM was similar between BH × RO and AN × BH cows. In addition, no differences existed in d 70 ECM among AN × BH, AN × RO, and BH cows.

During the 70-d test period, mean ADG of calves was 0.51 kg/d and they consumed an average of 0.44 kg/d of feed and 3.98 kg/d ECM (0.52 kg/d on a DM basis). Performance among male and female calves was similar for ADG ($P = 0.751$) and DMI ($P = 0.628$). Correlations were similar between total DMI of the calf and RFI of the dam during lactation ($P = 0.875$, $r = 0.0191$) and RFI of the dam as a heifer ($P = 0.9714$, $r = 0.004$). In addition, there was no correlation between DMI of the dam as a lactating cow and total DMI of the calf ($P = 0.172$, $r = 0.160$), or between DMI as a heifer and the total calf DMI ($P = 0.340$, $r = 0.112$). Calf G:F was
not correlated to the dam RFI as a cow \( (P = 0.301 \ r = -0.125) \) or RFI as a heifer \( (P = 0.741 \ r = 0.039) \). No significant correlations were observed between the amount of DMI from feed consumed to the amount of DM from the milk being consumed by the calf \( (P = 0.498, \ r = 0.080) \). There was a correlation between G:F and the DMI of feed of the calf \( (P = 0.0002, \ r = 0.424) \); however, DMI of ECM consumed and the G:F of calves \( (P = 0.040, \ r = -0.238) \) were not related.

**Discussion**

Mean ADG of heifers during Phase I was slightly lower than those reported in similar studies for growing heifers (Kelly et al., 2010a; Lancaster et al., 2009a) and may be a function of the relatively high forage content of the diet. Mean ADG for cows was low and positive, indicating that the diet fulfilled maintenance requirements for lactation while minimizing the potential for substantial increases in adipose tissue deposition.

In the heifer RFI model, ADG and MBW accounted for 52% of the variation in daily DMI. In young *Bos taurus* crossbred heifers, it was reported that ADG and MBW accounted for 77% of the variation in DMI (Kelly et al., 2010a); however, it was also reported that 30% of the variation in daily DMI was explained by ADG and MBW in tropically adapted *Bos taurus* and *Bos indicus* cattle (Elzo et al., 2009). The cow RFI model, which was adjusted for d 14 ECM, d 70 ECM, and d 70 BF, accounted for 42% of the variation in DMI. The model resulted in independence from ECM and BF, as these traits were all similar among Low, Medium, and High ranked cows (Table 2-4). Cow ADG, MBW, d 14 ECM, d 70 ECM, and d 70 BF contributed 65.0, 3.0, 14.3, 13.5, and 4.2% to the overall model, respectively, indicating that ADG and ECM are large contributors to the variation in DMI. The large proportion of remaining variation is likely due to complex cellular and metabolic processes (Herd and Arthur, 2009; Moore et al., 2009) that have yet to be identified.
Because the model for RFI is phenotypically independent of body weight and growth, it is not surprising that ranking heifers and cows into Low, Medium, and High RFI groups did not affect initial weight, final weight, or ADG among groups. Kelly et al. (2010a) reported this phenotypic independence in weaned heifers and also observed a similar range in RFI values between the most and least efficient heifers (-1.25 to 1.87 kg/d, respectively). The range in cow RFI values cannot be compared within the literature because this is the first data collected in lactating beef cows where actual DMI for each individual cow was measured in an RFI test. However, the wide range in RFI values between the most and least efficient cows indicates that a greater degree of variation in RFI may exist for increased levels of maturity and DMI, when milk production and d 70 BF were considered. Systematic reductions in DMI for decreasing RFI rank groups which were observed in Phase I and Phase II have also been reported by several groups for growing cattle (Elzo et al., 2009; Lancaster et al., 2009a; Shaffer et al., 2010), confirming that more efficient cattle consume less feed for similar body weights and growth rates.

Correlations between RFI/RFI rank measured for cows and heifers were not significant in this study. This may indicate that relative within-animal efficiency was not maintained as a female develops from a growing heifer to a mature, lactating cow. When RFI was evaluated in crossbred Bos taurus heifers within the growing phase and the subsequent finishing phase, a relatively high estimate of repeatability (r = 0.62; P < 0.0001) was reported (Kelly et al., 2010b). Moderate correlations were also observed between RFI values for growing heifers and RFI values for subsequently reevaluated gestating cows (r = 0.51, P < 0.001; Morgan et al., 2010) or non-pregnant, non-lactating mature cows (r = 0.40, P-value not reported; Archer et al., 2002), resulting in the previous suggestion that post-weaning RFI may be an accurate predictor of feed efficiency throughout the beef female’s lifetime. However, it appears that the relationship
between post-weaning and mature cow RFI is unclear when cows are lactating and nursing calves.

The most efficient (Low) heifers consumed the least DM as cows and maintained the most desirable feed efficiency while producing comparable amounts of ECM at peak lactation. Cows that were Low heifers also maintained similar body condition and reproductive performance compared to cows which were least efficient as heifers. Although DMI and cow RFI were similar between cows ranked Medium and High as heifers, the Medium group appeared to have poorer performance, with significantly decreased ECM production throughout lactation compared with the High group. In contrast to High heifers, the Medium heifers tended to calve later in the calving season as 3-yr old cows were therefore older as cows. A trend for low RFI cows to calve 5 d later on average than high RFI cows has been observed (Arthur et al., 2005), and dams producing Low RFI progeny were reported to calve 5 to 6 d later in the year ($P < 0.001$) than cows that produced Medium and High RFI progeny (Basarab et al., 2007); however there was no reported difference in pregnancy rate among RFI groups. Nevertheless, late-calving cows which tend to become pregnant later in the subsequent breeding season may fail to become pregnant in subsequent years.

In contrast to our results, it has been reported that divergent lines of cows selected to produce low and high RFI progeny had similar milk yield (7.5 ± 0.3 vs. 7.8 ± 0.3 kg/d) and similar performance (Arthur et al., 2005). However, positive correlations observed between d 14 ECM and heifer DMI/RFI, as well as between d 70 ECM and heifer DMI, RFI, and RFI rank confirm that the least efficient heifers produced the greatest amounts of ECM in this study. In addition, reports have indicated the importance of milk production on the performance of suckling calves, as increasing milk yield resulted in greater weaning weight, efficiency to
weaning (Kress et al., 1969; Marshall et al., 1976; Freking and Marshall, 1992), increased weight at slaughter (Clutter and Nielsen, 1987; Lewis et al., 1990), and increased efficiency to slaughter (Miller et al., 1999). However, conflicting results demonstrate that maximizing milking ability may not necessarily be desirable. Some studies have reported that greater milk yield resulted in reduced efficiency to slaughter (Cartwright, 1970) and increased maintenance requirements (Montaño-Bermudez et al., 1990). It has also been reported that a 1-kg/d increase in milk yield for first lactation beef cows was associated with a greater number of services per pregnancy ($P = 0.02$) and days to pregnancy ($P = 0.03$) as heifers (Fiss and Wilton, 1989). Therefore, milk production needs to be considered when optimizing the economic and biological efficiency of a cow-calf operation.

Although correlations indicated that heifers with higher ADG and DMI tended to have reduced BF thickness as cows, carcass composition as mature, lactating cows was not affected by relative feed efficiency rank as heifers. Arthur et al. (2005) did not compare heifer and cow performance within animal; however, they observed that divergent selection for low and high RFI lines of cattle across 3 mating seasons resulted in high RFI cows with significantly higher rib fat depths. Therefore, a genetic component for fat deposition based on energetic efficiency may be important to consider when selecting for cattle based on RFI.

The duration of postpartum anestrous was similar among all RFI groups based on heifer and cow RFI ranks, indicating that selection for improved feed efficiency as heifers or cows may have little effect on reproductive performance. However, because only 20% of the cows resumed postpartum estrous cycles during the feeding trial, there likely was insufficient statistical power to detect any potential differences in the length of the postpartum interval.
Overall, when considering relationships between heifer RFI and mature cow performance in this study, it appears that selecting the most feed efficient heifers based on post-weaned RFI may not result in subsequent changes in performance or productivity for mature cows during lactation.

Cow RFI rank was not correlated to any temperament parameters except for heifer PS. Cow PS was the only temperament trait related with heifer or cow DMI, and its negative association indicates that lower feed consumption may be a function of increased excitability. More temperamental heifers and cows also had reduced ADG, which was likely a result of decreased DMI. Similarly, it has been reported that flight speed (FS; similar to EV but cattle traverse 2.44 m after leaving the squeeze chute) for Bos taurus composite steers was unrelated phenotypically to RFI and was negatively correlated with DMI ($P < 0.001$) and ADG ($r = -0.26$; $P < 0.01$), indicating that temperament traits warrant selection consideration in production scenarios (Nkrumah et al., 2007). Although cow PS was the only trait that tended to be associated with d to calving, cow PS and CS were negatively correlated with d to first postpartum ovulation. Therefore, more excitable cows may actually be associated with earlier resumption of normal estrous activity postpartum. In contrast, it has been reported that more excitable temperament decreased ($P < 0.05$) the probability of pregnancy in Brahman-influenced cows (Cooke et al., 2009). Both heifer and cow CS were positively associated with ECM production throughout lactation, indicating that more nervous cows in the squeeze chute may actually have greater milk-producing potential their counterparts.

Contrary to the findings of Nkrumah et al. (2004), who found that RFI values were similar for different breed compositions of Bos taurus cattle, breed differences for RFI values were observed during Phase I and II of this study. In heifers, purebred heifers possessed greater
feed efficiencies compared to the least efficient breed, BH × RO. In addition, BH heifers were more efficient than their Brahman-influenced crossbred counterparts. It has been suggested that increasing Brahman influence results in reduced feed consumption, as Brahman-influenced cattle tended to be more feed efficient than Angus-influenced cattle (Elzo et al., 2009). However, when breed differences for RFI in mature cows were analyzed, AN × BH cows were more efficient than purebred AN counterparts, as well as RO and BH × RO cows. Differences in RFI for various breeds of *Bos taurus* cattle have also been observed by Schenkel et al. (2004). Results from this study confirm that breed does have an effect on RFI. However, purebred BH females had consistently greater feed efficiency in the growing and lactating phases. Still, this study indicates that BH influence on AN and RO breedtypes does not necessarily result in improved feed efficiency, regardless of physiological status.
CHAPTER 4
CONCLUSION

Successful cow-calf enterprises require early identification of high quality replacement heifers in order to facilitate the selection of animals which will remain in the breeding herd. Selection of growing heifers that are highly feed efficient (Low RFI ranking) may become cows that consume less feed without compromising body condition, milk production, or reproductive performance. It also appears that some temperament traits may influence DMI, ADG, d to resumption of estrous cycles in the postpartum cow, and milk production throughout lactation. In addition, diverse breedtypes in this study demonstrated significant variation in RFI and ECM, indicating that breedtype and ECM may need to be considered when evaluating mature suckled beef cows for RFI. Understanding the energetic efficiency of growing and mature cattle, as well as their relationship to one another still remains an important factor in the selection of replacement females. While this study provides insight to the phenotypic relationships between RFI as heifers and as cows, more research is needed to fully understand the impact of feed efficiency selection on the entire beef cattle production system.
Figure 1-1. Schematic for data collection of heifers during Phase I. BCS = body condition score; BS = blood sample; BW = body weight; Carc U/S = carcass ultrasound; CS = chute score; EV = exit velocity; HH = hip height; PS = pen score
Figure 1-2. Schematic for data collection of cows during Phase II. BCS = body condition score; BS = blood sample; BW = body weight; Carc U/S = carcass ultrasound; CS = chute score; EV = exit velocity; HH = hip height; PS = pen score. All measurements taken on cows except those noted for calves.
Figure 1-3. Residual feed intake of heifers (Phase I) associated with breed. \( a,b,c \) Means differ \((P < 0.05)\). A = Angus, \( n = 14 \); B = Brahman, \( n = 11 \); R = Romosinuano, \( n = 22 \); AN × BH = Angus × Brahman, \( n = 10 \); AN × RO = Angus × Romosinuano, \( n = 9 \); BH × RO = Brahman × Romosinuano, \( n = 8 \)
Figure 1-4. Residual feed intake of lactating (Phase II) associated with breed. \(^{a,b,c}\) Means differ \((P < 0.05)\). A = Angus, n = 14; B = Brahman, n = 11; R = Romosinuano, n = 22; AN × BH = Angus × Brahman, n = 10; AN × RO = Angus × Romosinuano, n = 9; BH × RO = Brahman × Romosinuano, n = 8
Figure 1-5. Association of breedtype on d 14 energy-corrected milk (ECM) production. 

Superscript letters (a, b, c) indicate means differ (P < 0.05). 

- A = Angus, n = 14
- B = Brahman, n = 11
- R = Romosinuano, n = 22
- AN × BH = Angus × Brahman, n = 10
- AN × RO = Angus × Romosinuano, n = 9
- BH × RO = Brahman × Romosinuano, n = 8
Figure 1-6. Association of breedtype on d 70 energy-corrected milk (ECM) production. 
\(a, b, c\) Means differ (P < 0.05). A = Angus, n = 14; B = Brahman, n = 11; R = Romosinuano, n = 22; AN \(\times\) BH = Angus \(\times\) Brahman, n = 10; AN \(\times\) RO = Angus \(\times\) Romosinuano, n = 9; BH \(\times\) RO = Brahman \(\times\) Romosinuano, n = 8.
Table 2-1. Nutrient composition of diets fed in Phase I and II

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Phase I&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Phase II&lt;sup&gt;c&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry matter (DM), %</td>
<td>90.0</td>
<td>64.0</td>
</tr>
<tr>
<td>Crude protein, %</td>
<td>14.1</td>
<td>16.0</td>
</tr>
<tr>
<td>NE&lt;sub&gt;M&lt;/sub&gt;, mcal/kg DM</td>
<td>1.5</td>
<td>1.0</td>
</tr>
<tr>
<td>NE&lt;sub&gt;G&lt;/sub&gt;, mcal/kg DM</td>
<td>0.9</td>
<td>0.4</td>
</tr>
<tr>
<td>NE&lt;sub&gt;L&lt;/sub&gt;, mcal/kg DM</td>
<td>-</td>
<td>0.8</td>
</tr>
</tbody>
</table>

<sup>a</sup> NE<sub>M</sub> = net energy for maintenance; NE<sub>G</sub> = net energy for gain; NE<sub>L</sub> = net energy for lactation.
<sup>b</sup> Phase in which heifer RFI and performance was evaluated (2007).
<sup>c</sup> Phase in which cow RFI and performance was evaluated (2010).
Table 2-2. Heifer performance characteristics for Low, Medium, and High RFI ranked heifers (Phase I)\textsuperscript{a}.

<table>
<thead>
<tr>
<th>Trait</th>
<th>RFI Classification\textsuperscript{b}</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of heifers</td>
<td></td>
<td>24</td>
<td>24</td>
<td>26</td>
<td>-</td>
</tr>
<tr>
<td>Initial age, d</td>
<td></td>
<td>295.8 ± 4.6</td>
<td>298.6 ± 4.6</td>
<td>288.9 ± 4.4</td>
<td>0.2923</td>
</tr>
<tr>
<td>Initial BW, kg</td>
<td></td>
<td>260.3 ± 5.8</td>
<td>253.4 ± 5.8</td>
<td>259.6 ± 5.6</td>
<td>0.6318</td>
</tr>
<tr>
<td>Final BW, kg</td>
<td></td>
<td>313.1 ± 6.2</td>
<td>307.7 ± 6.2</td>
<td>313.6 ± 6.0</td>
<td>0.7550</td>
</tr>
<tr>
<td>BCS</td>
<td></td>
<td>5.83 ± 0.06</td>
<td>5.79 ± 0.06</td>
<td>5.88 ± 0.06</td>
<td>0.5261</td>
</tr>
<tr>
<td>ADG, kg/d</td>
<td></td>
<td>0.81 ± 0.03</td>
<td>0.84 ± 0.03</td>
<td>0.82 ± 0.03</td>
<td>0.7638</td>
</tr>
<tr>
<td>DMI, kg/d</td>
<td></td>
<td>8.47 ± 0.24\textsuperscript{x}</td>
<td>9.63 ± 0.24\textsuperscript{y}</td>
<td>10.82 ± 0.23\textsuperscript{z}</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>RFI, kg/d</td>
<td></td>
<td>-1.19 ± 0.09\textsuperscript{x}</td>
<td>-0.02 ± 0.09\textsuperscript{y}</td>
<td>1.12 ± 0.08\textsuperscript{z}</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

\textsuperscript{a}ADG = average daily gain; BCS = body condition score; BW = body weight; DMI = dry matter intake; RFI = residual feed intake;
\textsuperscript{b}Heifers were sorted and placed into Low (< 0.5 SD), Medium (< 0.5 SD >), and High (> 0.5 SD) RFI groups based on their RFI values, with more negative values (Low) being efficient and positive values (High) inefficient.
\textsuperscript{xyz} Significant differences of Least Squared Means within a row (P < 0.05).
Table 2-3. Cow performance characteristics when cows are categorized as Low, Medium, or High RFI ranked cows (Phase II)<sup>a</sup>

<table>
<thead>
<tr>
<th>Trait</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of cows</td>
<td>20</td>
<td>34</td>
<td>16</td>
<td>-</td>
</tr>
<tr>
<td>Initial age, d</td>
<td>1118.4 ± 7.7</td>
<td>1117.4 ± 5.9</td>
<td>1137.5 ± 8.6</td>
<td>0.1395</td>
</tr>
<tr>
<td>Initial BW, kg</td>
<td>433.82 ± 9.33</td>
<td>432.71 ± 7.16</td>
<td>422.04 ± 10.44</td>
<td>0.6463</td>
</tr>
<tr>
<td>Final BW, kg</td>
<td>444.27 ± 9.89</td>
<td>441.23 ± 7.59</td>
<td>440.00 ± 11.06</td>
<td>0.9367</td>
</tr>
<tr>
<td>Average BCS</td>
<td>4.48 ± 0.13</td>
<td>4.47 ± 0.10</td>
<td>4.3 ± 0.15</td>
<td>0.7470</td>
</tr>
<tr>
<td>ADG, kg/d</td>
<td>0.20 ± 0.07</td>
<td>0.16 ± 0.05</td>
<td>0.22 ± 0.08</td>
<td>0.7408</td>
</tr>
<tr>
<td>DMI, kg/d</td>
<td>13.76 ± 0.56&lt;sup&gt;x&lt;/sup&gt;</td>
<td>16.43 ± 0.43&lt;sup&gt;y&lt;/sup&gt;</td>
<td>19.58 ± 0.62&lt;sup&gt;z&lt;/sup&gt;</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>RFI, kg/d</td>
<td>-2.69 ± 0.27&lt;sup&gt;x&lt;/sup&gt;</td>
<td>0.06 ± 0.21&lt;sup&gt;y&lt;/sup&gt;</td>
<td>3.24 ± 0.31&lt;sup&gt;z&lt;/sup&gt;</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>d 14 ECM, kg/d</td>
<td>5.48 ± 0.43</td>
<td>5.67 ± 0.33</td>
<td>5.24 ± 0.48</td>
<td>0.7537</td>
</tr>
<tr>
<td>d 70 ECM, kg/d</td>
<td>4.66 ± 0.38</td>
<td>4.81 ± 0.29</td>
<td>4.52 ± 0.42</td>
<td>0.8427</td>
</tr>
<tr>
<td>d to calving</td>
<td>34.15 ± 5.16</td>
<td>31.06 ± 4.02</td>
<td>37.94 ± 5.77</td>
<td>0.6158</td>
</tr>
<tr>
<td>d to first estrous</td>
<td>86.90 ± 1.75</td>
<td>86.65 ± 1.34</td>
<td>86.94 ± 1.96</td>
<td>0.9896</td>
</tr>
</tbody>
</table>

<sup>a</sup>ADG = average daily gain; BCS = body condition score; BW = body weight; DMI = dry matter intake; ECM = energy corrected milk; RFI = residual feed intake.

<sup>b</sup>Cows were sorted and placed into Low (< 0.5 SD), Medium (< 0.5 SD >), and High (> 0.5 SD) efficiency groups based on their Phase II RFI values, with more negative values (Low) being efficient and positive values (High) inefficient.

<sup>x</sup><sup>y</sup><sup>z</sup> Significant differences of Least Squared Means within a row (P < 0.05).
Table 2-4. Cow performance, milk, and carcass ultrasound parameters (Phase II) based on heifer rankings considered as Low, Medium, and High feed efficiency categories.\(^a\)

<table>
<thead>
<tr>
<th>Trait</th>
<th>RFI Classification(^b)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>No. of cows</td>
<td>24</td>
</tr>
<tr>
<td>Initial age, d</td>
<td>1123.2 ± 6.9(^xy)</td>
</tr>
<tr>
<td>Initial BW, kg</td>
<td>423.9 ± 8.28(^xy)</td>
</tr>
<tr>
<td>Final BW, kg</td>
<td>433.5 ± 8.9</td>
</tr>
<tr>
<td>BCS</td>
<td>4.35 ± 0.12</td>
</tr>
<tr>
<td>ADG, kg/d</td>
<td>0.30 ± 0.10</td>
</tr>
<tr>
<td>DMI, kg/d</td>
<td>13.6 ± 0.60(^x)</td>
</tr>
<tr>
<td>Cow RFI, kg/d</td>
<td>-1.17 ± 0.50(^x)</td>
</tr>
<tr>
<td>d 14 ECM, kg/d</td>
<td>5.45 ± 0.38(^xy)</td>
</tr>
<tr>
<td>d 70 ECM, kg/d</td>
<td>4.58 ± 0.33(^xy)</td>
</tr>
<tr>
<td>d 0 REA, cm(^2)</td>
<td>31.15 ± 1.07</td>
</tr>
<tr>
<td>d 70 REA, cm(^2)</td>
<td>28.37 ± 1.02</td>
</tr>
<tr>
<td>d 0 BF, cm(^2)</td>
<td>0.24 ± 0.01</td>
</tr>
<tr>
<td>d 70 BF, cm(^2)</td>
<td>0.27 ± 0.01</td>
</tr>
<tr>
<td>d to calving</td>
<td>31.83 ± 4.52</td>
</tr>
<tr>
<td>d to first postpartum ovulation</td>
<td>86.4 ± 1.6</td>
</tr>
</tbody>
</table>

\(^a\)ADG = average daily gain; BCS = body condition score; BF = backfat; DMI = dry matter intake; ECM = energy corrected milk; RFI = residual feed intake; REA = ribeye area.

\(^b\)Heifers were sorted and placed into Low (<0.5 SD), Medium (<0.5 SD >), and High (>0.5 SD) efficiency groups based on their RFI values, with more negative values (Low) being efficient and positive values (High) inefficient.

\(^xy\) Significant differences of Least Squared Means within a row (P < 0.05).
Table 2-5. Pearson correlation coefficients among feed efficiency and performance parameters between heifers and cows\textsuperscript{a}.

<table>
<thead>
<tr>
<th></th>
<th>Heifer ADG</th>
<th>Heifer DMI</th>
<th>Heifer RFI</th>
<th>Heifer rank\textsuperscript{b}</th>
<th>Heifer age</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-----------</td>
<td>------------</td>
<td>------------</td>
<td>-------------------------------</td>
<td>------------</td>
</tr>
<tr>
<td>Cow ADG</td>
<td>0.179 (0.127)</td>
<td>0.203 (0.083)</td>
<td>-0.017 (0.884)</td>
<td>-0.021 (0.857)</td>
<td>0.371 (0.001)</td>
</tr>
<tr>
<td>Cow DMI</td>
<td>0.444 (0.001)</td>
<td>0.633 (0.001)</td>
<td>0.299 (0.010)</td>
<td>0.288 (0.013)</td>
<td>0.295 (0.011)</td>
</tr>
<tr>
<td>Cow RFI</td>
<td>0.237 (0.048)</td>
<td>0.293 (0.014)</td>
<td>0.187 (0.122)</td>
<td>0.227 (0.059)</td>
<td>0.237 (0.048)</td>
</tr>
<tr>
<td>Cow rank\textsuperscript{b}</td>
<td>0.155 (0.201)</td>
<td>0.215 (0.074)</td>
<td>0.151 (0.213)</td>
<td>0.175 (0.148)</td>
<td>0.207 (0.085)</td>
</tr>
<tr>
<td>d 14 ECM</td>
<td>0.077 (0.512)</td>
<td>0.211 (0.071)</td>
<td>0.211 (0.071)</td>
<td>0.184 (0.117)</td>
<td>-0.257 (0.027)</td>
</tr>
<tr>
<td>d 70 ECM</td>
<td>0.101 (0.393)</td>
<td>0.277 (0.017)</td>
<td>0.240 (0.040)</td>
<td>0.204 (0.081)</td>
<td>-0.181 (0.123)</td>
</tr>
<tr>
<td>d 0 BF</td>
<td>-0.211 (0.081)</td>
<td>-0.035 (0.775)</td>
<td>0.119 (0.331)</td>
<td>0.241 (0.046)</td>
<td>-0.233 (0.054)</td>
</tr>
<tr>
<td>d 70 BF</td>
<td>-0.207 (0.086)</td>
<td>-0.224 (0.062)</td>
<td>0.016 (0.895)</td>
<td>0.120 (0.117)</td>
<td>-0.425 (0.001)</td>
</tr>
</tbody>
</table>

\textsuperscript{a}ADG = average daily gain; BF = backfat; DMI = dry matter intake; ECM = energy corrected milk; RFI = residual feed intake.

\textsuperscript{b}Rank refers to heifers or cows being sorted and placed into Low (<0.5 SD), Medium (<0.5 SD >), and High (>0.5 SD) efficiency groups based on their RFI values, with more negative values (Low) being efficient and positive values (High) inefficient.
Table 2-6. Pearson correlation coefficients among temperament traits and performance or productivity traits\(^a\).

<table>
<thead>
<tr>
<th>Heifer CS</th>
<th>Heifer EV</th>
<th>Heifer PS</th>
<th>Cow CS</th>
<th>Cow EV</th>
<th>Cow PS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heifer DMI</td>
<td>-0.116</td>
<td>-0.123</td>
<td>-0.059</td>
<td>0.088</td>
<td>0.088</td>
</tr>
<tr>
<td>(0.324)</td>
<td>(0.296)</td>
<td>(0.619)</td>
<td>(0.458)</td>
<td>(0.458)</td>
<td>(0.096)</td>
</tr>
<tr>
<td>Heifer ADG</td>
<td>-0.281</td>
<td>-0.026</td>
<td>-0.111</td>
<td>-0.028</td>
<td>-0.028</td>
</tr>
<tr>
<td>(0.016)</td>
<td>(0.829)</td>
<td>(0.346)</td>
<td>(0.815)</td>
<td>(0.815)</td>
<td>(0.605)</td>
</tr>
<tr>
<td>Cow DMI</td>
<td>-0.083</td>
<td>-0.129</td>
<td>-0.181</td>
<td>0.071</td>
<td>-0.144</td>
</tr>
<tr>
<td>(0.482)</td>
<td>(0.273)</td>
<td>(0.123)</td>
<td>(0.550)</td>
<td>(0.220)</td>
<td>(0.082)</td>
</tr>
<tr>
<td>Cow ADG</td>
<td>-0.315</td>
<td>-0.202</td>
<td>-0.141</td>
<td>-0.294</td>
<td>-0.037</td>
</tr>
<tr>
<td>(0.006)</td>
<td>(0.084)</td>
<td>(0.229)</td>
<td>(0.011)</td>
<td>(0.753)</td>
<td>(0.105)</td>
</tr>
<tr>
<td>d to calving</td>
<td>-0.069</td>
<td>-0.150</td>
<td>0.113</td>
<td>-0.022</td>
<td>0.021</td>
</tr>
<tr>
<td>(0.564)</td>
<td>(0.205)</td>
<td>(0.342)</td>
<td>(0.854)</td>
<td>(0.859)</td>
<td>(0.081)</td>
</tr>
<tr>
<td>d to estrous</td>
<td>-0.167</td>
<td>0.010</td>
<td>-0.147</td>
<td>-0.256</td>
<td>0.165</td>
</tr>
<tr>
<td>(0.155)</td>
<td>(0.932)</td>
<td>(0.212)</td>
<td>(0.028)</td>
<td>(0.160)</td>
<td>(0.010)</td>
</tr>
<tr>
<td>ECM 14</td>
<td>0.239</td>
<td>0.207</td>
<td>0.093</td>
<td>0.455</td>
<td>-0.009</td>
</tr>
<tr>
<td>(0.041)</td>
<td>(0.076)</td>
<td>(0.428)</td>
<td>(0.001)</td>
<td>(0.938)</td>
<td>(0.553)</td>
</tr>
<tr>
<td>ECM 70</td>
<td>0.251</td>
<td>0.171</td>
<td>0.110</td>
<td>0.328</td>
<td>-0.072</td>
</tr>
<tr>
<td>(0.031)</td>
<td>(0.146)</td>
<td>(0.325)</td>
<td>(0.004)</td>
<td>(0.545)</td>
<td>(0.725)</td>
</tr>
</tbody>
</table>

\(^a\)CS = average chute score; DMI = dry matter intake; ECM = energy corrected milk; EV = average exit velocity; PS = pen score.
Table 2-7. Pearson correlation coefficients among heifer and cow temperament parameters\(^a\).

<table>
<thead>
<tr>
<th></th>
<th>Heifer CS</th>
<th>Heifer EV</th>
<th>Heifer PS</th>
<th>Cow CS</th>
<th>Cow EV</th>
<th>Cow PS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heifer CS</td>
<td>-</td>
<td>0.271</td>
<td>0.498</td>
<td>0.400</td>
<td>0.227</td>
<td>0.382</td>
</tr>
<tr>
<td></td>
<td>(0.019)</td>
<td>(&lt;0.0001)</td>
<td>(0.0004)</td>
<td>(0.052)</td>
<td>(0.0008)</td>
<td></td>
</tr>
<tr>
<td>Heifer EV</td>
<td>0.271</td>
<td>-</td>
<td>0.474</td>
<td>0.435</td>
<td>0.604</td>
<td>0.408</td>
</tr>
<tr>
<td></td>
<td>(0.019)</td>
<td>(&lt;0.0001)</td>
<td>(0.0001)</td>
<td>(&lt;0.0001)</td>
<td>(0.0003)</td>
<td></td>
</tr>
<tr>
<td>Heifer PS</td>
<td>0.498</td>
<td>0.474</td>
<td>-</td>
<td>0.308</td>
<td>0.515</td>
<td>0.482</td>
</tr>
<tr>
<td></td>
<td>(&lt;0.0001)</td>
<td>(&lt;0.0001)</td>
<td>(&lt;0.0001)</td>
<td>(&lt;0.0001)</td>
<td>(&lt;0.0001)</td>
<td></td>
</tr>
<tr>
<td>Cow CS</td>
<td>0.400</td>
<td>0.435</td>
<td>0.308</td>
<td>-</td>
<td>0.367</td>
<td>0.445</td>
</tr>
<tr>
<td></td>
<td>(0.0004)</td>
<td>(0.0001)</td>
<td>(0.0076)</td>
<td>(&lt;0.001)</td>
<td>(&lt;0.001)</td>
<td></td>
</tr>
<tr>
<td>Cow EV</td>
<td>0.227</td>
<td>0.604</td>
<td>0.515</td>
<td>0.367</td>
<td>-</td>
<td>0.580</td>
</tr>
<tr>
<td></td>
<td>(0.052)</td>
<td>(&lt;0.0001)</td>
<td>(&lt;0.0001)</td>
<td>(0.0013)</td>
<td>(&lt;0.0001)</td>
<td></td>
</tr>
<tr>
<td>Cow PS</td>
<td>0.382</td>
<td>0.408</td>
<td>0.482</td>
<td>0.445</td>
<td>0.580</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>(0.0008)</td>
<td>(0.0003)</td>
<td>(&lt;0.0001)</td>
<td>(&lt;0.001)</td>
<td>(&lt;0.0001)</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) CS = average chute score; EV = average exit velocity; PS = pen score.
LIST OF REFERENCES


BIOGRAPHICAL SKETCH

Tera Loyd was born in Defiance, Missouri, in 1987 to Mike and Charlene Loyd. There she grew up on a small family farm, raising and showing sheep and cattle throughout her 4-H years. Tera graduated from Francis Howell High School in 2005 and began her educational career at the University of Missouri-Columbia, where she completed her Bachelor of Science degree in the field of Animal Science. Upon graduation, she moved to Florida to work in Dr. Cliff Lamb’s research program, where she has focused her studies on feed efficiency and applied reproductive strategies in beef cattle. She was also a teaching assistant for various animal science reproduction courses and received her Master of Science in the spring of 2011.