Recommended Duration for Evaluating Feed Intake and Validating the Residual Feed Intake Model in Brangus Heifers

by

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Abstract

In order to determine optimal measurement days, variables best describing variation for dry matter intake (DMI) and effect of residual feed intake (RFI) classification on reproductive and performance traits, RFI was predicted by measuring individual dry matter intake (DMI) and average daily gain (ADG) using 186 Brangus heifers from two southeastern farms over a 70 d test period during 2014 and 2015. Results from standard 70 d DMI intake trials were compared to shortened test length periods of 14, 28, 42 and 56 d by regressing 70 d values of RFI, ADG and DMI on each shortened test length. Test length to predict RFI can be shortened to 56 d without loss of prediction accuracy (R=0.93 ($P < 0.0001$), R^2= 0.90, r_p= 0.95 ($P < 0.0001$), and r_s= 0.95 ($P < 0.0001$)). Including 70 d ultrasound 12th rib fat (UBF) in prediction of RFI, along with DMI and metabolic midweight, accounted for an additional 2% of model variation suggesting inclusion of UBF measurements is warranted. There were no significant differences for ADG, beginning or ending weight or age at first calving for heifers classified as efficient, average or inefficient based on RFI values. This suggests using RFI as a measure of efficiency will not affect other economically important traits. DMI was significantly different (P< 0.001) between RFI classifications. Significant feed cost savings ($63.91) were realized between efficient and inefficient RFI heifers. Shortening the measurement period by 14 d also could provide additional feed cost savings ($11.62/hd) and allow additional animals to be measured for DMI each year.

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ADG_1	Average daily gain computed by the linear regression of weight on day on test
ADG_2	Average daily gain computed as (final BW – initial BW)/days on test
DMI	Dry matter intake
EBV	Estimated Breeding Value
FAO	Food and Agriculture Organization
FCR	Feed Conversion Ratio
LMA	Longissimus muscle area
MMWT	Metabolic midweight$^{0.75}$
P8	Rump fat depth
RADG	Residual average daily gain
RFI	Residual Feed Intake
RFI_{bf}	Residual feed intake adjusted for ultrasound backfat thickness
$RFI_{bf\ \&\ activity}$	Residual feed intake adjusted for ultrasound backfat thickness and feeding activity
RFI_{70}	Residual feed intake based on a test duration of 70 d
RFI_{56}	Residual feed intake based on a test duration of 56 d
RFI_{42}	Residual feed intake based on a test duration of 42 d
UBF	Ultrasound backfat thickness

INTRODUCTION

There is a large amount of genetic variability among and within breeds in today's beef cattle. This wide genetic base is disadvantageous for beef producers expected to provide a consistent and uniform end product, in comparison to the more specialized selection lines developed within other species. Genetic progress tends to be much slower in beef cattle due to low reproductive rates and longer generation intervals. In addition, beef cattle have three primary production stages, where animals are managed in independent sectors according to the specific phase within the supply chain. Because of the wide geographical dispersion between different operations within the production system, costs associated with transporting animals to each location further impedes vertical cooperation among the different sectors. Producers can overcome some of these barriers by improving production system efficiency through genetic selection for residual feed intake (RFI).

A robust measure of feed efficiency is difficult to quantify in the U.S. beef industry because of different energy requirements associated with each production phase. Previous measures of feed efficiency such as feed conversion ratio (FCR) were only relevant within a specific industry segment, limiting the progress of efficiency in regard to the entire production system. However, residual feed intake (RFI) partitions feed intake into portions required for stage and level of production, and a residual portion that is related to true metabolic efficiency, which is comparable across industry segments (Crews, 2005). Consistent use of seedstock animals superior for RFI can improve the efficiency of feed utilization in commercial cow herds. Long term, this may narrow the diversified genetic base and simplify the breeding systems used

by cow/calf producers, resulting in a more consistent end product. Because improving RFI can be beneficial at all stages of production, it may also help unify the different segments of the beef industry.

The overall goal of a beef cattle producer is to improve profitability. In the past, selection was focused on optimizing outputs such as growth, fertility, and carcass traits (Archer et al., 1999). More recently, there has been increased interest in reducing inputs in order to improve production efficiency and increase profits. Because providing feed to animals is a major cost to producers, improving the efficiency of feed utilization would be of significant economic benefit. Efficient feeding programs are designed to provide cattle with the essential nutrients for maintenance and growth with minimal excesses and losses (Nkrumah et al., 2007). Traditional measures of feed efficiency include feed conversion ratio (FCR) defined as the amount of feed consumed divided by live weight gain. Efficient animals with a lower FCR show a potential response in increased growth rates, mature size, and maintenance requirements (Crews, 2005). While segments of the beef industry producing growing animals may benefit from FCR, if the increased feed requirements in the breeding herd do not offset the gains in market animals, there will not be any progress in regard to total system efficiency (Archer et al., 1999). Selection against feed intake may lead to a decrease in growth and weight at maturity, which may be unfavorable for the feedlot sector (Nkrumah et al., 2004). In addition, improvement in FCR may not necessarily reflect better production system efficiency. Because it is a ratio trait, a decrease in FCR may be the result of the heavy emphasis placed on increasing growth rate or reducing feed intake. Therefore, a more desirable measure of efficiency is needed to eliminate antagonistic responses in correlated traits.

RFI was first proposed by Koch et al. (1963) in growing beef cattle and is defined as the actual feed intake minus expected feed intake based on maintenance and production requirements. Expected feed intake is calculated by regressing daily feed intake on ADG and midtest metabolic body weight (MMWT), with RFI as the remaining residual. By definition, RFI is phenotypically independent of its regression components, ADG and (metabolic) body weight, allowing for comparison between individuals differing in production during the measurement period. For example, in young animals a majority of their energy resources are devoted to growth and development. In mature cows, feed is utilized for maintenance and lactation. Using RFI as a measure of feed efficiency, animals are identified that consume less feed than expected, putting selection pressure directly on feed intake. While the majority of feed costs go towards maintaining the breeding herd, growing cattle often consume feed of higher value (Archer et al., 2002). By incorporating measures of live weight and ADG, RFI attempts to account for some of the underlying genetic variation in feed used for maintenance and growth. As a selection tool, the resulting progeny will be more efficient as slaughter animals and in the breeding herd (Arthur et al., 2001a). Therefore, improving feed efficiency using RFI would be beneficial at all levels of the production system.

REVIEW OF LITERATURE

Feed inputs are the largest input cost associated with producing beef, while profitability is highly dependent on the amount of saleable product produced for each unit of feed consumed (Nielsen et al., 2013). There are many measures of feed efficiency in beef production, yet accurately identifying feed efficient animals remain challenging. Measuring efficiency across the entire integrated beef system can be difficult due to the differing classes of cattle, breed differences, and ways in which the biological systems (nutrition, reproduction, lactation, basal metabolism) interact (Maddock et al., 2015).

Additionally, other protein producing species, such as pork and poultry, compete with beef in the marketplace. Beef animals consume large amounts of low-cost, low-quality forages relative to higher-cost concentrates compared to swine and poultry. However, beef production still needs to improve cost per unit of product because it has greater cost per edible pound (Nielsen et al., 2013). When comparing edible product per unit of feed energy input, beef production is about one-third as efficient as pork production and one-fifth to one-sixth as efficient as broiler production (Dickerson, 1978). Traditional measures of feed efficiency include feed conversion ratio (FCR) defined as the amount of feed consumed divided by live weight gain. The broiler industry has been successful at improving feed efficiency by emphasizing selection for FCR to produce faster growing birds (Nielsen et al., 2013). The swine industry has also been successful using FCR, where the majority of genetics provided to this market originate from only three to four suppliers (Nielsen et al., 2013). However, because of physiological differences between cattle and other protein producing species, the beef industry has not been as

successful at improving feed efficiency through selection for FCR. Efficient cattle with a lower FCR show a correlated response in increased growth rates, mature size, and maintenance requirements (Crews, 2005). While FCR is a useful management tool when evaluating the economics of growing and finishing cattle, it is not a good indication of feed efficiency in pregnant or lactating mature cows, which consume the most feed throughout the beef production system (Maddock et al., 2015). A similar measure called gross feed efficiency is the ratio of live-weight gain to dry matter intake (DMI).

Cow efficiency is traditionally defined as the pounds of calf weaned per pound of cow weight. Perhaps a more effective way to maximize production system efficiency is to improve feed utilization of grazing cows in the reproductive herd. Considering total herd production efficiency, 65% of the feed energy is utilized by the reproducing cow herd as opposed to the growing cattle in feedlots (Nielsen et al., 2013). However, because the cowherd primarily consumes a forage-based diet, it is difficult to measure feed intake for grazing cattle. Therefore, identifying efficient animals based on indicator traits in cattle fed primarily a grain based diet would be ideal.

Residual feed intake (RFI) is another measure of feed efficiency and can be used as a selection tool to genetically improve seedstock and slaughter animals. RFI was first proposed by Koch et al. (1963) in growing beef cattle and is defined as the actual feed intake minus expected feed intake based on maintenance and production requirements. Expected feed intake is calculated by regressing daily feed intake on ADG and MMWT. RFI is the remaining residual not accounted for by measurable traits. By definition, RFI is phenotypically independent of its regression components, ADG and MMWT, allowing for comparison between individuals differing in production during the measurement period. Statistical properties of RFI calculated by

linear regression show RFI is normally distributed (RFI ~ $N(0, \sigma^2_{RFI})$) with a mean of zero (Crews, 2005). Efficient animals have daily intakes less than predicted after accounting for production and body weight. Inefficient animals have daily intakes more than predicted after accounting for production and body weight.

Another measure of efficiency is residual average daily gain (RADG). Residual average daily gain is the difference between actual gain and predicted gain based on feed intake, body weight, and composition (MacNeil et al., 2011). Animals with a positive RADG gain weigh more than predicted and are considered more efficient.

Based on current knowledge of feed efficiency, specifically RFI, feed is utilized as energy to meet maintenance requirements, production requirements, and residual waste. Maintenance energy refers to the energy required to keep body weight and body energy constant without sacrificing production or outputs. Maintenance energy is utilized for functions such as basal metabolism, tissue repair, thermal regulation, and locomotor activity (Nielsen et al., 2013). Production energy refers to energy required for growth, lactation, reproduction, or other functions beyond maintenance. Two individual animals of the same chronological age but at different stages of development will differ in feed efficiency because of how they utilize feed they consume. A growing animal will use most feed energy for protein deposition compared to a mature animal that does not have the same energy requirements. Excess energy will be deposited as fat which is more energetically demanding and therefore, less efficient. Efficient animals are better able to digest, absorb, and utilize nutrients from the feed they consume. As ruminants, digestibility is highly dependent on how microbial populations metabolize carbohydrates, where waste is emitted in the form of methane. Therefore, efficient cattle not only have a reduced feed

intake but also lower methane emissions, which is beneficial to the environment and sustainability of beef production.

Measuring feed intake and ADG for residual feed intake (RFI)

To accurately determine RFI, individual feed intake and ADG must be measured. Currently, Beef Improvement Federation Guidelines (BIF, 2010) suggest a 21 d adaptation period followed by a 70 d test period to accurately measure feed intake and ADG using Calan® (Northwood, NH) or GrowSafe® (Airdrie, Alberta) technologies. Test length was determined from studies of Archer et al. (1997) and Wang et al. (2006). The adaptation period allows animals to acclimate to the test facility and diet, while the 70 d test period provides feed intake and weight records used to calculate rate of gain and estimate RFI. Calan® (Northwood, NH) and GrowSafe® (Airdrie, Alberta) technologies are designed to measure individual feed intake on animals housed in groups in order to minimize external effects on feeding behavior.

Archer et al. (1997) conducted a study to determine optimal duration of test length measuring growth rate, feed intake, feed conversion ratio (FCR), and RFI in 760 British breed cattle. Variance components, heritability estimates, phenotypic and genetic correlations, and efficiency of selection in shortened tests (7, 21, 35, 49, 63, 77, 91, 105 days) were compared with a 119 d test. According to Archer et al. (1997), there were few reports in the scientific literature describing optimal test length for measuring feed intake, FCR, or RFI. However, based on results from studies measuring growth rate, most centralized test stations in North America used a 140 d test. In a parent study (Arthur et al., 1996), a 119 d test was used to measure growth rate to reflect the fact that most studies recommended a test period shorter than 140 d. Therefore, 119 d was used as a benchmark to determine optimal test duration for feed intake, FCR, and RFI. The

authors found 35 d was sufficient for measuring feed intake, while 70 d with cattle weighed every two weeks was appropriate to measure growth rate, FCR, and RFI without compromising accuracy. These results suggest that the limiting factor in determining feed efficiency is the time needed to measure growth rate or ADG post-weaning.

Wang et al. (2006) conducted a study on 456 steers to determine optimum test duration for ADG, DMI, FCR, and RFI. Results indicated test length could be shortened to 35 d for DMI, 42 d for FCR, and 63 d for ADG and RFI, when body weight was measured weekly. Weighing animals weekly provided a more accurate measure of growth and feed efficiency traits and allowed for shorter on-test duration. These results further supported the conclusion made by Archer et al. (1997) that test length for RFI was limited by ADG measurements. While test duration for feed intake can be reduced by more frequent measurements, it is not practical to weigh cattle at intervals shorter than one week to reduce the test duration for growth and feed efficiency.

Culbertson et al. (2015) conducted a study to determine if DMI and RFI measurements from shorted tests lengths were comparable to standard 70 d trials recommended by BIF (2010). Data was obtained from 593 *bos taurus* bulls, steers, and heifers over a total of four 70 d performance tests. Animals were weighed every two weeks and feed intake was collected daily. Data subsets ranging from 14 to 56 d in length were used to calculate average daily DMI, RFI, MMWT, and ADG. When average daily DMI for the full 70 d test was regressed on the 42 d subset of data, the resulting regression coefficient was 0.99, an R^2 of 0.97, with a Pearson correlation coefficient of 0.97. The Spearman rank correlation was 0.97 between d 42 and 70. These results indicated a 42 d test period was sufficient to obtain an accurate measure of average daily DMI in this population. Regressing RFI full test values on the 56 d subset of data resulted

in a regression coefficient of 1.00, a R^2 of 0.89, and a Pearson correlation coefficient of 0.94. The Spearman rank correlation was 0.95, indicating a minimal change in rank of animals based on their RFI values. These results suggest a 56 d performance test should predict RFI values similar to results from a 70 d test, reducing the test duration by 2 weeks. As testing lengths increased so did the regression coefficient for ADG, reaching 0.85 at 56 d. This is in contrast with the regression coefficient for MMWT, reaching 1.01 by 14 d. Because RFI estimation is dependent on ADG and MMWT, longer test periods are required due to the accuracy of measuring ADG (Culbertson et al., 2015).

Because feed intake is highly dependent on physiological age, animals must be of similar age when feed intake tests are conducted. Cattle evaluated for post-weaning feed intake should be at least 240 d at the start and within a 60 d range of their contemporary group. Feed intake measurements should be completed before an animal reaches 390 d of age (BIF, 2010).

RFI Models

RFI is the residual term from the linear regression of DMI on ADG and MMWT. While many of the physiological factors influencing feed intake are still unknown, inclusion of ultrasound backfat thickness in the regression model can improve RFI estimation. Several studies reported RFI has weak phenotypic and genetic correlations with carcass backfat thickness (Arthur et al., 2001b; Basarab et al., 2003; Lancaster et al. 2009a,b; Nkrumah et al., 2004; Nkrumah et al., 2007; Schenkel et al., 2004). This is significant because selecting individuals with lower RFI values could result in a concomitant reduction in backfat thickness, which could potentially affect carcass measures at slaughter. Additionally, fatness and body condition affect reproductive function. Because low RFI animals tend to have less bodyfat, long-term selection

for RFI raises concerns about age at puberty and maintenance of reproduction (Arthur et al., 2005). Therefore, including body composition traits (e.g. ultrasound backfat) into the regression equation allows for selection on RFI without compromising carcass characteristics. Adjusting RFI for ultrasound backfat thickness may also prevent any negative effects on reproduction, although long-term studies are currently lacking.

Arthur et al. (2003) conducted a study to determine the effects of including ultrasound measures of body composition in the model for predicting feed requirements used in determining RFI. Traits analyzed were DMI, ADG, MMWT, end of test rump fat depth (P8), change in P8 over 70 d, end of test longissimus muscle area (LMA), change in LMA over 70 d, FCR, and RFI. Inclusion of P8 in the model (DMI= $a + b_1$MMWT+ b_2ADG + b_3P8 + residual) increased the R^2 by 3.6% and 1.8 % in males and females, respectively. Effects of other body composition traits (LMA, change in P8, and change in LMA) were minimal and not included in the new model. RFI and RFI adjusted for end of test P8 had strong phenotypic correlations for both sexes (r_{male}= 0.94, r_{female} = 0.97) and the change in rank of individuals was not significant when body composition traits were included. Therefore, the authors concluded ADG and MMWT was sufficient for predicting daily feed intake.

Schenkel et al. (2004) conducted a study with young beef bulls of six breeds and compared two measures of feed efficiency, RFI and RFI adjusted for ultrasound backfat thickness. A total of 2,284 records were used to determine RFI for Charolais, Limousin, Simmental, Hereford, Angus, and Blonde d'Aquitaine bulls. There was a 0.014 kg^2 increase in DMI variation explained by ultrasound backfat, where the respective R^2 for RFI and RFI adjusted for ultrasound backfat were 0.678 and 0.692. RFI and RFI adjusted for ultrasound backfat had a genetic correlation of 0.99, indicating they were essentially the same trait. There was only a very

minor reduction in phenotypic variance (0.95 vs. 0.92 mm) due to a reduction in residual variance when adjusting RFI for backfat. There was no change in the genetic component of variance for RFI and RFI adjusted for ultrasound backfat thickness, remaining at 0.36 mm for the two models. However, adjusting for ultrasound backfat tends to change across breed rankings for RFI, despite the high within-breed genetic correlation between the two RFI measures. RFI for Angus and Hereford improved considerably by including ultrasound backfat in the model. The two leanest breeds, Blonde d'Aquitaine and Limousin remained the most efficient with or without adjusting for subcutaneous fat based on RFI values. Hereford ranked above Charolais when adjusting for fatness, whereas RFI values for Charolais and Simmental did not change. However, since RFI measures are only comparable based on individuals within a contemporary group, there is not enough evidence to justify adjusting for ultrasound backfat thickness.

Basarab et al. (2003) conducted a study using 176 crossbred steers to quantify differences in RFI independent of differences in body composition over two consecutive years. Three different models were used to compare RFI classification with carcass trait measurements. Model 1 represented unadjusted RFI, where expected feed intake was calculated from the linear regression of DMI on ADG and MMWT. On average, Model 1 accounted for 76.9% of the variation in expected feed intake. Model 2 adjusted RFI for estimated gain in empty body fat and gain in empty body water, which accounted for an additional 3.9% and 1.1% of the variation in actual feed intake, respectively. Model 3 adjusted RFI for live animal measures of body composition, gain in ultrasound backfat thickness and gain in ultrasound marbling score, which accounted for an additional 1.8% and 1.1% of the variation in actual feed intake, respectively. RFI values from Model 1 had weak phenotypic correlations with gain in ultrasound backfat thickness (0.22, $P < 0.01$), gain in ultrasound marbling (0.22, $P < 0.01$), gain in empty body fat

(0.26, *P < 0.01*), and dissectible carcass lean (-0.21, *P < 0.01*). Successful adjustment of RFI for differences in composition of gain was confirmed by the lack of relationship (*P > 0.05*) between RFI values for Model 2 and carcass traits, empty body composition, and gain in empty body composition. As expected, RFI values from Model 3 were not related (*P > 0.05*) to most measures of body composition. However, there were weak phenotypic correlations with carcass lean (r_p= -0.17, *P= 0.04*) and gain in empty body fat (r_p= 0.22, *P < 0.01*), indicating that adjusting RFI for gain in ultrasound backfat thickness and marbling does not completely eliminate correlations with body composition. Basarab et al. (2003) concluded RFI should be adjusted for ADG, MMWT, gain in ultrasound fat thickness and gain in ultrasound marbling score (Model 3). While RFI using Model 2 was independent of body composition, these measures were obtained from carcass traits, requiring the sacrifice of the selected animal. Model 3 significantly reduced the phenotypic correlations between RFI and body composition compared to Model 1, indicating that adjusting RFI for ultrasound traits reduces the potential effects of long term selection for RFI on carcass composition.

Lancaster et al. (2009a) conducted a study with 341 Angus bulls to analyze the effects of RFI and RFI adjusted for body composition on performance traits. RFI was computed from the linear regression of DMI on ADG and MMWT with trial and trial*independent variable (ADG and MMWT) interactions as random effects. Real-time ultrasound measurements of backfat, LMA, and intramuscular fat were obtained at the start and end of each trial. Stepwise linear regression analysis revealed order of inclusion of body composition traits statistically significant were gain in backfat and gain in LMA, and were included as variables in the final regression model used to compute RFI adjusted for body composition. Gain in backfat accounted for an additional 2% variation in DMI beyond ADG and MMWT, increasing the R^2 from 0.755 to

0.775. While the R^2 (0.777) did not significantly improve by including gain in LMA into the regression equation, RFI computed from ADG, MMWT, and gain in backfat had a weak phenotypic correlation with gain in LMA (r_p= 0.14, $P < 0.05$). Pearson (0.92) and Spearman (0.91) rank correlations were strong between RFI and RFI adjusted for body composition, and simple regression revealed a correlation coefficient of 1.01 between the two measures. RFI and adjusted RFI had strong phenotypic correlations with DMI of 0.60 and 0.55, respectively, with low RFI bulls consuming 16% less ($P < 0.01$) DMI than high RFI bulls. Final ultrasound backfat and gain in backfat had weak phenotypic correlations with RFI of 0.20 and 0.30, suggesting more efficient bulls were leaner. Low RFI bulls had significantly ($P < 0.01$) lower final ultrasound backfat measurements than high RFI bulls (0.59 vs. 0.67 cm), and gained less backfat than high RFI bulls during the trial (0.21 vs. 0.32 cm). Additionally, low RFI bulls gained significantly ($P = 0.04$) less LMA (18.99 vs. 22.04 cm^2) than high RFI bulls. As expected, gain in backfat and gain in LMA were not correlated with RFI adjusted for body composition since the linear regression model forces RFI to be independent of its component traits. While inclusion of body composition traits on the computation of RFI appears to have minimal impact on the accuracy of selection in seedstock animals, inclusion of body composition may be useful to reduce the impact of selection on carcass yield and quality of steer progeny during the finishing period (Lancaster et al., 2009a).

Lancaster et al. (2009b) conducted a study using 468 Brangus heifers to evaluate differences in RFI and RFI adjusted for body composition. Heifers were weighed at 7 d intervals and real-time ultrasound measures were obtained at the start and end of each of the 4 trials. A two-step approach was used to determine if individual animal variation in body composition traits affected the derivation of expected DMI. Stepwise linear regression analysis revealed order

of inclusion of body composition traits that were statistically significant included gain in backfat and final ultrasound LMA. RFI was computed from the linear regression of DMI on ADG and MMWT with trial and trial*independent variable (ADG and MMWT) interactions as random effects. The final regression model used to compute RFI adjusted for body composition included gain in backfat and final ultrasound LMA, in addition to ADG and MMWT. Inclusion of gain in backfat alone explained the largest amount of additional variation in DMI increasing the R^2 by 4.2%, (R^2= 0.555 vs. 0.597). Even though RFI was not phenotypically or genetically correlated with final LMA, including final LMA into the adjusted RFI model resulted in a R^2= 0.602. RFI and ultrasound adjusted RFI had strong phenotypic correlations with DMI at 0.70 and 0.67, respectively. Additionally, there was a significant difference (*P = 0.01*) in DMI based on RFI classification. On average, low RFI heifers consumed 8.76 kg/d, medium RFI heifers consumed 9.48 kg/d, and high RFI heifers consumed 10.34 kg/d. There was a weak phenotypic correlation between RFI and gain in backfat (r_p= 0.22), and a significant difference (*P = 0.01*) between efficient and inefficient heifers for gain in backfat. However, the phenotypic and genetic correlations for RFI and final ultrasound backfat (r_p= 0.12, r_g= 0.36) indicated selection for favorable RFI may reduce subcutaneous fat deposits. Final ultrasound LMA was not phenotypically or genetically correlated with RFI and there was no significant difference in final LMA based on RFI classification. Therefore, inclusion of final LMA in RFI adjusted for body composition may have been unnecessary. Pearson (0.97) and Spearman rank (0.96) correlation coefficients were strong between RFI and adjusted RFI, suggesting that selection using either RFI model would result in similar corresponding changes in feed intake and efficiency. While the inclusion of body composition traits in calculating RFI has minimal impact on growing

animals, it may be useful to reduce the potential impact of selection for RFI on carcass quality in progeny destined for feedlots.

Mao et al. (2013) conducted a study using 551 Angus and 417 Charolais steers to determine the appropriate RFI model for predicting expected daily DMI. RFI computed by linear regression of DMI on ADG and MMWT (Model 1) accounted for 65.6% of the variation in expected DMI for the Angus steers and 73.0% of the variation in expected DMI for the Charolais steers. Model 2 adjusted for ultrasound backfat and accounted for 66.1% and 75.3% of the variation in expected DMI for Angus and Charolais steers, respectively. The additional 0.5% variation in DMI explained by adding ultrasound backfat in the regression model for Angus steers, is likely due to the weak genetic correlation between RFI and ultrasound backfat (r_g= 0.17 ± 0.21) in Angus cattle. However, Model 2 had a larger effect on the Charolais steers and accounted for an additional 2.3% variation in DMI in comparison with Model 1. This increase in explained variation is slightly greater than the 1.4% reported by Schenkel et al. (2004) and 1.8% by Basarab et al. (2003). Additionally, the phenotypic and genetic correlations between RFI and ultrasound backfat thickness are much stronger in Charolais steers, where r_p= 0.19 ± 0.06 and r_g= 0.33 ± 0.18, respectively. Model 3, adjusted for ultrasound backfat and LMA, was of little additional significance when compared with Model 2. The results indicate including ultrasound backfat thickness in the model for calculating RFI should reduce the negative impacts on carcass fat and marbling that accompany selection for more efficient animals.

RFI Classification

Individual animal RFI measurements are obtained by taking the difference between actual feed intake and expected feed intake considering production and maintenance

requirements. Animals are classified based on RFI value in order to compare how feed efficient an individual animal is within their contemporary group. Typically animals are classified as low RFI, medium RFI, or high RFI equating to efficient, average, or inefficient, respectively. Statistically, RFI is normally distributed with a mean of zero. Depending on a determined standard deviation away from the mean, animals can then be classified into their respective categories. When animals are classified based on ±1 SD away from the mean, 68% of individuals within that population are considered average. Therefore, about 16% of the individuals deviate from the mean by > -1 and classified as low RFI or efficient. The remaining 16% deviate from the mean by > 1 and classified as high RFI or inefficient. RFI classification is useful for producers looking to improve feed efficiency through genetic selection for low RFI animals.

Estimates of heritability for RFI

Heritability of a trait measures the proportion of phenotypic variation influenced by additive genetic variation. A highly heritable ($h^2 > 0.50$) trait has a larger additive genetic variance and genetic selection can be quite effective. A lowly heritable ($h^2 < 0.15$) trait is largely influenced by environmental rather than genetic factors, and can most likely improve through appropriate management strategies. Therefore, breeding programs looking to improve a trait of interest need to ensure the surrounding environment is conducive to the breeding objective, in addition to the use of genetic selection.

RFI has been found to be a moderately heritable trait and can be improved through genetic selection. Koch et al. (1963) first reported a heritability estimate for RFI of 0.28 ± 0.11 in British breed bulls and heifers. Archer et al. (1997) reported a heritability estimate of 0.62 for RFI based on a 70 d testing period in British breed bulls and heifers. Differences in heritability

estimates between the two studies probably are due to different populations of cattle and differences in estimating variance components.

Arthur et al. (2001a) estimated heritability of RFI in young Charolais bulls at 15 and 19 mo of age. The average age at the start of the test was 274 d. All the animals were fed until 15 mo of age and half the animals continued until 19 mo of age. Heritabilities were estimated using multivariate REML procedures. The heritability estimate for RFI at 15 mo of age was 0.39 and the heritability estimate at 19 mo of age was 0.43. The phenotypic and genetic correlations between the RFI measurements at 15 mo of age and 19 mo of age were 0.85 and 0.95, respectively. The results suggest that there is no need to prolong a feed intake test beyond 15 mo of age to genetically improve feed efficiency. In another study, Arthur et al. (2001b) estimated RFI heritability at 0.39 in young Angus bulls and heifers. Similarly, RFI and RFI adjusted for backfat thickness had heritability estimates of 0.38 and 0.39, respectively, in purebred beef bulls of six breeds in Ontario bull test stations (Schenkel et al., 2004). Crowley et al. (2010) reported the heritability estimate for RFI of 0.45 ± 0.06 in Irish performance tested beef bulls.

Heritability estimates in steers seem to vary more than those reported in bulls. According to Nkrumah et al. (2007), differences in genetic and phenotypic variances are related to differences in genetic background and environmental variances associated with measuring feed intake. Feedlot steers are typically evaluated for RFI just prior to slaughter, whereas, breeding animals are evaluated for RFI for purposes of creating EPDs. While breeding stock are typically evaluated at one year of age, feedlot steers are older and vary in age when they enter the feedlot and are processed. Additionally, there is a large amount variability in feedlot steers regarding breed, sire growth potential, bodyweight, days on feed, bodyweight gain, and amount of fat deposition compared to seedstock animals that are primarily in the growing phase. Since the

additive genetic variance in steers is can be much larger, especially due to lack of pedigree records, heritability estimates tend to be more diverse than those seen in bulls. Additionally, methods of calculating RFI may differ among studies and contribute to differences in heritability estimates (Rolfe et al., 2011).

Nkrumah et al. (2007) conducted a study using crossbred steers managed and tested for growth and efficiency under feedlot conditions. Phenotypic and genetic parameters were obtained using SAS (version 9.1.3, SAS Inst. Inc., Cary, NC) and ASREML (Gilmour et al., 2000) software. Estimated phenotypic RFI (RFI_p) and genetic RFI (RFI_g) values were calculated by regressing DMI on ADG and MMWT, using the appropriate phenotypic (co)variances and genotypic (co)variances. Heritability estimates for RFI_p and RFI_g were 0.21 ± 0.12 and 0.42 ± 0.15, respectively. The genetic (r_g= 0.92) and phenotypic (r_p= 0.97) correlations between the two RFI measures were strong, indicating that both indices are very similar.

Rolfe et al. (2011) conducted a study with 1,141 mixed-breed steers over five years to estimate genetic and phenotypic parameters for feed intake and other traits in growing cattle. Steers were started on test at approximately 270 d of age and were slaughtered approximately one week after the test ended. Because steers were slaughtered on different dates each year and varied for days on feed, body weight and feed, data were adjusted to a 140 d feeding period. ASREML was used to obtain a heritability estimate for RFI of 0.52 ± 0.14. Adjusting RFI for carcass backfat and marbling had little effect on the heritability estimate. Additionally, the phenotypic and genetic correlations between the two RFI measures were 0.96 ± 0.003 and 0.98 ± 0.009, respectively.

In a study by Mao et al. (2013), heritability estimates for RFI were determined using three different models utilizing Angus and Charolais steers. The first model reported heritability

estimates for unadjusted RFI values in Angus and Charolais steers at 0.47 ± 0.12 and 0.68 ± 0.14, respectively. The second model adjusted RFI for ultrasound backfat. The estimate of RFI heritability for Angus steers remained the same while the heritability estimate for Charolais steers slightly decreased to 0.64 ± 0.14. The third model adjusted RFI for ultrasound backfat and ultrasound LMA. This third model reduced the heritabilities further in both breeds (Angus h^2= 0.46 ± 0.12, Charolais h^2= 0.60 ± 0.13). The high heritability estimates indicate there is considerable genetic variation in RFI in both the Angus and Charolais populations. Adjusting RFI for measures of body composition correlate with a slight decrease in heritability thus, reducing the amount of genetic variation. However, this reduction is not significant and has no impact on the ability to improve RFI through genetic selection.

An Australian study analyzed post-weaning feed efficiency records from 1,180 Angus bulls and heifers (Arthur et al., 2001b). The heritability estimate for RFI was 0.39 ± 0.03 with an additive variance of 0.15 kg/d. A follow up study retested 751 cows that had been tested for RFI as heifers (Archer et al., 2002). Following the post-weaning test, all heifers entered the cow herd and after weaning their second calf, returned to the same facility and were retested for feed intake at four years of age. The heritability estimate for RFI as a mature cow was 0.23 with an additive variance of 0.46 kg/d. Phenotypic and genetic correlations between RFI measured post-weaning and on mature cows were 0.40 and 0.98, respectively. While the results and implications of the two studies are only applicable within their respective production phase, the strong genetic correlation for RFI between the two ages suggest some biological processes regulating intake and efficiency post-weaning are similar to processes regulating intake of adult animals (Archer et al., 2002).

Fewer studies have examined RFI in growing heifers and productive females compared to male counterparts. However, reported heritability estimates remain moderate, similar to those in bulls and steers. In young Brangus heifers, heritability for RFI was reported as 0.47 with a genetic variance of 0.25 kg/d (Lancaster et al., 2009b). RFI adjusted for gain in ultrasound subcutaneous fat depth and ultrasound LMA reduced the heritability estimate to 0.42 ± 0.13 with a genetic variance of 0.22 kg/d. This reduced heritability estimate for RFI when adjusted for body composition is similar as reported by the Mao et al. (2013) study, where the heritability estimate for RFI reduced by 0.08 when adjusted for ultrasound backfat and ultrasound LMA.

Phenotypic and genetic correlation estimates between ADG and other measures of weight

By definition, RFI is phenotypically independent of its regression components, ADG and MMWT. Therefore, a change in RFI should not affect growth rate or result in increased mature weight. However, genetic correlations still exist when phenotypic regression is used to predict RFI. Weak negative and positive genetic correlations between RFI and ADG have been reported but most studies find this correlation to be negligible. Kennedy et al. (1993) suggested computing RFI using genetic regression as an alternative to prevent genetic correlations with the component traits of RFI. Studies differ in their findings as to whether RFI is genetically independent of its components when using phenotypic regression.

Arthur et al. (2001a) reported no significant phenotypic correlations between RFI with MMWT and ADG in Charolais bulls at 15 mo of age. However, genetic correlation estimates of 0.32 ± 0.10 between RFI and MMWT and -0.10 ± 0.13 between RFI and ADG, respectively, were reported. In 464 crossbred steers, Nkrumah et al. (2007) reported genetic correlation estimates of 0.27 ± 0.33 between RFI and MMWT and 0.46 ± 0.45 between RFI and ADG,

respectively. Since the sample size in this study was sufficient for accurate feed intake measurements, the large standard error suggests there is a large amount of genetic variation and genetic correlations between RFI and MMWT and RFI and ADG could be strong or negligible. However, RFI predicted from genetic regression had a weak but significant negative phenotypic correlation with ADG (r_p= -0.21; *P < 0.01*) but was genetically independent of ADG and MMWT. Using Angus steers, RFI calculated by phenotypic regression had weak positive genetic correlations with ADG (r_g= 0.18 ± 0.21) and MMWT (r_g= 0.19 ± 0.21) (Mao et al., 2013).

Some studies suggest RFI only is genetically correlated with MMWT and is genetically independent of ADG. Archer et al. (2002) and Schenkel et al. (2004) reported weak negative genetic correlations between RFI and MMWT (r_g= -0.21, r_g= -0.17, respectively) and a near zero correlation with ADG. Alternatively, a moderate genetic correlation between RFI and MMWT (r_g= 0.33 ± 0.29) was reported in Brangus heifers suggesting a reduction in RFI may reduce body size (Lancaster et al., 2009b). Mao et al. (2013) also reported a positive genetic correlation between RFI and MMWT (r_g= 0.14 ± 0.22) and a near zero genetic correlation between RFI and ADG in Charolais steers.

Conversely, Arthur et al. (2001b) reported near zero phenotypic and genetic correlations for RFI predicted using phenotypic regression with ADG and MMWT. Results from this study suggest potential antagonistic correlated responses to selection for RFI were negligible.

Basarab et al. (2007) conducted a study using 222 yearling calves and their dams to examine the phenotypic relationships between progeny RFI and maternal productivity across 10 production cycles. Progeny RFI was adjusted for off-test ultrasound backfat thickness (RFI_{bf}) and compared to RFI predicted using phenotypic regression with ADG and MMWT. A negative phenotypic correlation was reported between calf birth weight and RFI (r_p= -0.16; *P < 0.05*), but

it became insignificant when RFI was adjusted for off-test ultrasound backfat thickness. RFI in mature cows was also unrelated to ADG and MMWT when adjusted for conceptus. Cow body weight was similar at weaning, pre-calving, and pre-breeding for dams that produced low, medium, and high RFI_{adj} progeny. In addition, cows with efficient progeny produced the same weight of calf weaned per cow exposed to breeding compared with cows that produced inefficient progeny.

Phenotypic and genetic correlation estimates between feed intake and FCR

RFI is associated with feed intake and other measures of feed efficiency. Genetic correlations between RFI and feed intake are positive and strong suggesting improvement in RFI will result in decreased feed intake, without effecting growth rate or mature body size. Additionally, selection for RFI generally results in a concomitant improvement in other measures of feed efficiency, specifically FCR.

Arthur et al. (2001a) reported strong genetic correlations between RFI and feed intake (r_g= 0.79) and FCR (r_g= 0.85) in 15 month old Charolais bulls. Phenotypic correlations measure the strength of the relationship between performance in one trait and performance in another trait. Genetic correlations measure the strength of the relationship between breeding values for one trait and breeding values for another trait. Phenotypic correlations were of similar strength at 0.60 and 0.57, respectively. In growing Angus bulls, RFI showed moderate phenotypic correlations between DMI (r_p= 0.60) and FCR (r_p= 0.49) (Lancaster et al., 2009a). In addition, low RFI Angus bulls consumed 16% less feed than high RFI bulls, while maintaining similar ADG and final bodyweight (Lancaster et al., 2009a). This suggests selection for low RFI would decrease feed intake, while maintaining the same level of growth performance.

During a performance test on young Angus bulls and heifers, feed intake was genetically correlated with both measures of feed efficiency but stronger with RFI (r_g= 0.69) than with FCR (r_g= 0.31) (Arthur et al., 2001b). Schenkel et al. (2004) saw a similar trend using young beef bulls. Schenkel et al. (2004) reported a genetic correlation between RFI and DMI of 0.81 and RFI and FCR of 0.39. These studies reported moderate genetic correlations between RFI and FCR (Arthur et al., 2001b, r_g= 0.66; Schenkel et al., 2004, r_g= 0.69) and cattle with a lower RFI tend to have a lower FCR due to reduced feed intake consumption.

In steers managed under feedlot conditions, strong genetic correlations were reported between RFI or RFI calculated by genetic regression with FCR (r_g=0.62 ± 0.09, r_g= 0.78 ± 0.10) and DMI (r_g= 0.73 ± 0.18, r_g= 0.65 ± 0.16) (Nkrumah et al., 2007). Similar results were seen in a hybrid population of bulls and steers, where RFI had strong phenotypic correlations with FCR (r_p= 0.62) and DMI (r_p= 0.77) (Nkrumah et al., 2004). In Angus and Charolais steer populations, RFI had strong phenotypic correlations with DMI (r_p= 0.58 ± 0.04, r_p= 0.52 ± 0.06, respectively) and FCR (r_p= 0.45 ± 0.04, r_p= 0.44 ± 0.05, respectively). Strong genetic correlations were also reported between RFI and DMI and between RFI and FCR in Angus steers (r_g= 0.75 ± 0.10, r_g= 0.54 ± 0.18) and Charolais steers (r_g= 0.66 ± 0.11, r_g= 0.66 ± 0.12) (Mao et al., 2013). These results are similar to those reported in Angus bulls and heifers (Arthur et al., 2001b), in Charolais bulls (Arthur et al., 2001a), and in mixed breed populations (Schenkel et al., 2004; Nkrumah et al., 2007).

In young Brangus heifers, a strong, positive phenotypic correlation was found between RFI and DMI (r_p= 0.70; Lancaster et al., 2009b). This phenotypic correlation was substantiated by low RFI classified heifers consuming 15% less DM than high RFI classified heifers. In addition, heifers classified as low RFI had a 16% lower FCR compared with high RFI classified

heifers. RFI and FCR had strong genetic (r_g= 0.59) and phenotypic (r_p= 0.94) correlations and thus, an improvement in RFI will result in a concomitant improvement in FCR (Lancaster et al., 2009b).

Archer et al. (2002) reported strong genotypic (r_g= 0.71) and phenotypic (r_p= 0.88) correlations between mature cow DMI and RFI. Basarab et al. (2007) conducted a study on pregnant cows and their RFI classified progeny. Both progeny RFI and progeny RFI_{bf} had moderate to strong phenotypic correlations with DMI (r_p= 0.51 to 0.53) and FCR (r_p= 0.44 to 0.46), with more efficient steers and heifers consuming less feed and having improved feed to gain ratios. Cow RFI was phenotypically correlated to feed intake (r_p= 0.83) and cow RFI was phenotypically independent of FCR (r_p= -0.07). Additionally, dams that produced low RFI_{bf} progeny consumed less feed during their second trimester of pregnancy and had lower RFI values than dams that produced high RFI_{bf} progeny. These results indicate that efficient RFI progeny and dams consumed less feed and had improved feed to gain ratio than inefficient cows and calves (Basarab et al., 2007).

Genetic and phenotypic correlations between RFI and ultrasound carcass measurements

Several studies report weak phenotypic and genetic correlations between RFI and ultrasound carcass measurements, primarily backfat thickness (Arthur et al., 2001b; Basarab et al., 2003; Lancaster et al., 2009a,b; Mao et al., 2013; Nkrumah et al., 2004, 2007; Schenkel et al., 2004). Because ultrasound measurements are an excellent indicator of carcass measurements, this allows producers to monitor cattle that have been selected for low RFI for any potential changes that may occur in body composition.

In young Angus bulls and heifers, RFI had weak genetic (r_g= 0.17 ± 0.05) and phenotypic (r_p= 0.14) correlations with ultrasound backfat thickness (Arthur et al., 2001b). Schenkel et al. (2004) found similar genetic (r_g= 0.16; *P = 0.11*) and phenotypic (r_p= 0.17; *P < 0.05*) correlations between the two traits, however, both correlations were negligible when adjusting RFI for ultrasound backfat thickness (r_g= -0.01, r_p= -0.01). In Brangus heifers, RFI was weakly correlated with final ultrasound backfat thickness and gain in ultrasound backfat (r_p= 0.12; *P < 0.05* and r_p= 0.22; *P < 0.05*) (Lancaster et al., 2009b). Lancaster et al. (2009b) also reported a moderate genetic correlation between RFI and final ultrasound backfat thickness (r_g= 0.36 ± 0.26), suggesting a decrease in RFI will reduce subcutaneous fat. In contrast to Schenkel et al. (2004), Lancaster et al. (2009b) found a moderate genetic correlation remained between RFI and final ultrasound backfat thickness after adjusting for body composition (r_g= 0.39 ± 0.27). These results suggest that adjusting RFI for body composition will facilitate selection that is phenotypically independent of its component traits, but genetic correlations may remain. Basarab et al. (2003) also found a phenotypic correlation of 0.22 (*P < 0.01)* between RFI and gain in ultrasound backfat thickness.

Nkrumah et al. (2007) saw even stronger phenotypic (r_p= 0.25; *P < 0.01*) and genetic (r_g= 0.35 ± 0.30) correlations between RFI and ultrasound backfat thickness, suggesting that selection for RFI might result in selection for leaner animals. Compared with low classified RFI steers, high classified RFI steers had significantly greater rate of gain in ultrasound backfat (0.029 mm/d vs. 0.038 mm/d) and final ultrasound backfat thickness (8.27 mm vs. 9.86 mm). In an earlier study, Nkrumah et al. (2004) reported small phenotypic correlations between RFI and gain in ultrasound backfat (r_p= 0.30; *P < 0.01*) and between RFI and final ultrasound backfat thickness (r_p= 0.19; *P < 0.05*), with low RFI cattle having reduced ultrasound backfat thickness

in comparison to high RFI cattle (5.28 mm vs. 6.31 mm). Similarly, Lancaster et al. (2009a) reported small phenotypic correlations between RFI and final ultrasound backfat thickness (r_p= 0.20; $P < 0.05$) and RFI and gain in ultrasound backfat thickness (r_p= 0.30; $P < 0.05$), where bulls of low RFI had smaller final ultrasound backfat measurements (0.59 cm vs. 0.67 cm) and less gain in ultrasound backfat (0.21 cm vs. 0.32 cm) than bulls of high RFI.

While the relationship between RFI and ultrasound LMA remains unclear, there are some reports of correlations between the two traits of varying magnitude. Arthur et al. (2001b) found a weak genetic correlation between RFI and ultrasound LMA (r_g= 0.09 ± 0.09) in Angus cattle. Another study using Angus bulls reported weak phenotypic correlations between RFI and gain in ultrasound LMA (r_p= 0.17; $P < 0.05$) but final ultrasound LMA was similar among all RFI classification (Lancaster et al., 2009a). Low RFI bulls tended to have larger initial ultrasound LMA and less gain in ultrasound LMA. When RFI was adjusted for body composition, there were no genetic or phenotypic correlations with gain in ultrasound backfat and ultrasound LMA. This was to be expected since phenotypic linear regression forces RFI to be independent of its component traits. Similarly in Brangus heifers, Lancaster et al. (2009b) reported a strong genetic correlation between RFI and gain in ultrasound LMA (r_g= 0.55 ± 0.24). In addition, heifers classified as low RFI had larger initial ultrasound LMA than those heifers classified as high RFI. However, in the Nkrumah et al. (2007) study strong negative phenotypic (r_p= -0.52 ± 0.32) and genetic (r_g= -0.65 ± 0.20) correlations between RFI and ultrasound LMA in crossbred beef steers were reported.

Mao et al. (2013) determined differences in breed affect the strength of correlations between RFI and ultrasound measures of carcass traits. In Angus steer populations, RFI had near zero phenotypic correlations with ultrasound LMA and ultrasound backfat thickness. However,

RFI had moderate genetic correlations with ultrasound LMA (r_g= 0.31 ± 0.32) and RFI had weak genetic correlations with ultrasound backfat thickness (r_g= 0.17 ± 0.21) in these same Angus cattle. The high standard error indicates these correlations could be strong or negligible in both instances. When RFI was adjusted for ultrasound backfat thickness, these genetic correlations reduced to 0.25 ± 0.32 and 0.12 ± 0.21, respectively. In Charolais steers, RFI had a weak phenotypic correlation with ultrasound backfat (r_p= 0.19 ± 0.06), moderate genetic correlations with ultrasound LMA (r_g =0.30 ± 0.20), and moderate genetic correlations with ultrasound backfat thickness (r_g= 0.33 ± 0.18). Phenotypic correlations between ultrasound backfat thickness and RFI adjusted for backfat thickness were near zero, while genetic correlations significantly reduced to 0.19 ± 0.19. These results indicate that later maturing breeds have stronger correlations with measures of ultrasound backfat, even though early maturing breeds deposit more backfat at a younger age. Adjusting RFI for ultrasound backfat thickness tends to reduce correlations with carcass backfat and carcass marbling score to a greater extent in Charolais breeds than for Angus cattle. Additionally, adjusting RFI for ultrasound backfat had minimal effect on ribeye area in both breeds.

Phenotypic and genetic correlations between RFI and carcass traits

Some studies report weak phenotypic and genetic correlations exist between RFI and carcass traits (Basarab et al., 2003, 2007; Mao et al., 2013; Nkrumah et al., 2004, 2007). This is significant because alterations in body composition can effect yield grade and therefore, affect the type of cattle sent to market. Because selection for RFI could potentially result in leaner animals, this may have a large impact on producers whose income is dependent on finished cattle. However, even though carcass traits are highly heritable, it is unlikely that long term

selection for RFI will affect body composition enough to have any substantial impact on meat quality.

In a serial slaughter study by Basarab et al. (2003), RFI had positive phenotypic correlations with carcass backfat thickness (r_p= 0.12), carcass marbling (r_p= 0.15), dissectible carcass fat (r_p= 0.14), gain in empty body fat (r_p= 0.26), and negative correlations with dissectible carcass lean (r_p= -0.21) and empty body protein (r_p= -0.14). Thus, high RFI steers had a faster gain in empty body fat and slower gain in empty body protein than low RFI steers. This can be consequential for producers with inefficient feeder cattle in a market where lean meat yields greater profits than carcasses with too much fat. When RFI was adjusted for gain in ultrasound backfat thickness and gain in ultrasound marbling, these phenotypic correlations with RFI were reduced; carcass backfat to -0.06, carcass marbling to 0.10, dissectible carcass fat to 0.06, gain in empty body fat to 0.22, dissectible carcass lean to -0.17, and empty body protein to -0.06. Inefficient steers still had a slightly faster gain in empty body fat and less dissectible carcass lean, but adjusting RFI to a common ultrasound backfat thickness helped improve changes in body composition.

Studies suggest selection for more efficient cattle can potentially reduce carcass fatness while improving lean meat yield and yield grade. RFI is reported to have positive phenotypic correlations with carcass backfat thickness (r_p= 0.22 to 0.25) and yield grade (r_p= 0.17 to 0.28) and negative correlations with lean meat yield (r_p= -0.21 to -0.22) using the Canadian Grading System (Basarab et al., 2007; Nkrumah et al., 2004, 2007). Nkrumah et al. (2004) found that low RFI animals had significantly lower carcass backfat thickness (low RFI= 8.83 ± 0.71 mm; medium RFI= 10.55 ± 0.53 mm; high RFI= 11.56 ± 0.67 mm) and yield grade measurements (low RFI= 1.19 ± 0.13; medium RFI= 1.50 ± 0.10; high RFI= 1.61 ± 0.12) but higher lean meat

yields (low RFI= 59.26 ± 0.67; medium RFI= 58.48 ± 0.51; high RFI= 57.04 ± 0.63) using the Canadian Grading System, compared to medium or high RFI animals. In a later study, a moderate genetic correlation between RFI and carcass backfat thickness (r_g= 0.33 ± 0.29) was estimated, with animals classified as high RFI having greater carcass backfat thickness (11.80 ± 0.46 mm) than those classified as medium (9.76 ± 0.38 mm) or low (9.59 ± 0.45 mm) RFI animals (Nkrumah et al., 2007). Also, RFI had a strong negative genetic correlation with lean meat yield (r_g= -0.54 ± 0.26) and low classified RFI animals had greater lean yield (59.00% vs. 56.95%) and better yield grades (1.52 vs. 1.84) according to the Canadian Grading System compared with high classified RFI animals. Weak phenotypic (r_p= 0.17 to 0.19) and genetic (r_g= 0.28) correlations have been reported between RFI and carcass marbling score (Nkrumah et al., 2004, 2007; Basarab et al., 2007) However, there is no significant difference in marbling score between animals of different RFI classification (Nkrumah et al., 2004, 2007).

Mao et al. (2013) reported adjusting RFI for ultrasound backfat will lessen the effects RFI selection has on other carcass characteristics. Adjusting RFI for ultrasound backfat thickness reduced phenotypic and genetic correlations with carcass backfat, marbling, and lean meat yield in Angus and Charolais steers. In the Angus steer population, adjusted RFI had weak or close to zero phenotypic correlations with carcass merit traits. Adjusted RFI had weak genetic correlations between hot carcass weight and carcass marbling score at 0.12 ± 0.20 and 0.18 ± 0.21, respectively. These weak relationships suggest selection for RFI may have limited effects on carcass traits in the Angus breed. In Charolais steers, RFI had weak phenotypic (r_p= 0.15 ± 0.06) and moderate genetic (r_g= 0.42 ± 0.29) correlations with carcass backfat, suggesting that more efficient steers will have a decrease in carcass backfat. RFI also had weak positive genetic correlations between hot carcass weight, carcass LMA, and marbling score (0.14 ± 0.17; 0.19 ±

0.18; 0.14 ± 0.17). After adjusting RFI for ultrasound backfat, phenotypic correlations between RFI and carcass backfat reduced from 0.08 to 0.03 and from -0.09 to -0.05 for lean meat yield in Angus steers. In Charolais, adjusting RFI for ultrasound backfat thickness reduced phenotypic correlations between RFI and carcass backfat thickness from 0.15 to 0.02, from 0.11 to 0.06 for carcass marbling, and from -0.07 to -0.02 for lean meat yield. There was also a reduction in magnitude of genetic correlations when RFI was adjusted, with carcass fat from 0.42 to 0.23 and carcass marbling from 0.14 to 0.02 in Charolais steers, and carcass marbling from 0.18 to 0.15 in Angus steers. The results suggest that RFI correlations with measures of fatness are stronger in Charolais cattle, and adjusting RFI for ultrasound backfat can mitigate the negative effects selection for more efficient animals may have on carcass traits and marbling score.

Reproductive Performance

Maximizing total production system efficiency largely impacts the profitability of the beef production system. Story et al. (2000) suggested an economic model that estimates net income of the cow/calf enterprise, taking into consideration returns based on retained and finished steer calves. Reproductive performance, specifically calf age at weaning, largely impacts net income, and an increase in profit potential may be realized by greater herd reproductive performance (Story et al., 2000). Therefore, reproductive traits are arguably more important than performance and carcass traits for beef cattle profitability. Additionally, beef production sustainability is heavily reliant on sound reproductive performance. The world population is expected to exceed 9 billion by 2050 with the demand for agriculture products growing 1.5% annually (Bruinsma and FAO of United Nations, 2003). In order to meet high demand and remain competitive with poultry and pork industries, the beef industry should focus

on improving total production efficiency. In comparison to other meat animal species, there are several physiological differences in beef cattle that contribute to lower production system efficiency, with reproductive function as one of the biggest biological limitations. In addition to low reproductive rates, cattle have much longer gestation lengths and produce fewer progeny on an annual basis compared to litter bearing species (Nielsen et al., 2013). However, improving inputs that can be controlled, like feed intake, may help make the beef supply chain more efficient and sustainable. Therefore, it's critical to ensure selection for feed efficiency does not have antagonistic effects on reproductive performance.

Effects of RFI selection on reproduction

While studies following lifetime production are currently lacking, preliminary studies suggest selecting for RFI may have some repercussions on reproductive performance. Feed intake trials are conducted post-weaning prior to selection decisions being made. Because there is a large variation in age at puberty, *Bos taurus* cattle tend to be at different stages of sexual development during this time and differences in physiological age may affect RFI classification. Consequentially, RFI testing tends to favor later maturing animals that don't have increased energy demands associated with sexual development and activity (Basarab et al., 2011). Therefore, prepubertal animals have lower feed intakes than those undergoing puberty and may be considered more efficient.

Basarab et al. (2011) analyzed the effects of feed efficiency associated with sexual development and activity by identifying when heifers reached puberty relative to the start of the testing period. Feed intake and feeding behaviors revealed heifers that attained puberty near the start of the test consumed more feed, spent more time at the bunk in feeding event duration and

head-down behaviors, but removed their head from the bunk or went to the bunk less frequently than heifers reaching puberty near the end of the test. Additionally, pre-pubertal heifers had 4% to 7% improved feed efficiency given equal growth, body size, and body composition compared to post-pubertal heifers. These results suggest later maturing animals will be favored when predicting RFI from a mixture of pre- and post-pubertal animals.

Since later maturing animals tend to be more efficient at the time of testing, long term selection for low RFI heifers may affect herd reproductive performance, specifically age at puberty. However, some authors suggest a delay in puberty and conception may continue throughout the cow's lifetime, but will not affect herd fertility (Arthur et al, 2005; Basarab et al., 2007). Heifers that have multiple estrus cycles before first breeding are more likely to conceive early and maintain similar reproductive performance in subsequent breeding seasons (Byerly et al., 1987). According to Crowley et al. (2011), a delay in onset of puberty is biologically possible because the partitioning of energy among animals differing in RFI may be altered with more energy in low RFI partitioned toward growth and away from reproductive function. Low RFI females tend to conceive later and calve later than high RFI females, most likely attributed to a delay in first estrus (Arthur et al., 2005; Basarab et al., 2007; Donoghue et al., 2011). However, several studies report selection for post-weaning RFI does not have any effect on pregnancy rates, calving rates, and maternal productivity (Arthur et al., 2005; Basarab et al., 2007; Donoghue et al., 2011; Shaffer et al., 2011).

Shaffer et al. (2011) analyzed the relationship between RFI and fertility in yearling beef heifers of British breed types. Blood samples were collected weekly to determine age at puberty. Heifers were considered pubertal when progesterone concentrations exceeded 1 ng/mL. There was negative a linear relationship between RFI and age at puberty, where a 1-unit increase in

RFI corresponded to a decrease in age at puberty by 7.5 days. Further, RFI had a weak phenotypic correlation with age at puberty (r= -0.16). Heifers classified as high RFI reached puberty 13 days earlier than low RFI heifers (414 vs. 427 days of age). Regardless of RFI classification, all heifers reached puberty before 14 months of age and selection for RFI did not delay onset on puberty enough to be of any concern for cow productivity. Shaffer et al. (2011) concluded since there was a large variation in age at puberty regardless of RFI classification, selection for efficiency could be accompanied by selection for earlier reproductive maturity.

Heifers that calve early in their first calving season tend to calve early throughout their lives and have greater calf lifetime production (Randel and Welsh, 2013). Current research suggest low classified RFI females calve later in the calving season than high classified RFI females, because more efficient females tend to have a delay in pregnancy as heifers (Arthur et al., 2005; Basarab et al., 2007, 2011; Donoghue et al., 2011). Donoghue et al. (2011) conducted a study to evaluate early life reproductive performance and onset of puberty in Angus heifers. There was a moderate phenotypic correlation between RFI classification and calving day (r_p= -0.45), where low RFI was associated with a later calving day. Low RFI heifers calved 8.1 days later than high RFI heifers (35.7 ± 3.0 vs. 27.6 ±2.4 days) due to a delayed pregnancy date during the first mating season. The later calving date was maintained at subsequent calving but did not impact pregnancy or calving rates. Crowley et al. (2011) reported a negative genetic correlation (r_g= -0.29) between RFI and age at first calving, indicating selection for improved RFI may result in heifers that conceive later in the calving season. In a study examining the effects of divergent selection for RFI on maternal productivity, low RFI cows tended (*P= 0.07*) to calve 5 days later than high RFI cows (Arthur et al., 2005). Basarab et al. (2007) reported similar results where cows producing more efficient progeny calved 5 to 6 days later than cows

producing inefficient progeny. However, there was no difference in calving interval indicating that dams producing steers classified as low RFI were bred later in the breeding season as heifers and continually bred later in the breeding season in subsequent years. In a study by Basarab et al. (2011), low classified RFI heifers had fewer calves born by day 28 of the calving season than high classified RFI heifers (82.6% vs. 95.0%). The delay in calving was removed by adjusting RFI for ultrasound backfat thickness and feeding event frequency. These results suggest selection for more efficient cattle may negatively impact age at puberty, but does not affect reproductive performance and productivity of mature cows.

Factors that impact onset of puberty:

Body weight

Because age and bodyweight at puberty varies by breed, typical management practices suggest heifers should be developed to a specific target bodyweight to initiate a normal estrous cycle. Approximately 90% of most beef breed heifers should be cycling when they reach 65% of their mature body weight at the beginning of the breeding season. While studies show heifers can reach puberty as light as 50% to 55% of mature body weight, these heifers conceive later in the breeding season compared to those reaching puberty at 65% mature body weight (Perry, 2012). Additionally, heifers developed to 55% of mature body weight tend to take longer to reinitiate postpartum estrous cycles after calving compared with heifers developed to 65% mature body weight (Perry, 2012).

Body composition

A critical amount of body fat is required to initiate puberty and maintain reproductive function in many species. As puberty approaches, changes in body composition shift from protein deposition to fat deposition. According to Shaffer et al. (2011), less efficient animals likely store excess consumed energy as fat, which may initiate reproductive function at an earlier age. On the other hand, high efficiency animals may need a longer feeding period to reach the degree of fatness required for puberty onset (Randel and Welsh, 2013). Additionally, changes in body fat are associated with changes in pulsatile LH secretion and reproductive activity in postpartum cows (Randel, 1990). According to Dziuk and Bellows (1983), body fatness at calving is inversely proportional to the length of the postpartum anestrous period in beef cows.

In a long term selection study by Donoghue et al. (2011), Angus heifers were classified by selection line and analyzed for fat measures and reproductive performance traits. Heifers selected for low RFI had significantly reduced ultrasound rump fat depths and calved 8 days later than those from the high RFI selection line. There was a moderate negative phenotypic correlation between first parity calving day and RFI (r_p= -0.45), most likely due to the later onset of puberty. Irrespective of selection line, heifers that cycled had significantly more rump fat depth than those not yet pubertal. This indicates that a minimum level of fatness is needed to initiate ovarian activity. Therefore, it was expected that leaner, more efficient heifers would attain puberty at an older age. There was a tendency for more heifers from the high RFI selection line to cycle at each of the scan dates. Results from this study suggest heifers divergently selected for low RFI have less fat and tend to reach puberty later.

Basarab et al. (2011) conducted a study in crossbred beef heifers to examine the effects of RFI adjusted for body composition and feeding behavior on heifer productivity and fertility. Low

RFI heifers had a reduced conception rate, pregnancy rate, and calving rate compared to high RFI heifers. Low RFI_{bf} heifers had a lower conception rate but there was no difference in pregnancy rate and calving rate compared to high RFI heifers. RFI adjusted for ultrasound backfat and feed activity ($RFI_{bf\ \&\ activity}$) was completely independent of conception rate, pregnancy rate, and calving rate. Unadjusted RFI was completely independent of age and weight at puberty. However, when RFI was adjusted for body composition, efficient heifers took longer to reach puberty and weighed more at puberty compared to those considered inefficient. Regardless of how RFI was calculated, 97% of heifers reached puberty by 15 months of age which is required if they are to calve by 24 months of age. Results show RFI is completely independent of fertility when adjusted for backfat and feeding activity. Since all heifers completed at least one estrus cycle prior to the first breeding season, the delay puberty onset is not currently a concern when selecting for RFI. However, long-term selection for RFI may exacerbate some of these potential consequences regarding reproductive performance.

In the same study, heifer productivity, expressed as kg of calf weaned per heifers exposed to breeding, was similar across all RFI groups (Basarab et al., 2011). Even though low RFI heifers had a lower pregnancy rate, high RFI heifers had a higher calf death loss. This difference in calf death loss was more pronounced in high RFI_{bf} heifers and high $RFI_{bf\ \&\ activity}$ heifers, with a 2.2-fold and 3-fold lower calf death loss compared to low RFI heifers. Similar results were reported by Basarab et al. (2007) where cows producing high RFI progeny had nearly double the rate of calf death loss compared to cows producing low RFI progeny. Although the reason for higher calf death loss in high RFI heifers is uncertain, dams with better feed efficiency may have more available nutrients for their progeny and a better uterine environment compared to high RFI mothers (Basarab et al., 2011).

Nutrition and neuroendocrine control

Plane of nutrition is inversely proportional to age at puberty, where low planes of nutrition can inhibit reproductive hormone secretion. Nutritional status influences the pulsatile release of LH in developing heifers and therefore, the timing of puberty. According to Schillo et al. (1992), prepubertal increase in pulsatile LH secretion could be the rate-limiting step in sexual maturation. Dietary restriction can prevent the prepubertal increase in LH pulse frequency, delaying puberty onset (Kurtz et al., 1990; Schillo et al., 1992; Steiner et al., 1983). On the other hand, increasing energy intake can increase LH pulse frequency (Kurtz et al., 1990). Additionally, growth rate is inversely correlated with age at puberty in heifers. Hall et al. (1990) reported heifers fed at a higher rate of gain exhibited earlier prepubertal increases in LH release and attained puberty at younger ages than those fed at a lower rate of gain. While most studies agree postweaning nutrition can influence the timing of puberty onset, consideration of preweaning nutrition and management may increase the potential for effective control of puberty. A study by Gasser et al. (2006) indicates early weaning and feeding a high concentrate diet can induce precocious puberty by decreasing estradiol negative feedback on secretion of LH. These management strategies may help later maturing animals, like *Bos Indicus* cattle, lower the age for puberty onset but further studies are warranted.

Exposure to a progestin can hasten the onset of puberty in heifers (Perry, 2012). Additionally, many estrus synchronization protocols use a progestin to induce ovulation. Previous research indicates a 21% increase in fertility from pubertal estrus to the third estrus of a heifer (Byerley et al., 1987; Perry et al., 1991). First estrus heifers may experience premature luteolysis after oocyte fertilization due to an early release of $PGF_{2\alpha}$ from the uterus. Treatment

with progesterone can eliminate the occurrence of short-duration corpus luteum and allow for a normal-length luteal phase (Perry et al., 2012).

Results from several studies suggest the reproductive endocrine axis is functional long before the onset of puberty. According to Schams et al. (1981) and Schillo et al. (1982a), peripheral circulation of LH occurs as early as 1 month of age. This indicates that the hypothalamus and pituitary are functional and LH is responsive to GnRH release. Additionally, exogenous GnRH can induce LH release in heifers as early as 1 month of age and the magnitude of response increases with age (Schams et al., 1981). Studies on ovarectomized heifers show an increase in circulating LH concentration could be suppressed with exogenous estradiol (Day et al., 1984; Odell et al., 1970; Schillo et al., 1982b). However, the reduction in responsiveness to estradiol negative feedback decreases with age. In beef heifers, an increase in pulsatile LH frequency (Schams et al., 1981; Schillo et al., 1982a; Day et al., 1984; Kinder et al., 1987) and the mechanism mediating the effect of estradiol on LH secretion develop several months before puberty onset (Staigmiller et al., 1979; Schillo et al., 1983).

Conclusion

Given feed inputs are the largest cost associated with producing beef, breeding programs looking to increase profitability should reduce feed inputs without compromising economically relevant output traits. Since RFI is independent of growth, carcass merit, and lifetime productivity, selecting for negative RFI or efficient cattle will allow producers to recoup profits from outputs like yearling weight, milk, offspring, and meat yield while saving on feed costs. However, accurately identifying feed efficient cattle is a timely and costly process. Therefore, this study aimed to determine the optimal days on feed for accurately measuring feed intake and

ADG in Brangus heifers undergoing genetic evaluation for RFI. The current RFI model measures expected feed intake based on the linear regression of DMI on ADG and MMWT. However, weak correlations between RFI and carcass traits indicate adjusting RFI for body composition may alleviate the phenotypic effects of long term selection on measures like backfat thickness. This research examined different RFI models to assess if ultrasound measurements of carcass merit increase feed intake model accuracy. Additionally, since preliminary research indicates more efficient heifers may calve later in the calving season, this study examined reproductive traits in heifers with RFI phenotypes.

RECOMMENDED DURATION FOR EVALUATING FEED INTAKE AND DETERMINATION OF THE RESIDUAL FEED INTAKE MODEL IN BRANGUS HEIFERS

INTRODUCTION

Feed cost for maintenance is estimated to represent at least 60 to 65% of the total feed requirement for the beef cowherd (Arthur et al., 2001b). One of the biggest threats facing the beef supply chain is its heavily reliance on stored feed, an input whose cost cannot be controlled due to unpredictable market fluctuations. Additionally, the world population is expected to exceed 9 billion by 2050 with the demand for agriculture products growing 1.5% annually (Bruinsma and FAO of United Nations, 2003). Therefore, improving feed utilization and efficiency is important to protect the sustainability of beef production. Selection programs can improve profitability by reducing feed inputs without compromising economically relevant traits like carcass merit or reproduction. Traditional measures of feed efficiency, like feed conversion ratio (FCR), have long term consequences associated with increased mature size, maintenance requirements, and DMI. Residual feed intake (RFI) is a measure of feed efficiency that is phenotypically independent of growth rate and body weight (Archer et al., 1999; Arthur et al., 2001a). RFI appears to be a more favorable measure of feed efficiency and has fewer antagonistic selection effects. Reducing daily DMI by just 0.91 kg/d could reduce the cost of beef production by $1 billion annually within the United States and incorporating RFI into

selection programs could improve profitability for beef producers by as much as 33% (Herd et al., 2003; Archer et al., 2004; Weaber 2012).

According to the Beef Improvement Federation Guidelines (BIF, 2010), a 70-day testing period is required to accurately measure daily feed intake. However, reducing test duration could have a significant financial impact on seedstock producers looking to genetically evaluate cattle for RFI. Reducing the time cattle are at centralized testing facilities would reduce the upfront costs associated with genetic evaluation, as well as allow more cattle to be tested within a year. BIF Guidelines (2010) currently recommend computing RFI by the regression of DMI on ADG, which should be calculated by linear regression, and MMWT. While RFI is phenotypically independent of body weight and gain, studies found weak correlations between RFI and carcass traits (Arthur et al., 2001b; Basarab et al., 2003; Lancaster et al. 2009a,b; Nkrumah et al., 2004; Nkrumah et al., 2007; Schenkel et al., 2004). In order to eliminate potential antagonistic correlations genetic selection for RFI may have on carcass merit, some literature suggests ultrasound measures of body composition should be included in the RFI model (Basarab et al., 2003; Lancaster et al., 2009a,b; Mao, 2013). Additionally, sound reproductive performance is essential in maintaining a profitable cattle operation, and some initial short-term studies indicate selection for favorable RFI may cause a later calving day (Arthur et al., 2005; Basarab et al., 2007; Donoghue et al., 2011). Therefore, the objectives of this study were to 1) determine the optimal days on feed for accurately measuring feed intake and ADG in Brangus heifers 2) assess if ultrasound measures of carcass merit increase feed intake model accuracy, and 3) examine reproductive traits in Brangus heifers with RFI phenotypes.

MATERIALS AND METHODS

Animals and Management

All procedures involving animals were approved by the Auburn University Animal Care and Use Committee (IACUCC 2014-2483). Daily feed intake was measured on 186 Brangus replacement heifers obtained from two purebred southeastern Brangus breeders. Heifers were delivered to the Auburn University Beef Cattle Evaluation Center (AUBCE) during 2014 and 2015. Table 1 provides the number of heifers and time of year daily feed intake was measured. Seven contemporary groups were assigned based on date of trial and farm.

The Auburn University Beef Cattle Evaluation Center had 8 pens, each fitted with 12 Calan® gates (American Calan, Northwood, NH). Each pen of cattle had indoor and outdoor access with a capacity of 12 cattle per pen. Pens were 6.1 by 9.1 m inside and 18.3 by 92.7 m outside. The outside portion of each pen was 18.6 m at the widest point by 92.7 m long and divided into three 6.2-m strips. Paddocks contained common bermudagrass (*Cynodon dactylon* L.) as the forage base. Heifers were allowed access to a different strip of forage weekly which served to minimize erosion and promote hoof health. Heifers had continuous access to automatic water troughs.

Heifers were transported to the AUBEC on 18-wheeler cattle trucks from their farm of origin. Heifers were randomly unloaded into one of the eight pens. Upon arrival, heifers were allowed to rest a minimum of 8 hours prior to processing. Heifers were given access to hay and water. At processing, heifers were weighed and measured for hip height. Heifers were then placed in pens based on hip height and weight to minimize social hierarchy effects.

Heifers were trained to their individual Calan® gates during a 21 d acclimation period. Initially, gates remained open and heifers were group fed the diet in Table 2. The diet was

formulated to be 2.4 Mcal/NE_m and each pen was initially offered 2% BW of the diet. Volunteers observed and recorded heifers eating from each gate. Once the majority of heifers were observed eating, Calan® gates were locked and heifers were fitted with transponders. The gate each heifer was assigned was determined by the observation data. Not all heifers could be trained to the Calan® gates. Heifers unable to learn to open their gate were excluded from the study.

Following the adaptation period, heifers underwent a 70 d feed intake trial to measure daily feed intake and growth performance. Heifers were fed twice a day *ad libitum* amounts such that 0.45 kg to 0.91 kg of feed were left in their bunks at each feeding. Orts were weighed each morning. Heifers were weighed on-test two consecutive days, designated as d-1 and d 0. Heifers were weighed and measured for hip height every 14 d. At the conclusion of 70 d, each heifer was weighed off-test on 2 consecutive days. Carcass ultrasound measurements of 12^{th} rib fat, longissimus dorsi area, and percent intramuscular fat were taken by a certified ultrasound technician within 7 d of test completion. Ultrasound data were collected by an Ultrasound Guidelines Council certified technician using an Aloka 500 (Aloka America, Wallingford, CT) with a 17-cm transducer using Centralized Ultrasound Processing, Ames, Iowa.

Upon completion of each trial, heifers were transported via 18-wheeler cattle trucks to their respective farms. Each farm was responsible for the breeding and calving of heifers.

Criteria for data exclusion

Data was edited for incomplete feed records and heifer age. According to BIF Guidelines (BIF, 2010), heifers must be at least 240 d at the initiation of the feed trial and no older than 390 d at the completion of the feed trial. A total of 79 heifers were removed from the data analysis that did not fall within the recommended age range according to BIF Guidelines (BIF, 2010)

leaving 186 records for this study. Individual feed intake was also checked to ensure total intake was within ± 4 SD of their contemporary group.

RFI Models

Residual feed intake (RFI) was calculated as actual DMI minus expected DMI to meet growth and maintenance energy requirements (Koch, 1963). It is assumed RFI is normally distributed with a mean of zero. Expected DMI is derived through a base model:

$$Y_i = \beta_0 + \beta_1 ADG + \beta_2 MMWT + e_i$$

Where:

Y_i= expected DMI

β_0= regression intercept

β_1= partial regression coefficient of DMI on ADG

β_2= partial regression coefficient of DMI on MMWT

e_i= RFI

ADG can be determined by two methods. Individual animal ADG_1 was computed by the linear regression of weight on day of test using the PROC REG procedure (Appendix II) in SAS (version 9.4, SAS Inst. Inc., Cary, NC). ADG_1 was derived from the following linear regression equation:

$$Y_i = \beta_0 + \beta_1 X_i + e_i$$

Where:

Y_i= weight of animal at observation i

β_0= Y-intercept (initial BW)

β_1= regression coefficient (ADG_1)

X_i= days on test at observation i

e_i= error in weight at observation i

ADG_2 is derived from the following equation:

ADG_2= (Final BW – Initial BW)/days on test

MMWT was derived using both ADG_1 and ADG_2, resulting in the following:

$MMWT_1$= (Final BW – (0.5 * days on test * ADG_1))$^{0.75}$

$MMWT_2$= (Final BW – (0.5 * days on test * ADG_2))$^{0.75}$

Additionally, RFI was determined by adjusting for 70 d ultrasound 12th rib fat depth (RFI_{bf}). The model adjusted for 12th rib fat depth for RFI used:

$$Y_i = \beta_0 + \beta_1 ADG + \beta_2 MMWT + \beta_3 UBF + e_i$$

Where:

Y_i= expected DMI

β_0= regression intercept

β_1= partial regression coefficient of DMI on ADG

β_2= partial regression coefficient of DMI on MMWT

β_3= partial regression coefficient of DMI on UBF

e_i= RFI_{bf}

All RFI values were derived using the PROC REG procedure in SAS (version 9.4, SAS Inst. Inc., Cary, NC). A maximum of four RFI values were determined for each individual heifer using the following prediction equations:

Model 1: $Y_i = \beta_0 + \beta_1 ADG_1 + \beta_2 MMWT_1 + e_1$

Model 2: $Y_i = \beta_0 + \beta_1 ADG_1 + \beta_2 MMWT_1 + \beta_3 UBF + e_2$

Model 3: $Y_i = \beta_0 + \beta_4 ADG_2 + \beta_5 MMWT_2 + e_3$

Model 4: $Y_i = \beta_0 + \beta_4 ADG_2 + \beta_5 MMWT_2 + \beta_3 UBF + e_4$

Where:

Y_i= expected DMI

β_0= regression intercept

β_1= partial regression coefficient of DMI on ADG_1

β_2= partial regression coefficient of DMI on $MMWT_1$

β_3= partial regression coefficient of DMI on UBF

β_4= partial regression coefficient of DMI on ADG_2

β_5= partial regression coefficient of DMI on $MMWT_2$

e_i= RFI_1

e_2= RFI_{bf1}

e_3= RFI_2

e_4= RFI_{bf2}

Once RFI values were determined for heifers using each model, heifers were classified into one of three categories. Heifers classified as high, or inefficient, RFI heifers were more than 1 SD above the mean within the contemporary group. Heifers classified as low, or efficient, RFI heifers were more than 1 SD below the mean within the contemporary group. Heifers within 1 SD of the contemporary group were classified as medium, or average, RFI heifers. Heifers received a RFI classification for each model.

The PROC REG procedure in SAS (version 9.4, SAS Inst. Inc., Cary, NC) was used to regress RFI_1 on RFI_{bf1}, RFI_2 on RFI_{bf2}, RFI_1 on RFI_2, and RFI_{bf1} on RFI_{bf2} to estimate the linear relationship between the models. The PROC CORR procedure in SAS was used to determine Pearson and Spearman correlations among the four models. A Pearson correlation is a parametric

measure of association for two variables, measuring the strength and direction of a linear relationship. The Spearman rank-order correlation is a nonparametric measure of association based on the ranks of the data values, which determines if any changes occur based on how cattle are classified. Measures of agreement were determined between RFI_1 and RFI_{bf1}, RFI_2 and RFI_{bf2}, RFI_{bf1} and RFI_{bf2}, and RFI_1 and RFI_2 using the PROC FREQ procedure in SAS. The AGREE option in the TABLE statement provided the respective kappa coefficient, standard error, and 95% confidence limits. The TEST WTKAP option within the PROC FREQ procedure computed the hypothesis test for weighted kappa values, where H_0= 0. Kappa values were used to determine the level of agreement between each RFI model pair, where < 0.4= low level of agreement beyond chance, 0.40-0.75= fair to good level of agreement beyond chance, and > 0.75= high level of agreement beyond chance.

Test Length

To assess whether a shorter feeding period could be implemented to accurately determine feed intake and ADG, subsets of the 70 d trials were created comparing on-test durations of 14, 28, 42, and 56 d. For each on-test duration, expected feed intake model components were estimated using both ADG_1, ADG_2 and $MMWT_1$, $MMWT_2$ definitions. The PROC REG procedure in SAS was then used to regress RFI, DMI, ADG, and MMWT for the full test (d 0 to 70) on the RFI, DMI, ADG, and MMWT values from the shorter tests. The CORR procedure in SAS was used to determine Pearson correlations for average DMI, RFI, ADG, and MMWT values, as calculated above, from a full 70 d test to these values from shorter on-test durations. Spearman rank correlations were also calculated to investigate potential changes in animal rank for d 70 average DMI, RFI, ADG, and MMWT when compared to the shorter testing periods.

The relationship between ADG_1 and ADG_2 was further investigated to determine the best indicator of 70 d ADG using the PROC REG procedure in SAS to regress ADG_1 values on ADG_2 values for the 56 d and 70 d test. The CORR procedure in SAS was used to determine Pearson and Spearman correlations between ADG_1 and ADG_2 for 56 d and between ADG_1 and ADG_2 for 70 d. No ultrasound carcass data was included in these analyses since ultrasound data was only collected at the conclusion of the 70 d test.

Effects of RFI on measures of growth and reproduction

Independent variables of RFI classification, farm, sire, and trial were used in a general linear model to assess their impact on initial BW, final BW, DMI, ADG, MMWT, and UBF. Heifers without sire records were omitted from this analysis. Calving records were obtained on 54 heifers from trials conducted beginning in June and December of 2014. Independent variables included farm, classification, and sex of calf and were used in a general linear model to assess their impact on age at first calving for the four models. Calving age of each heifer was determined as calving date minus date of birth. The PROC GLM procedure of SAS was used for these analyses. Least squares means was used to separate means with a significant *P-value* set at 0.05. Further analysis between age at first calving and off-test BW were performed using the PROC CORR and PROC REG procedure of SAS.

RESULTS AND DISCUSSION

Simple means for performance traits by contemporary group based on a 70 d test are presented in Table 3. Summary statistics for average daily DMI from test durations of 14 d, 28 d, 42 d, 56 d, and 70 d are presented in Table 4. DMI increased as test duration increased ranging from 9.43 kg/d to 9.80 kg/d, a difference of 0.37 kg/d. Culbertson et al. (2015) reported a slightly higher DMI range (10.62 kg/d to 11.29 kg/d) from subsets of equal test durations as reported in this study. However, the Culbertson et al. (2015) had a much larger sample size (n= 612) from *bos taurus* bulls, steers, and heifers.

Summary statistics for ADG_1 and ADG_2 from test durations of 14 d, 28 d, 42 d, 56 d, and 70 d are presented in Table 5. ADG decreased as test duration increased, ranging from 1.40 to 1.42 kg/d for ADG_1 and 1.39 to 1.49 kg/d for ADG_2. However, measures from 28 d to 70 d were almost equivalent for both measures of ADG. Culbertson et al. (2015) reported a slightly higher ADG range (1.45 kg/d to 1.49 kg/d), where ADG was calculated by linear regression, from subsets of equal test durations as reported in this study. There was a 0.04 kg/d difference between ADG_2 for 56 d and 70 d, where ADG was calculated by (final BW – initial BW)/days on test. Culbertson et al. (2015) reported a 0.04 kg/d difference between ADG for 56 d and 70 d using linear regression.

Summary statistics for $MMWT_1$ and $MMWT_2$ from test durations of 14 d, 28 d, 42 d, 56 d, and 70 d are presented in Table 6. MMWT increased as test duration increased, ranging from 62.70 kg to 66.30 kg for $MMWT_1$ and 60.84 kg to 66.33 kg for $MMWT_2$. However, MMWT from 28 d to 70 d were similar for both measures of MMWT. Culbertson et al. (2015) reported a slightly higher MMWT range (99.25 kg to 98.25 kg), where MMWT was calculated using the equation $(ADG * \text{midpoint day of subset})^{0.75}$, from subsets of equal test durations as reported in

this study. There was about a 4 kg difference between 28 d to 70 d for both measures of MMWT. Culbertson et al. (2015) reported a 5 kg difference between 28 d to 70 d for MMWT.

Test Duration

Average Daily DMI

Previous studies indicate accurate measurement of DMI can be measured in less than 70 d (Archer et al., 1997; Archer and Bergh, 2000; Culbertson et al., 2015; Wang et al., 2006). Table 7 contains results of regressing 70 d DMI on shorter test durations from the current study. Regression coefficients increased as the shortened test periods approached the 70 d BIF benchmark, maximizing at 0.96 ($P < 0.0001$) for a 56 d test. The R^2 value was also highest for the 56 d analysis. The 56 d test period had a R^2 of 0.94, a Pearson correlation coefficient of 0.97 ($P < 0.0001$), and a Spearman correlation coefficient of 0.97 ($P < 0.0001$), indicating little change in rank of cattle for DMI compared to a 70 d test. If the test period was shortened to 42 d, results are similar to those seen at 56 d. Results of shorter test lengths of 14 d or 28 d indicate a less accurate measure of DMI with more reranking of heifers occurring. Results from this study indicate that DMI collected from a 56 d period are equivalent predictors of DMI compared to DMI through a 70 d period and would be sufficient for accurate measurements of DMI in this population. However, a 42 d test may only result in a minor loss in accuracy and may be the optimal test duration in economic terms depending on the availability of pedigree data.

Results from this study are in agreement with literature reports for *bos taurus* cattle. Culbertson et al. (2015) recommended shortening tests to 42 d for the collection of DMI data. Reported Pearson and Spearman correlation coefficients for a 42 d test were 0.97 in the Culbertson et al. (2015) study, which are equivalent to our findings for a 56 d test period and

slightly greater than our findings for a 42 d test period. Culbertson et al. (2015) reported a regression coefficient of 0.99 ($P < 0.0001$) and a R^2 of 0.97 for a 42 d test, which are higher than those in this study for either a 42 d or 56 d trial. Archer et al. (1997) recommended a 35 d test for daily feed intake and reported a phenotypic correlation of 0.87 between a 35 d and 119 d test. A similar Spearman correlation coefficient of 0.88 was reported in this study for a 28 d test. Wang et al. (2006) reported changes of phenotypic residual variances for DMI stabilized after 35 d on test and Pearson and Spearman correlations between a 35 d test and a 91 d test reached 0.93. Archer and Bergh (2000) reported the residual variance for DMI stabilized at 56 d in *bos taurus* and *bos indicus* cattle and a 56 d test was appropriate to measure DMI.

Average Daily Gain (ADG)

Results from the regression of ADG_1 and ADG_2 from the 70 d test on shorter test durations are shown in Table 8. Regression coefficients increased as the shortened test periods approached the 70 d benchmark, maximizing at 0.84 ($P < 0.0001$) for a 56 d test. The 56 d test period had a R^2 of 0.86, a Pearson correlation coefficient of 0.93 ($P < 0.005$), and a Spearman correlation coefficient of 0.90 ($P < 0.0001$), indicating some rank changes of cattle for ADG_1 compared to a 70 d test. Results from the regression of ADG_2 values from the 70 d test on shorter test durations show regression coefficients increased as the shortened test periods approached the 70 d benchmark, maximizing at 0.84 ($P < 0.05$) for a 56 d test. Since regression coefficients were the same for both measures of ADG, they are equally as predictive of 70 d ADG from a 56 d test. ADG_2 for the 56 d test period had a R^2 of 0.74, a Pearson correlation coefficient of 0.86 ($P < 0.05$), and a Spearman correlation coefficient of 0.86 ($P < 0.005$). While correlations were slightly stronger for ADG_1, this only indicates ADG_1 for 56 d had a slightly stronger relationship

with ADG_1 for 70 d. Additionally, correlation coefficients between two measures that are progressively similar are not reliable indicators of the most accurate method due to autocorrelation.

Linear regression of ADG_1 values on ADG_2 values for 56 d and 70 d, confirmed the two measures are similar. Regression coefficients maximized at 1.06 ($P < 0.0001$) for the 56 d test and decreased slightly for the 70 d test to 0.99 ($P < 0.0001$). The 56 d test period had an R^2 of 0.92, a Pearson correlation coefficient of 0.96 ($P < 0.0001$), and a Spearman correlation coefficient of 0.95 ($P < 0.0001$). The 70 d test period had an R^2 of 0.93, a Pearson correlation coefficient of 0.97 ($P < 0.0001$), and a Spearman correlation coefficient of 0.96 ($P < 0.0001$), indicating a few rank changes of cattle regardless of how ADG was calculated. By these values alone, a definitive measure for calculating ADG cannot be determined when predicting expected feed intake. However, these results support those of other studies suggesting that ADG is the limiting factor in calculating RFI and longer test durations are required for measuring RFI in comparison to shorter tests for accurately measuring feed intake (Archer et al., 1997; Archer and Bergh, 2000; Wang et al., 2006).

Culbertson et al. (2015) recommended shortening feed intake trial length from 70 d to 56 d for the collection of ADG data. The Culbertson et al. (2015) study with *bos taurus* bulls, steers, and heifers reported a R^2 value, Pearson correlation coefficient, and Spearman correlation coefficient for a 56 d test of 0.95, 0.95, and 0.94, respectively, which are greater than our findings for a 56 d trial. Culbertson et al. (2015) reported a regression coefficient of 0.80 ($P < 0.005$), which is slightly lower than what is reported in this study. Archer et al. (1997) recommended a 70 d test length for RFI trials and reported a phenotypic correlation of 0.85 between a 70 d and 119 d test. In comparison to Archer et al. (1997), a similar Spearman

correlation coefficient of 0.86 was reported in this study for a 42 d test using ADG_1 values and for a 56 d test using ADG_2 values. Wang et al. (2006) reported changes of phenotypic residual variances for ADG continued to fluctuate throughout the 91 d test period, indicating ADG requires a longer testing period and more measurements are needed to obtain an accurate determination of test duration. However, Wang et al. (2006) reported Pearson and Spearman correlations between a 63 d test and a 91 d test were 0.90 and 0.87, respectively, and determined a 63 d test was sufficient for measuring ADG. Archer and Bergh (2000) reported the residual variance for ADG stabilized after 42 d, and a test between 42 d and 56 d is sufficient for measuring ADG when linear regression is used to model weight vs. time. These results also agree with the findings of our study where 56 d is adequate for measuring ADG.

Metabolic mid-weight (MMWT)

Results from the regression of MMWT values from the 70 d test on shorter test durations are shown in Table 9. There is little difficulty in estimating MMWT at shorter test lengths. $MMWT_1$ and $MMWT_2$ values from the 28 d test period had a regression coefficient, R^2, Pearson correlation coefficient, and Spearman correlation coefficient of 1.04 ($P < 0.005$), 0.98, 0.99 ($P < 0.0001$), and 0.99 ($P < 0.0001$), respectively. Culbertson et al. (2015) reported similar results for a 28 d test with a regression coefficient, R^2, Pearson correlation coefficient, and Spearman correlation coefficient of 1.02, 0.99, 0.99, and 0.99, respectively. Results indicate longer test periods are required to measure RFI due to ADG. MMWT is not the limiting factor.

Residual Feed Intake (RFI)

Table 10 contains results of regressing 70 d RFI_1 and RFI_2 on shorter test durations. Regression coefficients increased as the shortened test periods approached the 70 d benchmark, maximizing at 0.93 (*P < 0.0001*) for a 56 d test. The 56 d test period had a R^2 of 0.90, a Pearson correlation coefficient of 0.95 (*P < 0.0001*), and a Spearman correlation coefficient of 0.95 (*P < 0.0001*), indicating little change in rank of cattle for RFI_1 compared to a 70 d test. Results from the regression of RFI_2 values from the 70 d test on shorter test durations show regression coefficients increased as the shortened test periods approached the 70 d benchmark, maximizing at 0.91 (*P < 0.0001*) for a 56 d test. RFI_2 over a 56 d test period had a R^2 of 0.88, a Pearson correlation coefficient of 0.94 (*P < 0.0001*), and a Spearman correlation coefficient of 0.93 (*P < 0.0001*), indicating little change in rank of cattle for RFI compared to a 70 d test. While values for RFI_1 are slightly stronger than RFI_2 in Table 10, they are both good indicators of 70 d RFI based on a 56 d test. Out of 186 heifers, 25 changed rank when the 70 d test was shortened to 56 d. The following rank changes occurred; medium to high (n=9), low to medium (n= 4), high to medium (n=10), and medium to low (n=2). When the 70 d test was shortened to 42 d, 36 heifers changed rank. The following rank changes occurred; low to medium (n= 10), medium to high (n=10), high to medium (n= 9), and medium to low (n=7). These results suggest a 56 d performance test could reliably predict RFI values resulting from a 70 d test.

Previous studies indicate shortening the 70 d test duration for RFI may still reliably predict phenotypic RFI values (Archer and Bergh, 2002; Culbertson et al., 2015; Wang et al., 2006). Culbertson et al. (2015) recommended shortening tests to 56 d for the collection of feed intake and body weight. The reported Pearson and Spearman correlation coefficients for a 56 d test were 0.94 and 0.95, respectively, which are similar to our findings when the data is collected

in a 56 d trial. Culbertson et al. (2015) reported a stronger regression coefficient of 1.00 ($P < 0.0001$) and a similar R^2 of 0.89 for a 56 d test. Archer et al. (1997) recommended a 70 d test for daily feed intake and reported a phenotypic correlation of 0.91 between a 70 d and 119 d test. Similar Spearman correlation coefficients of 0.89 and 0.88 for RFI_1 and RFI_2, respectively, were reported in this study for a 42 d test. Wang et al. (2006) reported changes of phenotypic residual variances for DMI stabilized after 63 d on test and Pearson and Spearman correlations between a 63 d test and a 91 d test were 0.90. Archer and Bergh (2000) reported the residual variance for RFI stabilized at 70 d for *bos taurus* and *bos indicus* cattle but shortening the test duration to as little as 49 days would result in only minor losses in accuracy for all breeds.

Conclusions for test duration

Results from this study indicate accurate DMI measurements could be obtained from a 42 d performance test but a 56 d test is required for reliable estimation of RFI. While animals were weighed every two weeks in this study, weekly body weight measurements would provide a more accurate measure of ADG. These results support the conclusion that ADG is the limiting factor in determining test duration for RFI. Thus, reducing RFI test duration is dependent on the accuracy of ADG measurements. Currently, the Beef Improvement Federation (BIF, 2010) recommends a 70 d test, preceded by a 21 d acclimation period, and measuring body weights at least every two weeks. However, collecting body weight data at more frequent intervals would allow for a more accurate measure of ADG and RFI in a shorter amount of time. Recording live weights at periodic intervals during the test period and calculating rate of gain by regression may enhance the accuracy of measured rate of gain and allow for a slightly shorter test period (BIF, 2010). As expected, the results of this study are very similar to those reported by Culbertson et

al. (2015), as the experimental design and procedures follow BIF recommendations. Wang et al. (2006) reported test durations for measuring ADG could be reduced to 63 d when cattle are weighed weekly. Archer and Bergh (2000) reported the shortest test duration for ADG measurements at 42 d. However, cattle were weighed weekly and animals were fasted for 12 h before weighing (Archer and Bergh, 2000). Not only does this provide a more accurate measure of body weight, but it reduces the variation in weights due to gut-fill, reducing residual error. However, it also greatly disrupts feeding patterns, which seems contradictory in a feed intake study designed to encourage normal feeding activity. Archer et al. (1997) reported a 70 d test is necessary to measure ADG, however, one of the biggest limitations in that study was the weighing frequency. Weights were only collected at 1, 2, 5, and 10 weeks and thus, took longer to accurately measure ADG. Therefore, any improvement in the measurement accuracy on ADG by reducing test length will automatically reduce the test duration for efficiency traits (Wang et al., 2006).

Decisions should not be based on phenotypic correlations between shorter tests and maximum test duration alone. This approach is problematic due to autocorrelation, where the correlation between two sets of the same data at similar lengths are by definition high, and fails to consider the measured trait is composed of biological variation and other variation, including measurement error (Archer and Bergh, 2000). Therefore, heritability estimates as a criterion may be more suitable in the context of selection programs because the variance of the test outcome reflects biological and unexplained residual error for a particular trait of interest (Archer and Bergh, 2000). When correlations are high between shortened tests and a maximum test length, it's most likely due to high residual error variance and is a less accurate indicator of genetic potential. When the same trait is measured in tests of different lengths, the amount of residual

error reduces as length of test increases whereas; the biological variance underlying the trait of interest is likely to remain relatively constant. Performance tests analyzing changes in variance are more reliable because once residual variance stabilizes; the remaining variation is due to additive genetic effects, providing a more accurate measure of heritability. While heritability estimates were not estimated in this study, our results are similar to those reported in the most recent literature and support shorter test durations for genetic evaluation of feed intake in beef cattle.

However, while variance components are able to provide the most biologically accurate measure of a trait, the most economically optimum test duration may be much shorter than the test duration maximizing the accuracy of measurement (Archer and Bergh, 2000). Reducing test duration allows for testing more animals in addition to reducing costs. If breeding programs test related animals and the data from relatives are used in genetic evaluations, the extra pedigree data may partially compensate for the loss in accuracy from a shorter test. Therefore, the optimum test duration may differ from that determined by phenotypic evaluation alone.

Results from this study suggest performance tests shorter than 70 d can still reliably predict feed intake and RFI. According to Culbertson et al. (2015), facilities could run one additional test per year when reducing test durations to 56 d, and reducing tests for DMI to 42 d would increase the number of animals tested by 33%. Considering the similarities between this study and current literature, there does not appear to be any significant breed differences or influence of sex on the results from shortened test lengths. This is significant because there has been increased interest in testing more heifers but reported literature is scarce. Seedstock producers typically select bulls for genetic evaluation but since the quality of replacement heifers

largely determines the quality of the breeding herd, more replacement heifers are being genetically evaluated for feed intake.

RFI Models

Several studies indicate RFI is weakly correlated with measures of body composition, specifically backfat thickness (Arthur et al., 2001b; Basarab et al., 2003; Lancaster et al., 2009a,b; Mao et al., 2013; Nkrumah et al., 2007; Schenkel et al., 2004). Potentially, long-term selection for RFI can affect body composition as more efficient cattle tend to be leaner. This can have a significant effect on slaughter animals as well as those in the breeding herd. Any significant changes in body composition can potentially affect carcass merit and reproductive fitness.

Model 1 (RFI_1, n= 186) accounted for 0.49 of the variation in DMI explained by ADG_1 and $MMWT_1$. Model 3 (RFI_2, n= 186) accounted for 0.50 of the variation in DMI explained by ADG_2. Pearson and Spearman correlation coefficients of 1.00 (*P < 0.0001)* and 0.99 (*P < 0.0001)* between RFI_1 and RFI_2 indicate they are nearly identical with little reranking of individuals with respect to determining RFI values. Linear regression of RFI_1 on RFI_2 revealed a regression coefficient of 1.00 ± 0.01 (*P < 0.0001*), which did not differ from 1 (95% confidence limits; $0.98 < \beta < 1.01$), again suggesting models were equivalent.

Comparing Model 1 (RFI_1, n=186) and Model 2 (RFI_{bf1}, n= 176), Model 2 (RFI_{bf1}) accounted for an additional 2% of the variation in DMI when including 70 d ultrasound backfat thickness measures (RFI_{bf1}) with a R^2 of 0.51. Pearson and Spearman correlation coefficients between RFI_1 and RFI_{bf1} were 0.91 (*P < 0.0001*) and 0.89 (*P < 0.0001*), respectively. Out of 176 heifers with backfat records, 28 changed rank. The following rank changes occurred; high to

medium (n= 7), medium to low (n= 8), medium to high (n= 4), and low to medium (n= 9). Linear regression of RFI_1 on RFI_{bf1} estimated a regression coefficient of 0.95 ± 0.03 (*P < 0.0001*), which did not differ from 1 (95% confidence limits; $0.89 < \beta < 1.02$). Including ultrasound backfat records do explain more variation, but reranking of individuals for RFI is minimal.

Comparing Model 3 (RFI_2) and Model 4 (RFI_{bf2}), Model 4 (RFI_{bf2}) accounted for an additional 2% of the variation in DMI when including 70 d ultrasound backfat thickness measures (RFI_{bf2}) with a R^2 of 0.52. RFI_2 and RFI_{bf2} had strong Pearson and Spearman correlation coefficients of 0.93 (*P < 0.0001*) and 0.90 (*P < 0.0001*), respectively. Out of 176 heifers with backfat records, 24 changed rank. The following rank changes occurred; high to medium (n= 2), medium to high (n= 9), low to medium (n= 7), and medium to low (n= 6). Linear regression of RFI_2 on RFI_{bf2} revealed a regression coefficient of 1.00 ± 0.03 (*P < 0.0001*), which did not differ from 1 (95% confidence limits; $0.94 < \beta < 1.06$).

RFI_{bf1} and RFI_{bf2}, had strong Pearson and Spearman correlation coefficients of 0.96 (*P < 0.0001*) and 0.95 (*P < 0.0001*), respectively. Linear regression of RFI_{bf1} on RFI_{bf2} revealed a regression coefficient of 1.00 ± 0.02 (*P < 0.0001*), which did not differ from 1 (95% confidence limits; $0.96 < \beta < 1.04$).

Measures of association show similar strength of agreement between models compared to strength of relationship between models using correlation coefficients. The kappa coefficient between RFI_1 and RFI_2 was 0.84 (95% confidence limits; $0.77 < \beta < 0.92$), which indicates high agreement. The hypothesis test confirms rejection of the null hypothesis of no agreement for all the models, suggesting the true kappa is greater than zero. The kappa coefficients between RFI_{bf1} and RFI_{bf2}, RFI_2 and RFI_{bf2}, and RFI_1 and RFI_{bf1} have the values 0.75 (95% confidence limits;

$0.65 < \beta < 0.84$), 0.75 (95% confidence limits; $0.65 < \beta < 0.84$), and 0.67 (95% confidence limits; $0.56 < \beta < 0.79$), respectively, indicating fair to good levels of agreement.

To date, only a few heifers (n= 54) have calved. A subset of the data just including heifers which calved was created. The four models were also examined with these 54 records. Model 1 (RFI_1) accounted for 0.43 of the variation in DMI explained by ADG_1 and $MMWT_1$. Model 2 (RFI_{bf1}) accounted for an additional 4% of the variation in DMI when including 70 d ultrasound backfat thickness measures (RFI_{bf1}) with a R^2 of 0.47. RFI_1 and RFI_{bf1} had Pearson and Spearman correlation coefficients of 0.90 ($P < 0.0001$) and 0.90 ($P < 0.0001$), respectively. Linear regression of RFI_1 on RFI_{bf1} revealed a regression coefficient of 0.88 ± 0.06 ($P < 0.0001$), which did not differ from 1 (95% confidence limits; $0.76 < \beta < 1.00$). Model 3 (RFI_2) accounted for 0.44 of the variation in DMI explained by ADG_2 and $MMWT_2$. Model 4 (RFI_{bf2}) accounted for an additional 4% of the variation in DMI when including 70 d ultrasound backfat thickness measures (RFI_{bf2}) with a R^2 of 0.48. RFI_2 and RFI_{bf2} had strong Pearson and Spearman correlation coefficients of 0.94 ($P < 0.0001$) and 0.95 ($P < 0.0001$), respectively. Linear regression of RFI_2 on RFI_{bf2} revealed a regression coefficient of 1.02 ± 0.05 ($P < 0.0001$), which did not differ from 1 (95% confidence limits; $0.92 < \beta < 1.11$). When comparing the two unadjusted models, RFI_1 and RFI_2 had the strongest Pearson and Spearman correlation coefficients at 1.00 ($P < 0.0001$) and 0.99 ($P < 0.0001$), respectively. Linear regression of RFI_1 on RFI_2 revealed a regression coefficient of 1.00 ± 0.01 ($P < 0.0001$), which did not differ from 1 (95% confidence limits; $0.97 < \beta < 1.02$). When comparing the two adjusted models, RFI_{bf1} and RFI_{bf2} had strong Pearson and Spearman correlation coefficients at 0.95 ($P < 0.0001$) and 0.95 ($P < 0.0001$), respectively. Linear regression of RFI_{bf1} on RFI_{bf2} revealed a regression

coefficient of 1.05 ± 0.05 (*P < 0.0001*), which did not differ from 1 (95% confidence limits; 0.96 < β < 1.14).

The subset of heifers with calving data revealed a similar trend. Kappa coefficients between RFI_1 and RFI_2 and between RFI_{bf1} and RFI_{bf2} were 0.85 (95% confidence limits; 0.72 < β < 0.98) and 0.77 (95% confidence limits; 0.61 < β < 0.93), respectively, indicating a high level of agreement beyond chance. Kappa coefficients between RFI_2 and RFI_{bf2} and between RFI_1 and RFI_{bf1} were 0.69 (95% confidence limits; 0.52 < β < 0.87) and 0.62 (95% confidence limits; 0.43 < β < 0.81), respectively, indicating a fair to good level of agreement beyond chance.

Measures of association and correlation coefficients were similar based on strength rankings between two models. The unadjusted RFI models (Model 1 and Model 3) had the strongest relationship and measures of agreement, followed by the RFI models adjusted for backfat (Model 2 and Model 4). Interestingly, the unadjusted RFI models and their respective adjusted RFI models were the weakest. Additionally, adjusting RFI for backfat explained an additional 2% variation in DMI in both RFI_{bf} models. In the data subset, adjusting RFI for backfat explained an additional 4% variation in DMI in both RFI_{bf} models. R^2 maximized at 0.52 using Model 4. These results suggest Model 4 (RFI_{bf2}) is superior, where ADG was calculated by using final BW and initial BW (ADG_2) and RFI is adjusted for backfat.

In Angus bulls, Lancaster et al. (2009a) reported a similar increase in model R^2 (3%) when including gain in ultrasound backfat thickness in the linear regression predicting DMI. Similar to Model 1 and Model 2, Pearson (0.92) and Spearman (0.91) rank correlation coefficients between RFI and RFI_{bf} were reported (Lancaster et al., 2009a). However, correlations by Lancaster et al. (2009a) remain weaker than correlations between Model 3 and Model 4 in the current study. A study with Brangus heifers revealed a slightly higher model R^2 of

0.555 when predicting DMI from ADG and MMWT, but the increase of R^2 (4.2%) when including gain in ultrasound backfat thickness was similar to the increase in R^2 seen in the current study using the calving data subset (Lancaster et al., 2009b). Pearson and Spearman correlation coefficients were even stronger at 0.97 and 0.96, respectively (Lancaster et al., 2009b) than seen in the current study. Schenkel et al. (2004) and Basarab et al. (2003) reported smaller increases in R^2 of 1.4% and 1.8%, respectively, when adjusting RFI for body composition. Schenkel et al. (2004) reported strong genetic correlations between RFI and RFI adjusted for final ultrasound backfat thickness (0.99). Basarab et al. (2003) reported similar Spearman rank correlations between RFI and RFI adjusted for ultrasound backfat thickness and ultrasound marbling (0.91, $P < 0.0001$) to those reported in this study. However, the Spearman correlation coefficient between Model 3 and Model 4 was stronger (0.95, $P < 0.0001$) in the current study than the Basarab et al. (2003) findings. Mao et al. (2013) reported RFI adjusted for ADG, MMWT, and ultrasound backfat accounted for 66.1% and 75.3% of the variation in expected DMI for Angus and Charolais steers, respectively. While the addition of UBF into the RFI model only accounted for an additional 0.5% variation in DMI for Angus steers, there was a much larger effect on Charolais steers and accounted for an additional 2.3% variation in DMI. Mao et al. (2013) concluded a larger impact was made in Charolais steers because they tend to mature later than Angus cattle. Animals that tend to mature later are able to use feed more efficiently because the growth phase is primarily concerned with protein deposition, which is more energetically efficient than fat deposition. Earlier maturing cattle, like Angus, consume more feed to support not only growth and production, but also increased energy demands associated with the onset of puberty. Because they are consuming larger quantities of feed and any excess energy is deposited as fat, they tend to be less efficient. However, there also tends to

be a greater correlation between RFI and backfat measures in later maturing breeds compared to those that are early maturing. Therefore, adjusting RFI for measures of ultrasound backfat thickness may have a greater effect on later maturing animals compared to those considered early maturing.

The results from this study are similar to current published literature analyzing RFI with measures of body composition, specifically ultrasound backfat thickness when ADG was computed by linear regression. Model 1 and Model 2 are appropriate comparisons to current studies on RFI. However, literature on RFI with ADG calculated using just beginning and end weights are limited. Thus, results from Model 3 and Model 4 suggest further research is warranted since this alternative calculation for RFI may be superior to current recommendations because fewer cattle changed rank, correlations were stronger, regression coefficients and kappa coefficients were higher, and RFI_2 is a more accurate indicator of RFI when adjusted for UBF (RFI_{bf2}).

Growth Performance

Tables 11 through 14 contain least squares means for initial BW, final BW, DMI, MMWT, ADG, and UBF by model. In all cases, given the definition of RFI classification, least squares means for low, medium, and high RFI classification were significantly different *($P < 0.0001$)* regardless of model. Additionally, DMI was significantly different among RFI classifications for each model. In Model 1, low RFI heifers consumed 25% less feed/day compared to high RFI classified heifers. Similarly, low RFI classified heifers ate 23%, 25%, and 23% less feed than high RFI heifers for Models 2, 3, and 4, respectively. Also, there were no

differences among groups for UBF in any model. Using Model 1, low RFI classified heifers did tend (*P= 0.10*) to have less UBF than medium and high RFI classified heifers.

Examining growth performance of the 54 heifers with calving records, results were similar to the larger dataset. Tables 15-18 contain least squares means for initial BW, final BW, DMI, MMWT, ADG, and UBF by model. In all cases, given the definition of RFI classification, least squares means for low, medium, and high RFI classification were significantly different *(P < 0.0001)*. Additionally, DMI was significantly different among RFI classifications for each model. In Model 1, low RFI heifers consumed 22% less feed/day compared to high RFI classified heifers. Similarly, low classified RFI heifers ate 23%, 24%, and 24% less feed than high RFI heifers for Models 2, 3, and 4, respectively. In Model 1, least squares means for UBF between medium and high RFI_1 classified heifers were significantly different (*P= 0.0210*) at 6.68 ± 0.33 mm and 8.55 ± 0.60 mm, respectively. This is of concern since current Beef Improvement Federation Guidelines (BIF, 2010) recommend calculating RFI based on Model 1, using linear regression to determine ADG. There were no differences among groups for UBF in Models 2, 3, and 4. Using Model 3, medium RFI classified heifers tended (*P= 0.08*) to have less UBF than low and high RFI classified heifers.

In a study by Lancaster et al. (2009a) using 341 Angus bulls, RFI and RFI adjusted for gain in UBF and gain in LMA had strong phenotypic correlations with DMI of 0.60 and 0.55, respectively, with low RFI bulls consuming 16% less (*P < 0.01*) DMI than high RFI bulls. Final ultrasound backfat and gain in backfat had weak phenotypic correlations with RFI of 0.20 and 0.30, suggesting more efficient bulls were leaner. Low RFI bulls had significantly (*P < 0.01*) lower final ultrasound backfat measurements than high RFI bulls (0.59 vs. 0.67 cm), and gained less backfat than high RFI bulls during the trial (0.21 vs. 0.32 cm). Additionally, low RFI bulls

gained significantly (*P = 0.04*) less LMA (18.99 vs. 22.04 cm^2) than high RFI bulls. As expected, gain in backfat and gain in LMA were not correlated with RFI adjusted for body composition since the linear regression model forces RFI to be independent of its component traits.

Lancaster et al. (2009b) conducted a study in 468 Brangus heifers, reporting RFI and RFI adjusted for gain in UBF and final ultrasound LMA had strong phenotypic correlations with DMI at 0.70 and 0.67, respectively. Additionally, there was a significant difference (*P = 0.01*) in DMI based on RFI classification. On average, low RFI heifers consumed 8.76 kg/d, medium RFI heifers consumed 9.48 kg/d, and high RFI heifers consumed 10.34 kg/d. There was a weak phenotypic correlation between RFI and gain in backfat (r_p=0.22; *P < 0.05*), and low RFI and medium RFI classified heifers gained significantly (*P < 0.01)* less UBF than high RFI classified heifers. However, the phenotypic and genetic correlations for RFI and final ultrasound backfat (r_p= 0.12, *P < 0.05*; r_g= 0.36) indicate that selection for favorable RFI may reduce subcutaneous fat deposits.

Nkrumah et al. (2007) conducted a study in crossbred steers and reported an 18.06% difference in DMI between low and high RFI classified steers. Phenotypic (r_p= 0.25; *P < 0.01*) and genetic (r_g= 0.35 ± 0.30) correlations between RFI and ultrasound backfat thickness were stronger, suggesting that selection for RFI might result in selection for leaner animals. Compared with low classified RFI steers, high classified RFI steers had significantly greater rate of gain in ultrasound backfat (0.029 mm/d vs. 0.038 mm/d) and final ultrasound backfat thickness (8.27 mm vs. 9.86 mm). In an earlier study using 150 *bos taurus* bulls and steers, Nkrumah et al. (2004) reported small phenotypic correlations between RFI and gain in ultrasound backfat (r_p= 0.30; *P < 0.01*) and between RFI and final ultrasound backfat thickness (r_p= 0.19; *P < 0.05*),

with low RFI cattle having reduced ultrasound backfat thickness in comparison to high RFI cattle (5.28 mm vs. 6.31 mm). There was a 13.21% difference in DMI between low and high RFI classified cattle, which is significantly lower than the 24% difference found in this study.

Results from this study agree with literature reports and there were no significant differences between heifers based on RFI classification when adjusted for ultrasound backfat thickness. However, differences in ultrasound backfat thickness between heifers based on RFI classification suggest there is a weak relationship between the two. While this may not affect the accuracy of selection in seedstock animals, inclusion of ultrasound measures of body composition on the computation of RFI may be useful to reduce the impact of selection on carcass quality of steer progeny during finishing.

Age at first calving

Least squares means are found in Tables 15 through 18 for age at first calving based on heifer RFI classification using the four models for RFI. There were no significant differences among RFI classification for age at first calving using Model 1, Model 2, or Model 4. Model 3 least squares means for medium and high RFI_2 classified heifers were significantly different ($P= 0.0422$), where high RFI classified heifers calved 32 d earlier than medium RFI classified heifers. High RFI classified heifers were the youngest at first calving in all four models. Calving age and off-test weight had Pearson and Spearman correlation coefficients of -0.45 ($P= 0.0007$) and -0.33 ($P= 0.0162$), respectively. Linear regression of calving age on off-test weight estimated a regression coefficient of -0.45 ± 0.13 ($P < 0.0007$). These results suggest as off-test bodyweight increases, age at first calving decreases. Indeed, when RFI was not adjusted for UBF (Model 1 and Model 3) high RFI classified heifers were the heaviest for off-test bodyweight.

However, inefficient heifers were not significantly different in bodyweight from efficient or average heifers. This association was not apparent when adjusting RFI for UBF (Model 2 and Model 4). Maximizing reproductive performance is essential for beef production system sustainability. Therefore, genetic selection for traits with potential negative effects on reproduction is not recommended. Results from this study suggest RFI should be adjusted for ultrasound backfat thickness as Model 2 and Model 4 are independent of age at first calving. While there were not any significant differences between age at calving and UBF, the adjusted RFI models suggest underlying processes associated with body composition may effect reproductive performance.

Current research suggest high classified RFI females calve earlier in the calving season because more efficient females tend to have a delay in pregnancy as heifers most likely attributed to a delay in first estrus (Arthur et al., 2005; Basarab et al., 2007,2011; Donoghue et al., 2011). Feed intake trials are conducted post-weaning prior to selection decisions being made. Because there is a large variation in age at puberty, *bos taurus* and *bos taurus* influenced cattle tend to be at different stages of sexual development during this time and differences in physiological age may affect RFI classification. Consequentially, RFI testing tends to favor later maturing animals that don't have increased energy demands associated with sexual development and activity (Basarab et al., 2011). Therefore, prepubertal animals have lower feed intakes than those undergoing puberty and may be considered more efficient.

Heifers that calve early in their first calving season tend to calve early throughout their lives and have greater calf lifetime production (Randel and Welsh, 2013). Current research suggest low classified RFI females calve later in the calving season than high classified RFI females, because more efficient females tend to have a delay in pregnancy as heifers (Arthur et

al., 2005; Basarab et al., 2007, 2011; Donoghue et al., 2011). Donoghue et al. (2011) conducted a study to evaluate early life reproductive performance and onset of puberty in Angus heifers. There was a moderate phenotypic correlation between RFI classification and calving day (r_p= -0.45), where low RFI is associated with a later calving day. Low RFI heifers calved 8.1 days later than high RFI heifers (35.7 ± 3.0 vs. 27.6 ±2.4 days) due to a delayed pregnancy date during the first mating season. The later calving date was maintained at subsequent calving but did not impact pregnancy or calving rates. Crowley et al. (2011) reported a negative genetic correlation (r_g= -0.29) between RFI and age at first calving, indicating selection for improved RFI may result in heifers that conceive later in the calving season. In a study examining the effects of divergent selection for RFI on maternal productivity, low RFI cows tended (*P= 0.07*) to calve 5 days later than high RFI cows (Arthur et al., 2005). Basarab et al. (2007) reported similar results where cows producing more efficient progeny calved 5 to 6 days later than cows producing inefficient progeny. However, there was no difference in calving interval indicating that the dams producing steers classified as low RFI were bred later in the breeding season as heifers and continually bred later in the breeding season in subsequent years. In a study by Basarab et al. (2011), low classified RFI heifers had fewer calves born by day 28 of the calving season than high classified RFI heifers (82.6% vs. 95.0%). The delay in calving was removed by adjusting RFI for ultrasound backfat thickness and feeding event frequency. These results suggest selection for more efficient cattle may negatively impact age at puberty, but does not affect reproductive performance and productivity of mature cows.

IMPLICATIONS

Results from this study suggest performance test duration for measuring feed intake can be reduced to 56 d from the current recommendation of 70 d by Beef Improvement Federation Guidelines (BIF, 2010). This has significant economic implications for seedstock producers looking to improve feed efficiency in their herd by genetic selection for RFI. Based on results from this study, there is an average difference of 2.86 kg/d in feed consumed between low RFI and high RFI classified heifers over a 70 d test period. Assuming feed cost is $0.29/kg, there is a $0.83/d difference in feed cost between low and high RFI classified heifers. Accounting for a 21 d adaption period, heifers are at the testing facility for 91 d. This equates to a $75.53/head difference in feed cost over 91 d between low and high RFI heifers. Reducing the test duration to 56 d for measuring feed intake and accounting for a 21 d adaptation period for a total of 77 d at the testing facility, there is a savings of $63.91/head difference in feed cost between low and high RFI heifers. This two week reduction equates to $11.62/head savings in feed cost for producers looking to performance test their herd. According to USDA January 1, 2016 cattle inventory, there are 13.2 million head feeder cattle in the United States. Assuming animals remain in feedlots for 120 d, this equates to a $1.31 billion difference in feed costs for feeder cattle.

Data analysis revealed Model 4 (RFI_{bf2}) accounted for the most variation when predicting expected feed intake. Additionally, RFI models that adjusted for UBF showed no significant differences for ADG, beginning or ending weight or age at first calving for heifers classified as efficient, average or inefficient based on RFI values. Since ultrasound measures of body composition are routinely collected in seedstock cattle for national cattle evaluation, these measures should be included in the RFI model used for cattle undergoing RFI evaluation.

In conclusion, these data indicate the accuracy of RFI estimation remained the same when on-test duration reduced to 56 d, but accuracy of the RFI model improved when including 70 d measures of UBF. Based on these results, further research is warranted and should examine 56 d RFI_{bf} with 70 d RFI_{bf}. A 56 d RFI_{bf} model would not only result in a significant cost savings for producers looking to measure cattle for RFI, but would also provide a more accurate measure of RFI estimation.

Table 1. Formation of contemporary group by on-test date and source of farm.

Contemporary Group	Date	Farm	Number of heifers
1	June 2014 to September 2014	1	20
2	June 2015 to August 2015	1	46
3	June 2014 to September 2014	2	22
4	August 2015 to October 2015	2	23
5	September 2015 to December 2015	1	22
6	December 2014 to March 2015	1	12
7	December 2014 to March 2015	2	41
Total			186

Table 2. Ingredient and nutritional value of diet fed to Brangus heifers in the 7 trials.

Item	Value, %
Dietary composition, (as fed)	
Cracked corn	13.75
Soyhull pellets	20.00
Dried distillers grain	5.00
Corn gluten pellets	22.50
Cottonseed hull pellets	15.00
Alfalfa meal	5.00
Mineral	2.50
Potassium chloride	0.15
Supplement	0.10
Cottonseed hulls	10.00
Molasses	6.00
Chemical composition, (DM basis)	
CP	13.40
NDF	44.10
NE_m	0.70
NE_g	0.42
ME, Mcal/kg	2.47

Table 3. Means (± SD) for performance traits by contemporary group based on a 70 d test.

Contemporary Group	N	Initial BW, kg	Final BW, kg	DMI, kg/d	ADG_1[1], kg/d	ADG_2[2], kg/d	$MMWT_1$[3], kg	$MMWT_2$[4], kg
1	20	301.87 ± 32.68	394.88 ± 34.21	9.58 ± 0.78	1.30 ± 0.18	1.32 ± 0.19	66.26 ± 4.68	66.12 ± 4.64
2	46	301.70 ± 31.98	392.56 ± 34.92	10.04 ± 1.18	1.29 ± 0.13	1.30 ± 0.13	65.96 ± 4.74	65.94 ± 4.76
3	22	278.24 ± 24.97	362.57 ± 30.49	8.40 ± 0.97	1.19 ± 0.15	1.21 ± 0.15	62.19 ± 3.91	62.10 ± 4.00
4	23	292.08 ± 29.62	397.01 ± 40.09	9.76 ± 1.50	1.50 ± 0.23	1.50 ± 0.23	65.61 ± 4.93	65.57 ± 4.92
5	22	323.72 ± 33.85	436.59 ± 42.27	10.96 ± 1.54	1.61 ± 0.21	1.58 ± 0.23	70.61 ± 5.34	70.75 ± 5.24
6	12	325.38 ± 28.98	430.20 ± 33.89	10.61 ± 1.59	1.55 ± 0.27	1.57 ± 0.28	70.03 ± 4.24	69.93 ± 4.31
7	41	299.49 ± 25.44	397.57 ± 35.30	9.57 ± 1.56	1.46 ± 0.24	1.40 ± 0.23	65.86 ± 4.22	66.15 ± 4.22

[1]ADG_1 is calculated by the linear regression of BW on days on test
[2]ADG_2 is calculated by (final BW – initial BW)/days on test
[3]$MMWT_1$ is calculated by (final BW – (0.5 * days on test * ADG_1))$^{0.75}$
[4]$MMWT_2$ is calculated by (final BW – (0.5 * days on test * ADG_2))$^{0.75}$

Table 4. Simple statistics for average daily DMI (kg/d) from all heifers.

	DMI, kg/d			
Days on Test	Mean	SD	Minimum	Maximum
14 d	9.43	1.53	5.25	13.27
28 d	9.47	1.52	4.35	14.67
42 d	9.63	1.49	5.70	15.80
56 d	9.75	1.50	5.77	16.07
70 d	9.80	1.48	6.40	16.21

Table 5. Simple statistics for ADG_1[1] (kg/d) and ADG_2[2] (kg/d) from all heifers.

	ADG_1[1], kg/d				ADG_2[2], kg/d			
Days on Test	Mean	SD	Minimum	Maximum	Mean	SD	Minimum	Maximum
14 d	1.42	0.43	0.29	2.62	1.49	0.47	0.29	2.62
28 d	1.42	0.31	0.29	2.20	1.43	0.33	0.29	2.49
42 d	1.43	0.29	0.72	2.72	1.44	0.28	0.70	2.79
56 d	1.42	0.26	0.73	2.38	1.43	0.23	0.77	2.16
70 d	1.40	0.24	0.69	2.03	1.39	0.23	0.73	1.96

[1]ADG_1 is calculated by the linear regression of BW on days on test
[2]ADG_2 is calculated by (final BW – initial BW)/days on test

Table 6. Simple statistics for metabolic midweight ($(MMWT_1)^1$ (kg) and $(MMWT_2)^2$) (kg) from all heifers

	$(MMWT_1)^1$, kg				$(MMWT_2)^2$, kg			
Days on Test	Mean	SD	Minimum	Maximum	Mean	SD	Minimum	Maximum
14 d	62.07	5.25	50.92	74.75	60.84	4.73	48.25	73.47
28 d	62.21	4.83	49.18	74.75	62.17	4.83	49.18	74.75
42 d	63.73	4.95	50.95	75.80	63.70	4.96	50.81	75.83
56 d	64.94	4.99	52.30	77.67	65.13	4.97	52.22	77.40
70 d	66.30	5.07	53.17	80.34	66.33	5.09	53.23	79.77

[1]$MMWT_1$ is calculated by (final BW – (0.5 * days on test * ADG_1))$^{0.75}$, where ADG_1 is calculated by the linear regression of BW on days on test.
[2]MMWT is calculated by (final BW – (0.5 * days on test * ADG_2))$^{0.75}$, where ADG_2 is calculated by (final BW – initial BW)/days on test.

Table 7. Regression coefficients, R^2, and correlations for average daily DMI (kg/d) over 70 d regressed on shorter durations within the 70 d test.

	DMI, kg/d				
0 to 70 d values regressed on	Regression Coefficient[1]	SE	R^2	Pearson[2]	Spearman[3]
0 to 14 d	0.80	0.04	0.69	0.83	0.84
0 to 28 d	0.87	0.03	0.79	0.89	0.88
0 to 42 d	0.94	0.02	0.89	0.95	0.94
0 to 56 d	0.96	0.02	0.94	0.97	0.97

[1]All regression coefficients were statistically different from 0 where $P < 0.0001$
[2]All Pearson correlations were statistically different from 0 where $P < 0.0001$
[3]All Spearman correlations were statistically different from 0 where $P < 0.0001$

Table 8. Regression coefficients, R^2, and correlations for ADG_1[1] (kg/d) and ADG_2[2] (kg/d) over 70 d regressed on shorter durations within the 70 d test.

	ADG_1[1], kg/d					ADG_2[2], kg/d				
0 to 70 d values regressed on	Regression Coefficient[3]	SE	R^2	Pearson[4]	Spearman[5]	Regression Coefficient[6]	SE	R^2	Pearson[7]	Spearman[8]
0 to 14 d	0.12	0.04	0.04	0.21	0.29	0.08	0.04	0.02	0.16	0.22
0 to 28 d	0.54	0.04	0.50	0.71	0.73	0.52	0.03	0.55	0.74	0.77
0 to 42 d	0.70	0.03	0.76	0.87	0.86	0.63	0.04	0.61	0.78	0.82
0 to 56 d	0.84	0.02	0.86	0.93	0.90	0.84	0.04	0.74	0.86	0.86

[1]ADG_1 is calculated by the linear regression of BW on days on test
[2]ADG_2 is calculated by (final BW – initial BW)/days on test
[3]All regression coefficients were statistically different from 0 where $P < 0.005$
[4]All Pearson correlations were statistically different from 0 where $P < 0.005$
[5]All Spearman correlations were statistically different from 0 where $P < 0.0001$
[6]All regression coefficients were statistically different from 0 where $P < 0.05$
[7]All Pearson coefficients were statistically different from 0 where $P < 0.05$
[8]All Spearman coefficients were statistically different from 0 where $P < 0.005$

Table 9. Regression coefficients, R^2, and correlations for metabolic midweight ($MMWT_1$[1] and $MMWT_2$[2]) (kg) over 70 d regressed on shorter durations within the 70 d test.

	$MMWT_1$[1], kg					$MMWT_2$[2] , kg				
0 to 70 d values regressed on	Regression Coefficient[3]	SE	R^2	Pearson[4]	Spearman[5]	Regression Coefficient[3]	SE	R^2	Pearson[4]	Spearman[5]
0 to 14 d	0.84	0.03	0.76	0.87	0.86	1.05	0.02	0.96	0.98	0.97
0 to 28 d	1.04	0.01	0.98	0.99	0.99	1.04	0.01	0.98	0.99	0.99
0 to 42 d	1.01	0.01	0.97	0.99	0.98	1.02	0.01	0.98	0.99	0.99
0 to 56 d	0.99	0.01	0.96	0.98	0.97	1.02	0.01	0.99	0.99	0.99

[1]$MMWT_1$ is calculated by (final BW – (0.5 * days on test * ADG_1))$^{0.75}$, where ADG_1 is calculated by the linear regression of BW on days on test.
[2]$MMWT_2$ is calculated by (final BW – (0.5 * days on test * ADG_2))$^{0.75}$, where ADG_2 is calculated by (final BW – initial BW)/days on test.
[3]All regression coefficients were statistically significant where $P < 0.0001$
[4]All Pearson correlations were statistically significant where $P < 0.0001$
[5]All Spearman correlations were statistically significant where $P < 0.0001$

Table 10. Regression coefficients, R^2, and correlations for residual feed intake (RFI_1[1] and RFI_2[2]) (kg/d) over 70 d regressed on shorter durations within the 70 d test.

	RFI_1[1], kg/d					RFI_2[2], kg/d				
0 to 70 d values regressed on	Regression Coefficient[3]	SE	R^2	Pearson[4]	Spearman[5]	Regression Coefficient[3]	SE	R^2	Pearson[4]	Spearman[5]
0 to 14 d	0.56	0.05	0.43	0.65	0.68	0.56	0.05	0.43	0.65	0.68
0 to 28 d	0.76	0.04	0.67	0.82	0.81	0.76	0.04	0.67	0.82	0.81
0 to 42 d	0.87	0.03	0.80	0.90	0.89	0.85	0.03	0.78	0.88	0.88
0 to 56 d	0.93	0.02	0.90	0.95	0.95	0.91	0.03	0.88	0.94	0.93

[1]RFI_1 is adjusted for ADG_1 and $MMWT_1$, where ADG_1 is calculated by linear regression and $MMWT_1$ is calculated by (final BW – (0.5 * days on test * ADG_1))$^{0.75}$.
[2]RFI_2 is adjusted for ADG_2 and $MMWT_2$, where ADG_2 is calculated by (final BW – initial BW)/days on test and $MMWT_2$ is calculated by (final BW – (0.5 * days on test * ADG_2))$^{0.75}$.
[3]All regression coefficients were statistically significant where $P < 0.0001$
[4]All Pearson correlations were statistically significant where $P < 0.0001$
[5]All Spearman correlations were statistically significant where $P < 0.0001$

Table 11. Least squares means ± SEM for growth and performance traits of heifers by residual feed intake (RFI_1[1]) (kg/d).

		RFI_1[1]			
Trait	N	Low (n= 29)	Medium (n= 130)	High (n= 27)	*P-value*
RFI_1[1], kg/d	181	-1.44 ± 0.12[a]	-0.08 ± 0.07[b]	1.43 ± 0.13[c]	< 0.0001
Initial BW, kg	181	295.63 ± 6.26	299.91 ± 3.69	298.03 ± 6.75	0.8241
Final BW, kg	181	391.72 ± 7.59	396.48 ± 4.48	393.07 ± 8.19	0.8211
DMI, kg/d	181	8.27 ± 0.21[a]	9.61 ± 0.12[b]	11.01 ± 0.23[c]	< 0.0001
ADG_1[2], kg/d	181	1.40 ± 0.05	1.39 ± 0.03	1.39 ± 0.05	0.9607
$MMWT_1$[3], kg	181	65.30 ± 0.97	66.06 ± 0.57	65.53 ± 1.04	0.7372
UBF[4], mm	175	6.69 ± 0.46	7.85 ± 0.29	7.80 ± 0.53	0.1001

[1]RFI_1 is adjusted for ADG calculated by linear regression (ADG_1) and metabolic midweight ($MMWT_1$)
[2]ADG_1 is calculated by the linear regression of BW on days on test
[3]$MMWT_1$ is calculated by (final BW – (0.5 * days on test * ADG_1))$^{0.75}$
[4]70 d ultrasound backfat thickness
[a-c]Least squares mean within a row are significantly different (*P < 0.0001)*
[4]70 d ultrasound backfat thickness

Table 12. Least squares means ± SEM for growth and performance traits of heifers by residual feed intake adjusted for ultrasound backfat thickness (RFI_{bf1}[1]) (kg/d).

		RFI_{bf1}[1]			
Trait	N	Low (n= 22)	Medium (n= 128)	High (n= 21)	*P-value*
RFI_{bf1}[1], kg/d	175	-1.51 ± 0.12[a]	-0.15 ± 0.06[b]	1.51 ± 0.12[c]	< 0.0001
Initial BW, kg	175	296.92 ± 6.65	299.17 ± 3.66	288.80 ± 7.16	0.3535
Final BW, kg	175	394.17 ± 8.02	396.59 ± 4.42	378.37 ± 8.65	0.1149
DMI, kg/d	175	8.27 ± 0.23[a]	9.54 ± 0.13[b]	10.75 ± 0.25[c]	< 0.0001
ADG_1[2], kg/d	175	1.42 ± 0.05	1.40 ± 0.03	1.31 ± 0.05	0.1946
$MMWT_1$[3], kg	175	65.58 ± 1.02	66.02 ± 0.56	63.83 ± 1.10	0.1408
UBF[4], mm	175	7.60 ± 0.50	7.62 ± 0.28	7.01 ± 0.54	0.5367

[1]RFI_{bf1} is adjusted for ADG calculated by linear regression (ADG_1), metabolic midweight ($MMWT_1$), and 70 d ultrasound backfat thickness (UBF)
[2]ADG_1 is calculated by the linear regression of BW on days on test
[3]$MMWT_1$ is calculated by (final BW – (0.5 * days on test * ADG_1))$^{0.75}$
[4]70 d ultrasound backfat thickness
[a-c]Least squares mean within a row are significantly different (*P < 0.0001)*

Table 13. Least squares means ± SEM for growth and performance traits of heifers by residual feed intake (RFI_2[1]) (kg/d).

		RFI_2[1]			
Trait	N	Low (n= 32)	Medium (n= 129)	High (n= 25)	*P-value*
RFI_2[1], kg/d	181	-1.41 ± 0.11[a]	-0.05 ± 0.07[b]	1.52 ± 0.13[c]	< 0.0001
Initial BW, kg	181	296.98 ± 6.01	300.51 ± 3.73	293.63 ± 7.01	0.6119
Final BW, kg	181	393.02 ± 7.21	397.48 ± 4.50	387.53 ± 8.50	0.5197
DMI, kg/d	181	8.32 ± 0.21[a]	9.62 ± 0.13[b]	11.04 ± 0.24[c]	< 0.0001
ADG_2[2], kg/d	181	1.38 ± 0.04	1.39 ± 0.03	1.35 ± 0.05	0.7360
$MMWT_2$[3], kg	181	65.57 ± 0.90	66.18 ± 0.58	64.96 ± 1.09	0.5336
UBF[4], mm	175	6.93 ± 0.48	7.82 ± 0.29	7.61 ± 0.56	0.2436

[1]RFI_2 is adjusted for ADG_2 and metabolic midweight ($MMWT_2$)
[2]ADG_2 is calculated by (final BW – initial BW)/days on test
[3]$MMWT_2$ is calculated by (final BW – (0.5 * days on test * ADG_2))$^{0.75}$
[4]70 d ultrasound backfat thickness
[a-c]Least squares mean within a row are significantly different (*P < 0.0001)*

Table 14. Least squares means ± SEM for growth and performance traits of heifers by residual feed intake adjusted for ultrasound backfat (RFI_{bf2}[1]) (kg/d).

		RFI_{bf2}[1]			
Trait	N	Low (n= 30)	Medium (n= 117)	High (n= 29)	*P-value*
RFI_{bf2}[1], kg/d	175	-1.22 ± 0.11[a]	-0.08 ± 0.07[b]	1.37 ± 0.11[c]	< 0.0001
Initial BW, kg	175	297.04 ± 6.05	298.58 ± 3.78	294.05 ± 6.43	0.7761
Final BW, kg	175	392.23 ± 7.36	395.93 ± 4.60	389.35 ± 7.82	0.6670
DMI, kg/d	175	8.30 ± 0.20[a]	9.54 ± 0.13[b]	10.72 ± 0.22[c]	< 0.0001
ADG_2[2], kg/d	175	1.37 ± 0.04	1.40 ± 0.03	1.37 ± 0.05	0.7945
$MMWT_2$[3] , kg	175	65.54 ± 0.94	65.93 ± 0.59	65.07 ± 1.00	0.6740
UBF[4], mm	175	7.52 ± 0.45	7.72 ± 0.28	6.85 ± 0.48	0.1980

[1]RFI_{bf2} is adjusted for ADG_2, metabolic midweight ($MMWT_2$), and 70 d ultrasound backfat thickness (UBF)
[2]ADG_2 is calculated by (final BW – initial BW)/days on test
[3]$MMWT_2$ is calculated by (final BW – (0.5 * days on test * ADG_2))$^{0.75}$
[4]70 d ultrasound backfat thickness
[a-c]Least squares mean within a row are significantly different (*P < 0.0001)*

Table 15. Least squares means ± SEM for growth and performance traits of heifers by residual feed intake (RFI_1[1]) (kg/d) with calving records.

		RFI_1[1]			
Trait	N	Low	Medium	High	*P-value*
RFI_1[1], kg/d	54	-1.16 ± 0.20[a]	-0.06 ± 0.12[b]	1.37 ± 0.21[c]	< 0.0001
Initial BW, kg	54	304.60 ± 8.15	297.56 ± 4.69	314.84 ± 8.51	0.1759
Final BW, kg	54	400.68 ± 10.64	392.26 ± 6.13	407.00 ± 11.12	0.4386
DMI, kg/d	54	8.51 ± 0.34[a]	9.35 ± 0.20[b]	10.87 ± 0.36[c]	0.0002
ADG_1[2], kg/d	54	1.38 ± 0.08	1.35 ± 0.05	1.35 ± 0.08	0.9443
$MMWT_1$[3], kg	54	66.68 ± 1.32	65.61 ± 0.76	67.76 ± 1.37	0.3353
UBF[4], mm	54	7.48 ± 0.57[ab]	6.68 ± 0.33[a]	8.55 ± 0.60[b]	0.0210
Age at Calving, d	53	711.50 ± 12.42	716.11 ± 7.52	694.45 ± 12.40	0.3212

[1]RFI_1 is adjusted for ADG calculated by linear regression (ADG_1) and metabolic midweight ($MMWT_1$)
[2]ADG_1 is calculated by the linear regression of BW on days on test
[3]$MMWT_1$ is calculated by (final BW – (0.5 * days on test * ADG_1))$^{0.75}$
[4]70 d ultrasound backfat thickness
[a-c]Least squares mean within a row are significantly different (*P < 0.0001)*

Table 16. Least squares means ± SEM for growth and performance traits of heifers by residual feed intake adjusted for ultrasound backfat thickness (RFI_{bf1}[1]) (kg/d) with calving records.

		RFI_{bf1}[1]			
Trait	N	Low	Medium	High	*P-value*
RFI_{bf1}[1], kg/d	54	-1.63 ± 0.27[a]	-0.11 ± 0.10[b]	1.54 ± 0.21[c]	< 0.0001
Initial BW, kg	54	302.17 ± 12.56	301.68 ± 4.69	300.25 ± 9.69	0.9862
Final BW, kg	54	405.73 ± 15.69	395.94 ± 5.86	390.91 ± 12.12	0.7570
DMI, kg/d	54	8.34 ± 0.54[a]	9.21 ± 0.20[b]	10.83 ± 0.42[c]	0.0015
ADG_1[2], kg/d	54	1.48 ± 0.11	1.35 ± 0.04	1.33 ± 0.09	0.5074
$MMWT_1$[3], kg	54	66.91 ± 1.97	66.18 ± 0.74	65.52 ± 1.52	0.8498
UBF[4], mm	54	8.03 ± 0.93	6.97 ± 0.35	7.19 ± 0.72	0.5791
Age at Calving, d	53	724.54 ± 15.70	710.24 ± 6.82	702.11 ± 13.91	0.5544

[1]RFI_{bf1} is adjusted for ADG calculated by linear regression (ADG_1) and metabolic midweight ($MMWT_1$), and 70 d ultrasound backfat thickness (UBF)
[2]ADG_1 is calculated by the linear regression of BW on days on test
[3]$MMWT_1$ is calculated by (final BW – (0.5 * days on test * ADG_1))$^{0.75}$
[4]70 d ultrasound backfat thickness
[a-c]Least squares mean within a row are significantly different (*P < 0.0001)*

Table 17. Least squares means ± SEM for growth and performance traits of heifers by residual feed intake (RFI_2[1]) (kg/d) with calving records.

		RFI_2[1]			
Trait	N	Low	Medium	High	*P-value*
RFI_2[1], kg/d	54	-1.19 ± 0.25[a]	-0.10 ± 0.13[b]	1.61 ± 0.26[c]	< 0.0001
Initial BW, kg	54	303.65 ± 10.00	300.20 ± 5.04	306.03 ± 10.61	0.8765
Final BW, kg	54	397.76 ± 12.62	394.83 ± 6.37	401.93 ± 13.40	0.8912
DMI, kg/d	54	8.43 ± 0.39[a]	9.33 ± 0.20[b]	11.14 ± 0.41[c]	< 0.0001
ADG_2[2], kg/d	54	1.36 ± 0.10	1.38 ± 0.05	1.40 ± 0.11	0.9696
$MMWT_2$[3], kg	54	66.31 ± 1.55	65.86 ± 0.78	66.79 ± 1.64	0.8732
UBF[4], mm	54	7.45 ± 0.69	6.76 ± 0.35	8.68 ± 0.74	0.0805
Age at Calving, d	53	695.73 ± 12.53[ab]	720.97 ± 6.86[a]	688.55 ± 13.44[b]	0.0422

[1]RFI_2 is adjusted for ADG_2 and metabolic midweight ($MMWT_2$)
[2]ADG_2 is calculated by (final BW – initial BW)/days on test
[3]$MMWT_2$ is calculated by (final BW – (0.5 * days on test * ADG_2))$^{0.75}$
[4]70 d ultrasound backfat thickness
[a-c]Least squares mean within a row are significantly different (*P < 0.0001)*
[a-b]Least squares mean within a row are significantly different (*P < 0.05*)

Table 18. Least squares means ± SEM for growth and performance traits of heifers by residual feed intake adjusted for ultrasound backfat thickness (RFI_{bf2}[1]) (kg/d) with calving records.

		RFI_{bf2}[1]			
Trait	N	Low	Medium	High	*P-value*
RFI_{bf2}[1], kg/d	54	-1.23 ± 0.19[a]	-0.01 ± 0.11[b]	1.55 ± 0.20[c]	< 0.0001
Initial BW, kg	54	300.95 ± 8.67	302.20 ± 5.16	300.41 ± 9.32	0.9811
Final BW, kg	54	396.81 ± 10.91	397.73 ± 6.36	391.27 ± 11.72	0.8906
DMI, kg/d	54	8.26 ± 0.35[a]	9.27 ± 0.21[b]	10.81 ± 0.38[c]	0.0002
ADG_2[2], kg/d	54	1.39 ± 0.09	1.40 ± 0.05	1.33 ± 0.09	0.7953
$MMWT_2$[3] , kg	54	66.06 ± 1.34	66.21 ± 0.80	65.60 ± 1.44	0.9321
UBF[4], mm	54	7.42 ± 0.65	7.00 ± 0.39	7.16 ± 0.70	0.8494
Age at Calving, d	53	709.92 ± 12.82	713.75 ± 7.51	701.55 ± 13.27	0.7219

[1]RFI_{bf2} is adjusted for ADG_2, metabolic midweight ($MMWT_2$), and 70 d ultrasound backfat thickness (UBF)
[2]ADG_2 is calculated by (final BW – initial BW)/days on test
[3]$MMWT_2$ is calculated by (final BW – (0.5 * days on test * ADG_2))$^{0.75}$
[4]70 d ultrasound backfat thickness
[a-c]Least squares mean within a row are significantly different (*P < 0.0001)*

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APPENDIX I

CALCULATION OF RESIDUAL FEED INTAKE (RFI)

A. General

a. Daily feed intake was converted to total feed intake of each animal during the entire feeding period.

b. Convert total feed intake to total energy intake by multiplying total Dry Matter (DM) intake by metabolizable energy of the diet fed determined by indirect calorimetry.

i. Look up energy values of feedstuffs in diet using nutrient requirements of beef cattle (National Research Council, 1996). The following is a list of feedstuffs used to calculate RFI for Auburn University BCIA bull test.

1. Corn = 3.25 Mcal kg-1
2. Cottonseed Hulls = 1.52 Mcal kg-1
3. Oats = 2.78 Mcal kg-1
4. Soybean Meal = 3.04 Mcal kg-1
5. Molasses = 2.60 Mcal kg-1
6. Cottonseed Meal = 2.71 Mcal kg-1
7. Barley Grain #2 = 3.03 Mcal kg-1
8. Fat = 7.30 Mcal kg-1

c. Change pounds of each ingredient to a percent of ingredient in diet by dividing pounds of each ingredient into total pounds of diet.

i. Example: Pounds of ingredient ÷ Total pounds of diet = % of ingredient in diet

d. Multiply percent of ingredient in diet by NRC values looked up.

i. Example: Corn = 0.30 * 3.25 = 0.975

ii. Then take the sum of all feedstuffs calculated previously (in d.i).

e. Take the sum (from d.ii) and multiply it by total feed intake (kg). This number is the total energy intake.

f. Convert total energy intake (from e) to Mj by multiplying it by 4.184

g. Total energy intake is then divided by 10 to give total DM intake standardized to an energy density of 10 MJ ME kg-1 DM.

h. Total standardized feed intake (SFI) is then divided by the number of days on test to give average standardized daily feed intake (SFI, kg d-1).

i. Calculate midweight (MWT): MWT = Final Weight – (0.50 * Days on Test * Average Daily Gain)

j. Calculate metabolic midweight ($MMWT^{0.75}$): $MMWT^{0.75} = (MWT)^{0.75}$

k. Convert $MMWT^{0.75}$ to Kg: $MMWT^{0.75} \div 2.20462$

l. Convert daily feed intake to Kg: total feed intake(kg)/days on test

m. Convert ADG from pounds per day to kg per day: ADG (lbs/d)/2.20462
n. Next calculate expected feed intake (EFI, kg d-1)
    i. Calculate expected feed intake (EFI) using a regression equation in a statistical analysis software program (SAS, SAS Inst. Inc., Cary, NC).
        1. Model fitted is basically of the form:
            a. Yi = a + b1ADGi + b2MMWT + ei
            Where
            Yi = SFI for animal i
            a = regression intercept
            b_1 = partial regression coefficient of SFI on ADG
            b_2 = partial regression coefficient on MMWT
            e_i = residual error in SFI of animal i
    ii. Regress feed intake against some descriptor of maintenance (e.g. bodyweight to the power of 0.73) and production (e.g. growth rate). The predicted value from this regression is the expected feed intake.
        1. Measures of average daily gain (ADG, kg d-1) and metabolic mid-weight ($MMWT^{0.75}$, kg) are used to model daily EFI.
o. Calculate RFI by the following equation: RFI = Average standardized feed intake per day (from h) – expected feed intake (from n.ii.1)

APPENDIX II

ADG USING LINEAR REGRESSION

```
ods rtf file= 'C:\users\TDBlab-HP2\desktop\oaks2015ADGSAS.rtf';
dm "out;clear;log;clear;";
options nocenter ps=5000 ls=240 formdlim="-" symbolgen;
*%let path =V:\Mahler_Lauren\;*always keep the last \;
%let path =C:\users\TDBLab-HP2\Dropbox\Mahler_Lauren\;*replace with your own path but
always keep the last \;
%let XL_in = Oaks2015weights.xlsx;
%let XL_out= Analysis_21JAN16.xls;
%let array_columns = Day_00 Day_14 Day_28 Day_42 Day_56 Day_70;
%let D_wide = wide;
%let D_long = long;
libname VT "&path";
/** 01_Import **/
data SASdata;
        set rawdata.oaks2015weights;
run;
Data wide;
        set SASdata;
run;
proc print Data=wide (obs=282);
run;
/*-------  Linerarizing response variable into a single column ------ */
data Linear; set SASdata;
array raw(*) &array_columns;
        do resp_n=1 to dim(raw);
                Day=scan(Vname(raw(resp_n)),-1,"_")/1;
                response=raw(resp_n)/1;
                output;
        end;
        drop &array_columns resp_n;
run;
proc print data=Linear (obs=282);run;
proc sort data=linear out=long;
        by Tag Day;
run;
proc print data=long (obs=282) ;run;
/** 02_Reg **/
```

```
%let resp_name=ADG;
Data selected;
        set long;
        resp_name="ADG";
run;
proc print data=long ;run;
ods trace on;
ods select None;
Proc reg data=selected;
        by resp_name tag;
        model response=Day/CLB;
        ods output ParameterEstimates=Pout FitStatistics=Fout;
run;
ods trace off;
ods select all;
quit;
proc print data=Pout;run;
proc print data=Fout;run;

proc sql;
        create table RSQ as
        select resp_name, tag, Cvalue2 as AdjRSQ
        from Fout where Label2="Adj R-Sq";
        create table ADG as
        select resp_name, tag, estimate as ADG, StdErr as SE, LowerCL as LL, UpperCL as UL
        from Pout where Variable="Day";
        create Table To_XL as
        select a.*, b.AdjRSQ
        from ADG a left join RSQ b
        on a.tag=b.tag;
quit;
proc print;run;
ods rtf close;
```

APPENDIX III

Heifers that changed rank based on RFI classification according to test duration and RFI model.

RFI Model	N	% Δ[1]	Rank increase[2] (n)	Rank decrease[3] (n)
RFI_{70}[4] -> RFI_{56}[5]	186	13	13	12
RFI_{70}[4] -> RFI_{42}[6]	186	19	20	16
RFI_1[7] -> RFI_{bf1}[8]	176	16	13	15
RFI_2[9] -> RFI_{bf2}[10]	176	14	16	8

[1]Percentage of heifers that changed rank based on RFI classification
[2]Number of heifers that increased in rank based on RFI classification by 1 standard deviation
[3]Number of heifers that decreased in rank based on RFI classification by 1 standard deviation
[4]RFI_{70} is adjusted for ADG calculated by linear regression (ADG_1) and metabolic midweight ($MMWT_1$) based on a test duration of 70 d
[5]RFI_{56} is adjusted for ADG calculated by linear regression (ADG_1) and metabolic midweight ($MMWT_1$) based on a test duration of 56 d
[6]RFI_{42} is adjusted for ADG calculated by linear regression (ADG_1) and metabolic midweight ($MMWT_1$) based on a test duration of 42 d
[7]RFI_1 is adjusted for ADG_1 and $MMWT_1$, where ADG_1 is calculated by linear regression and $MMWT_1$ is calculated by (final BW – (0.5 * days on test * ADG_1))$^{0.75}$
[8]RFI_{bf1} is adjusted for ADG_1, $MMWT_1$, and 70 d ultrasound backfat thickness (UBF)
[9]RFI_2 is adjusted for ADG_2 and $MMWT_2$, where ADG_2 is calculated by (final BW – initial BW)/days on test and $MMWT_2$ is calculated by (final BW – (0.5 * days on test * ADG_2))$^{0.75}$
[10]RFI_{bf2} is adjusted for ADG_2, $MMWT_2$, and 70 d ultrasound backfat thickness (UBF)