EFFECTS OF MATURITY AND PRODUCTION STAGE ON RESIDUAL FEED INTAKE CLASSIFICATION OF BEEF COWS

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By

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The undersigned, appointed by the dean of the Graduate School,

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EFFECTS OF MATURITY AND PRODUCTION STAGE ON RESIDUAL FEED INTAKE

CLASSIFICATION OF BEEF COWS

Presented by Barnett, R. L. (MU-Student)

A candidate for the degree of

Master of Science

And hereby certify that, in their opinion, it is worthy of acceptance.

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Dedication

To my parents Patrick Murphy and Ardella Bernell (Dees) Barnett

There is no way in which to express the gratitude that I feel for both of my parents. They taught me how to be a man of faith and determination. Without their love and support throughout my life this accomplishment would not be possible.

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CHAPTER 1

REVIEW OF LITERATURE

Introduction

Beef producers constantly look for ways to increase operation profitability. The largest single annual expenditure in most livestock operations is feed (Arthur and Herd, 2008); (Arthur et al., 2005); (Herd and Bishop, 2000). From 2005 to 2011 the total gross value per bred beef cow has decreased by 5% while feed costs increased by 23% (USDA, 2012). This makes the reduction of feed costs in livestock operations necessary for financial success. The beef industry over the last several years has explored ways to decrease feed cost without decreasing production. In the majority of production operations, 65 to 85% of feed is used by the breeding herd, with 50% of that used for maintenance energy needs of the dam (Montaño-Bermudez and Nielsen, 1990).

Historically, traits such as feed conversion ratio (**FCR**), also known as feed to gain (**F:G**), and average daily gain (**ADG**) were studied in an effort to maximize beef produced compared to feed consumed. The disadvantage with these measures is that they are dependent upon age, physiological state, weight, and weight gain (Archer et al., 1999). Genetic selection based upon these traits often leads to a larger mature size of the animal which inadvertently increases feed costs due to greater maintenance requirements of the breeding herd (Archer et al., 1999). From a metabolic standpoint lean weight and bone mass are more cost efficient to produce than fat, which is why large-framed, late maturing cattle have a favorable FCR when fed to a specific weight. Of more recent interest is residual feed intake (**RFI**). Residual feed intake compares the amount of feed actually consumed compared to expected intake (Archer et al., 1997). One advantage of using RFI is that it is phenotypically independent of mature animal size and several reviews of RFI suggest improvement of feed efficiency through selection is possible (Arthur et al., 2001b; Herd and Bishop, 2000; Richardson and Herd, 2004).

Residual Feed Intake (RFI)

Residual feed intake was first recognized as a way of calculating feed efficiency of cattle in 1963 (Koch et al., 1963). It was shown that there were differences in body condition maintained and body weight gained, and these differences affected the efficiency of feed use by individual animals (Koch et al., 1963). Residual feed intake is a moderately heritable trait with correlations (0.39±0.03) comparable to the heritability for FCR (0.29±0.04) (Arthur et al., 2001a). Data suggests cattle, previously determined to be low RFI (efficient) in a feed lot, will carry that efficiency to pasture and pass this trait on to their progeny (Herd et al., 1998). Further, Herd et al. (1998) indicated low RFI cattle have an improved growth rate on pasture where the quality and quantity of feed is typically lower than in a confined setting. Residual feed intake is phenotypically independent of other traits used to estimate efficiency like: ADG, and FCR (Herd, 2008). In other words, RFI should accurately predict efficiency throughout the different physiological states of an animal's life.

The importance of RFI and its benefits

Several studies conducted in Australia, Canada, and in the US have measured RFI in beef cattle. Most of these have focused primarily in feedlot settings, utilizing a total mixed ration (TMR) so individual intake and animal weight can be easily monitored. The majority of research indicates that use of RFI is a viable means to assess efficiency of growing and mature cattle. There is data to support that RFI has both genetic and phenotypic variation. Herd and Arthur (2009) estimated that 73% of variation in RFI is due to metabolic heat production, body composition and physical activity.

To date, little research on RFI of beef cattle has been conducted on mature cows using a forage based diets (Basarab et al., 2007; Meyer et al., 2008) where RFI could have the largest effect in beef production (Lawrence et al., 2011). Herd et al., (2002) studied Angus steers on pasture using alkanes to determine pasture intake. Steers with low RFI values had greater ADG and lower average daily feed intake than high RFI steers. Additionally, it has been shown that mature cows with differing RFI classifications preform similarly, with regards to body weight (**BW**), body condition score (**BCS**), ADG and FCR (Basarab et al., 2007; Lawrence et al., 2011; Meyer et al., 2008). There have also been correlations found between parental and progeny efficiency (Herd et al., 2002; Minton, 2010). Results from feedlot-type trials, has suggested that there is an association between feed efficiency of an animal in confined and pasture settings.

Possible concerns with RFI

Divergent selection for RFI may have an effect on carcass quality and gestation length. McDonagh et al. (2001) reported that there was a tendency for less back fat (12th/13th rib), and less fat over the rump in low RFI cattle, but there were no significant differences in carcass weight, cutability, marbling, color, or loin eye area between low and high RFI cattle. Meat tenderness could be compromised by divergent selection based upon RFI, a 13% higher level of calpastatin was found in first generation divergently selected low RFI steers. Later studies conducted reported that mature cows of high and low RFI genetics showed no significant differences in rib fat depth or rump fat (Arthur et al., 2005; Basarab et al., 2007; Herd et al., 2003).

Another concern raised is the tendency of low RFI cows to calve later than high RFI cows (Arthur et al., 2005). Although the mean calving date was only five days different between low and high RFI groups, this difference in calving date raises the concern of a longer gestation period in low RFI cows. Arthur et al. (2005) concluded that it did not affect the reproductive performance of the cows but it should be monitored because of the possibility that it might become significant with further divergent selection for low RFI.

Factors that affect efficiency

Efficiency in beef cattle

There are many different factors that affect the efficiency of beef cattle such as age, physiological state, breed, and genetics. These factors also affect the maintenance energy requirement for each animal; estimations of 70 -75% of feed intake goes toward maintenance functions before requirements for gestation and lactation can be met (Ferrell and Jenkins, 1985). If cattle with lower maintenance requirements (higher efficiency) are selected, more of the feed they consume could be used for protein/fat deposition, thus decreasing the cost per unit of gain (Basarab et al., 2003). Historically, replacement cattle have been selected based on measures of efficiency such as FCR and ADG; the problem with this method is that these measures are influenced by age, physiological state, weight and weight gain. Selection based upon these efficiency measurements results in cows with larger mature size and thus larger maintenance requirements as well. The advantage in using RFI as a measure of efficiency is that it is independent of these of these factors. This independence from production measurements suggests there is a correlation between RFI and basic biological processes such as: intake, digestion, metabolism, activity and thermoregulation (Herd et al., 2004).

As animal intake increases the size of organs involved in digestion also increase causing the energy used by the tissues per unit weight of the animal to increase. This is heat increment of feeding (**HIF**), which has been determined to account for approximately 9% of metabolizable energy expended in ruminants (Herd, 2008). Herd and Arthur (2009) stated that RFI is correlated to heat production which indicates that animals with higher efficiency (low RFI) would have lower amounts of heat production and thus lower maintenance energy requirements.

Digestion is the next process impacting efficiency. Less feed digested means less energy expended or retained. Richardson et al. (1996) determined low RFI (efficient) cattle utilize dry matter to a greater extent which in turn increases animal production. There was 1 percentage unit difference between high and low RFI cattle in their capability to digest dry matter, when fed a 68% digestible pelleted ration; this difference resulted in a 14% difference in intakes between the high and low RFI groups (Richardson and Herd, 2004). These authors concluded a lower RFI was connected with a greater ability to digest dry matter.

Metabolism and body composition are other mechanisms affecting efficiency. Lean gain requires less energy per unit mass than fat gain does. Diet changes that affect the animals' body composition will directly affect the animals' ability to produce lean gain or fat gain. In a study conducted by Herd and Bishop (2000), it was implied low RFI cattle have a greater percentage of lean gain compared to cattle with high RFI values.

Concerns have been raised dealing with the leanness of low RFI carcasses. Herd et al. (2003) suggested that continued divergent selection for low RFI cattle could reduce the suitability of replacement heifers for the herd as well as the value of slaughter cattle, due to a decrease in subcutaneous fat thickness. In contrast Richardson et al. (2001) reported no significant difference in subcutaneous or intramuscular fat of yearling steers that were the progeny divergent mating. Also, (Arthur et al., 2005) reported that after 5 years of divergent selection for RFI, Angus cows showed no significant difference in rib fat.

Activity is another process associated with variation related to RFI in cattle. The amount of energy used by an animal has a direct correlation to daily activity; more active animals use more energy. It has been shown that animals divergently selected for low RFI (efficient) have a lower rate of activity during feeding, rumination and locomotion (Herd et al., 2004). (Richardson and Herd, 2004) estimates approximately 10% of variation in RFI is directly correlated to activity. They also found high RFI bulls, equipped with pedometers, took 6% more steps than their low RFI counterparts. Less energy expended in activity means more energy is available to meet maintenance and/or production energy requirements.

The last major process that affects RFI is thermoregulation. Thermoregulation is the ability of an animal to control its body temperature in response to environmental changes. Cattle regulate their temperature through heat exchange using the respiratory system. This exchange or loss of heat is the primary method for energy loss in cattle. Animals that can better regulate their temperature lose less energy and improve their efficiency (Herd, 2008).

The importance of this research

The objective of this research was to determine if growing heifers classified as high RFI (inefficient), average or low RFI (efficient) using the GrowSafe feed intake system (Model 4000E, GrowSafe Systems Ltd., Airdrie, AB, Canada) are also efficient when they are reclassified as mature cows. From a herd of 90 heifers that were phenotyped for RFI in 2007; the top and bottom 25% were split into two study groups.

The 20 high RFI (inefficient) cows were bred to high RFI bulls while the 20 low RFI (efficient) cows were bred to low RFI bulls. The intakes of 33 of these cows were again measured at maturity and reclassified as such. Trials were conducted once during lactation and once as dry gestating cows in a confined and pasture setting. This study also determined whether the low RFI cattle continue to be as efficient as they mature and additionally on pasture as they were using a TMR.

CHAPTER 2

EFFECTS OF MATURITY AND PRODUCTION STAGE IN BEEF CATTLE IN RELATION TO RESIDUAL FEED INTAKE CLASSIFICATION

Abstract

In spite of its recent popularity, there has been limited research on the stability of RFI classification as influenced by animal age and production stage. The objective was to determine if the postweaning RFI classification of beef heifers remain consistent as the animals matured (postweaning vs. mature), went through different stages of production (dry vs. lactating) and were placed in different feeding systems (confined feeding vs. pasture). Three feed intake trials, using the GrowSafe feed intake system, (postweaning, dry and lactating) and a two-year pasture trial were conducted on the same 33 Simmental X Angus females from a single herd. Data from all three GrowSafe trials were pooled and stepwise regression (SAS PROC REG) was used to calculate expected feed intake (**EFI**) across all trials. Individual RFIs were calculated as the difference between actual dry matter intake (**ADMI**) and EFI. Cows were then categorically grouped as ***Low*** (RFI < 0.5 SD below the mean), ***Average*** (RFI ± 0.5 SD above and below the mean) and ***High*** (RFI > 0.5 SD above the mean) based upon individual RFI classifications for each trial. No correlations (*$P > 0.1$)* were found between postweaning RFI classifications and either trial as mature animals (dry or lactating). Moderate correlations ($r = 0.53$; $P < 0.001$) were found between RFI classifications

during the dry (**RFI$_{dry}$**) and lactating (**RFI$_{lac}$**) trials. The overall average daily intakes in the pasture study were lower ($P < 0.05$) than in the GrowSafe trials (15.0 kg and 18.4 kg, respectively). No relationship was found between individual animal intakes from pasture and the GrowSafe trials for either dry or lactating cows ($R^2 = 0.02$ and 0.002, respectively). When compared to the high category cows, the low category cows had reduced metabolizable energy intake (**MEI**) [Mcal/hd/d], and recovered less energy (**RE**), ($P < 0.01$) across all trials; they also produced less heat energy (**HE**) ($P = 0.05$) during the dry cow trial. It was also found, for all trials, that while cows in the low category produced less heat they partitioned a greater percentage of their MEI as HE ($P < 0.01$). Noticeable movement in regards to RFI ranking occurred between trials; 61%, 52% and 82% shifted categories among low, average or high rankings between heifer vs. dry; dry vs. lactating and heifer vs. lactating comparisons, respectively. Of the 33 animals tested only three remained in the same category across all three trials.

Introduction

The breeding herd consumes 65 to 85% of the feed used in the beef industry; of this, more than half of the energy consumed is used to support the maintenance requirements of the dam(Montaño-Bermudez and Nielsen, 1990). Efforts to reduce maintenance energy needs or the economic cost required to meet these demands have been a theme of scientific inquiry for more than 100 years(Henry, 1898). Historically, traits such as feed conversion ratio (FCR), also known as feed to gain (F:G), and average daily gain (ADG) were studied in an effort to maximize beef produced compared to feed consumed. The disadvantage with these measures is that they are dependent upon animal age, physiological state, weight, and weight gain (Salmon et al., 1990). Genetic selection based upon these traits often leads to a larger mature size of the animal which inadvertently increases feed cost due to greater maintenance requirements of the breeding herd (Lawrence et al., 2011).

Of more recent interest is residual feed intake (RFI). Residual feed intake is the difference between the amount of feed consumed and expected intake (Archer et al., 2002). One advantage of using RFI is that by definition it is phenotypically independent of mature animal size and several reviews of RFI suggest animal improvement through selection is possible (Arthur et al., 2001a; Herd and Bishop, 2000; Richardson and Herd, 2004). To date, little research on RFI of beef cattle has been conducted on mature cows using a forage based diet (Basarab et al., 2007; Meyer et al., 2008) where RFI could have the largest impact in beef production (Lawrence et al., 2011). Even less research has been conducted to determine how postweaning RFI classification relates to the efficiency of the same animal at maturity. Meyer et al. (2008) reported that groups of high and low (based upon postweaning RFI classification) lactating Hereford cows had comparable weight gains and body condition scores but the low (efficient) cows consumed 11% less forage (dry matter basis) compared to high (inefficient) cows. Based on this work, we hypothesized RFI classification would remain consistent over the life and production stages of an individual animal. The objectives of this research were to determine if postweaning RFI classification (efficient vs. inefficient) would remain consistent over:

1) Two levels of maturity (postweaning vs. mature),

2) Differing stages of production (dry vs. lactating), and

3) Differing feeding system (confined feeding [TMR] vs. pasture [forage]).

MATERIALS AND METHODS

The University of Missouri Animal Care and Use Committee approved the use of animals in these research experiments.

Heifer growth and feed intake trial

In 2007, the University of Missouri purchased 89 Simmental X Angus heifers, with similar genetics from a single herd. These heifers served as the base herd used to determine the effects of RFI classification in relation to age and production stage. The initial RFI classification of these heifers was determined at the University of Missouri Beef Research and Teaching Facility (BTRF; Columbia, MO) detailed by Minton (2010). The heifers (initial age = 1.2 ± .02 years; initial body weight = 374 ± 4 kg) were place on a 70 d feeding and intake trial with the GrowSafe feed intake system (model 4000E, GrowSafe Systems Ltd., Airdrie, AB, Canada). Heifers were acclimated to the test facility over a 14-d receiving period and then given *ad libitum* access to a 100% concentrate diet (Table 2-1) for the entire trial. Based on the RFI values determined from this trial, a high RFI group (RFI+) and a low RFI (RFI-) group were made using the 20 heifers with greatest and the 20 heifers with the smallest RFI values. After RFI classification, heifers were shipped to University of Missouri Southwest Center (SWC) near Mt. Vernon, MO.

Dry cow growth and feed intake trial

Simmental Angus cross bred females classified as RFI+, Average or RFI– as heifers were used in two separate growth and feed intake trials to determine RFI classifications as mature cattle. Of the original 40 animals in the high/low RFI groups, 33 still remained in the herd four years later. The first trial with the 33 cows at maturity was conducted from June 15 thru September 1, 2011 (78 d) at the SWC (initial body weight = 695 ± 22 kg; initial body condition score (**BCS)** = 7 ± .2; initial age = 5.2 ± .02 year; days pregnant = 180 ± 11 days). The data from this trial was used to determine non-lactating cow RFI (**RFI_{dry}**). Cows were placed into one of two test facilities at SWC, each facility is equipped with eight pens (7.3 x 26 m) each pen is equipped with two GrowSafe® feed bunks and access to a Cobett livestock waterer. The cross gates between pens within a feeding facility were left open to give increased access to feed and freedom of movement for cattle. Sawdust shavings were used for bedding and placed in pens as needed. Cows were acclimated to the test facility over a 14 d receiving period and then given *ad libitum* access to feed and water for the duration of the trial. Feed samples from each feed bunk were collected weekly, composited monthly and composited samples analyzed for moisture content and nutrient analysis. The averages of these analyses are presented in Table 2-1.

Lactating cow growth and feed intake trial

The second trial was conducted from December 22, 2011 thru March 7, 2012 (76 d) again at the SWC in the previously described test facilities. The same Simmental

Angus crossbred cows (n=33), (initial body weight = 705 ± 21 kg; initial BCS = 6.6 ± .5; initial age = 5.7 ± .02 year) with calves by side (initial body weight = 132 ± 9.7 kg; initial age= 85 ± 5 days) were placed on a 76 d feed intake and growth trial to determine lactating cow RFI (**RFI_{lac}**). All cows were synchronized to come into estrus at the same time and artificially inseminated (**A.I.**) once in early December, prior to the trial. Clean-up bulls were turned in two weeks later, at trial initiation, (one RFI+ and one RFI- per group) for a period of 30 days. Cow/calf pairs were given a 14 d receiving period and then given *ad libitum* access to feed, and water for the duration of the trial. Feed samples were collected using the same procedures as were used for the dry cow trial outlined above and are detailed in Table 2-1.

Animal growth and performance measurements

For the three trials in the GrowSafe system, animal body weight (**BW**) was determined by using the average of two-day consecutive weights at the initiation and conclusion of each trial as well as a single BW measurement at the mid-point of each trial. Weights were taken in the morning before feed delivery. Metabolic body weight (**MMWT**) of each animal was calculated as the average body weight raised to the 0.75 power for each trial period. Metabolizable energy intake (**MEI**) was determined by multiplying the ME (Mcal) of the diet by ADMI. Intake at the metabolic level was determined by the equation (MEI/MMWT). Average daily gain (**ADG**) was calculated as total weight gain divided by days on trial and feed conversion ratio (**FCR**) was determined as the ratio of DMI to ADG during the trial period for individual animals.

Body condition scores (**BCS**) and ultrasound (**US**) images were also recorded at initiation, mid-point and conclusion of both mature cow trials; no ultrasound data was collected on calves. Ultrasound images included longissimus thoracis area or rib eye area (**REA**), back fat depth (**BF**) and rump fat depth (**RF**) along with percent inter-muscular fat (**IMF**). Equipment used for the US images was a 500V Aloka (Coro metrics Medical Systems, Inc., Wallingford, CT) ultrasound machine with a 3.5-MHz transducer. Both REA and BF measurements were taken between the 12th and 13th ribs; a custom beef animal standoff (gel molding shaped to the contour of a beef animal between the 12th and 13th rib) was used for REA measurements, use of the standoff was not necessary for BF, RF and IMF measurements. All images were sent to an independent lab for processing (UltraInsights Processing Lab Inc., Maryville, MO).

Milk production estimates for lactating cows

Milk production estimates were collected just prior to, and at the conclusion of, the lactating trial. Using the weigh-suckle-weigh technique (**WSW**) (Knapp and Black, 1941), milk production was measured on December 20th 2011 (average 75 d postpartum) and March 9th 2012 (average 155 d postpartum), respectively. Beginning at approximately 1400 h, calves were separated from the dams for a period of six h, while cows were allowed free access to feed and water. During all calf separation periods, gates were used to allow nose to nose contact between cow/calf pairs to limit stress while suckling was restricted; at no point during the WSW phase were calves allowed access to feed or water. At approximately 2000 h calves were reintroduced to dams for a 20 min suckling period to ensure complete evacuation of the udder, calves were then separated again for a period of 12 h. Beginning the following morning at 0800 h calves were individually weighed and then reintroduced to their dam for 15 min. Six pens with five pairs and two pens of four pairs (eight total pens) allowed for quick pairing while removing the possibility of access to feed and water and cross fostering. At the end of the suckling period, calves were again separated and individually reweighed and then returned to their dam, unless they were included in the group of a mechanically milked subset (see below). Milk production over the 12 h period was then doubled to estimate 24 h milk production for individual cows.

A subset (n=9) of three cows from each category, based on RFI classification as dry cows, were randomly selected and mechanically milked to corroborate WSW results and to obtain milk samples for component analysis. These calves were separated from these cows for 6 h after post-suckling weights were collected. Milk production over this 6 h period, adjusted for time lapse between nurse out and mechanical milking, was then used to estimate 24 h milk production for individual cows. At milking, cows were restrained in a squeezable head chute and given a 5 mL intramuscular injection of Oxytocin (to hasten milk let down); the calf of the cow being milked was placed at the front of the chute. These steps were taken in an effort to limit stress and possible injury to cows and personnel. Milk samples were sent to an independent lab for analysis of fat, protein and solids non-fat (Mid-South Dairy Records, Springfield, MO).

Expected feed intake model development

At the conclusion of each trial, raw intake data compiled by the GrowSafe® feed intake system was analyzed and ADMI for each animal was determined for individual trials. Stepwise regression (SAS PROC REG) was used with individual as well as pooled trial data to calculate both individual and overall EFI prediction models. Table 2-2 has all possible variables stepwise could have selected for each trial. Criterion for entry and deletion from the model were $P \leq 0.25$. Table 2-3 shows best fit model predictions for EFI for individual trials as well as an overall prediction model. The model fitted for all cattle was:

$$Y_i = \beta_0 + \beta_1 Milk + \beta_2 InitPro + \beta_3 LipidRet;\ P < .0001, R^2 = 0.91$$

where: Y_i= expected feed intake EFI for animal *i*, β_0 = regression intercept, β_1 partial regression coefficient of ADMI on milk production for animal *i*, β_2 partial regression coefficient of ADMI on initial body protein for animal *i,* β3 partial regression coefficient of ADMI on lipid retained for animal *i.*

One-fourth of the animal intakes collected were reserved for model cross-validation. These validation data were used to confirm the veracity of the stepwise regression models developed to predict DMI. Validation of this model resulted in an R^2 = 0.88. The predictions from these validated models were then used to determine EFI for individual animals within an individual trial.

Residual feed intake values were calculated as the difference between the individual ADMI and its EFI (Herd and Bishop, 2000). For each GrowSafe trial individual RFI values were used to separate animals into three categories: ***Low*** (RFI < 0.5 SD below the mean), ***Average*** (RFI within 0.5 SD of the mean) or ***High*** (RFI > 0.5 SD above the mean).

Growth and feed intake trial calculations

Metabolizable energy partitioning

Metabolizable energy partitioning was calculated from known values, when available, and through the use of prediction models described by (Williams and Jenkins, 2003) to include: ME for maintenance (**ME_m**) [Mcal] = (FBW*28.8)/1000; and ME used for support metabolism (**H_iE_v**) [Mcal/d] = (9.7*(MEI/ME_m -1)*FBW)/1000. The above estimates, in conjunction with known values, the following equations were used to determine individual energy partitioning.

1) RE = MEI-ME_m-H_iE_v
2) HE = MEI – RE
3) H_iE = ME_m
4) H_eE = HE - H_iE
5) H_iE_m = ME_m- H_eE
6) H_iE_g = MEI-ME_m-RE
7) H_iE_r = H_iE_g*(HE/MEI)
8) H_iE_v = H_iE_g - H_iE_r

where: H_iE =heat increment; H_eE =basal heat; H_iE_m = heat production of maintenance; H_iE_g =heat increment of production; H_iE_r = heat production associated with gain.

Growth and body reserves

Initial body protein and final body protein were calculated on an empty body weight (**EBW**) basis: body protein, kg = (-2.1418 + (0.235*EBW) - (0.00013*EBW^2)) additionally initial and final body lipid were calculated as: body lipid, kg = (-0.061 + (0.037*EBW) + (0.00054 * EBW^2)) were calculated (NRC, 2000). The amount of protein and lipid retained (g/d) was determined by the difference between initial and final total body values multiplied by 1000 then divided by the number of days on feed.

Adjustments for pregnancy

During the dry cow trial, body weight was adjusted to account for pregnancy requirements; average BW less the gravid uterus mass (**GUM**) which was calculated as: $743.9*e^{((0.02-0.0000143*t)*t)}/1000$, where *t* represents days pregnant at trial midpoint (Ferrell et al., 1976).

Pasture trial

In addition to the confined feeding trials in the GrowSafe, animal intake was measured from the same 33 cows grazing endophyte infected tall fescue [*Festuca arundinacea* Schreb. Syn. *Lolium arundinaceum* (Schreb.) Darbysh.] pasture. Seed was purchased through a local supplier in August 2007, tested 86% endophyte presence, and was no-till seeded on August 29th and 30th. Intake was measured on pasture, twice a year during 2009 and 2010, for a total of four collections. This was done to determine if RFI classification remains constant in both a pasture and confined feeding systems.

Pasture design and management

The area used for grazing was approximately 26 ha, divided into 8, 3.25 ha pastures. Each pasture was then sub divided into eight, 0.4 ha paddocks with the use of electrified polywire and step-in posts. Each pasture had an alley equipped with a 3-m "J" bunk fitted with a five space headlock panel (Albers Dairy Equipment, Rock Valley, IA) and individual bunk dividers as well as a Cobett livestock waterer.

During the grazing season (April-December) cattle were rotationally stocked on 8 paddocks and body weights of cows were taken every 28 d. Hay made from paddocks in spring was fed back to stock within that system as needed. Paddocks were measured weekly using a rising plate meter during the growing season. Rising plate meter readings were used to decide the next paddock to graze and how many to harvest for stored forage, so that there were approximately equal amounts of forage offered to cows.

Pasture Sample Collection and Analysis

Animal intake on pasture was measured in late spring and fall of both 2009 and 2010. Titanium dioxide (TiO_2) was used as an external marker to measure total fecal output (Myers et al., 2004). A pelleted feed supplement consisting of 59% soy hulls, 37% dried distillers grains, 2% choice grease, 1% feed grade titanium dioxide (TiO_2) and 1% trace mineral/salt was individually fed to grazing cows in each pasture. Cows were restrained in headlocks to ensure the total amount of supplement was ingested, and fed 0.68 kg of supplement at 0700 and again at 1500 for a total consumption of 1.36 kg daily; thus TiO_2 intake was 13.6 g/hd/d. Feed for each animal was top dressed with 140 mL of brightly colored high-density polyethylene (HDPE) pellets (approximately 3000 pellets/hd/feeding) – each animal within a pasture receiving a different color pellet. Individual animal manure was then identified by corresponding colored pellets in the manure. Cows were fed this supplement a total of 12 d with a 9 d acclimation period prior to manure collections. On days 10, 11, and 12 after the start of TiO_2 feeding, fecal samples were collected from each cow at 0700 and again at 1300. Samples were stored at -20º C until lyophilized thoroughly and digested using methods described by (Myers et al., 2004). Assays were then read at 410 nm using a UV/Vis spectrophotometer to determine concentrations of TiO_2. Standard curves were made by adding 0, 2, 4, 6, 8, 10, 12 and 15 mg TiO_2 to manure samples devoid of TiO_2; the 0 mg standard was used to zero the instrument.

Naturally occurring n-alkanes in forage were used as the internal marker to determine forage digestibility. Forage samples from each pasture were collected twice daily during the periods in which fecal collections for TiO_2 were done. Samples were hand plucked to represent the forage that animals were currently consuming, placed in a plastic bag in the field, and stored at -20º C. At the end of the three day collection samples were lyophilized, composited and then ground to pass a 1-mm screen. The alkanes in these forage samples, as well as fecal samples, were extracted by using a modification of the methods described by (Dove and Mayes, 2006). Briefly, samples of forage (0.5g) and manure (0.25g) were placed into 16x100 mm glass culture tubes fitted with PTFE lined screw caps together with 5mL of 1.4 M ethanolic KOH and 200 µl of tetratriacontane (C-34) as an internal standard. Samples were then capped, well mixed, and placed in a block heater at 90°C for 4 h after which samples were cooled to 60°C. When the samples were cool, 2 mL of heptane and 1.5 mL of deionized water were added to the samples, and after mixing centrifuged for 10 min to separate the aqueous and solvent layers. The top aqueous layer was transferred into a 12x75 mm culture tube with approximately two g of silica gel (70x230 mesh). The elute and silica gel mixture was transferred to a filtered syringe and injected into 4 mL auto sampler vials. Samples were injected into a Varian Model 3400 gas chromatograph with a flame ionization detector using a SPB-5 bonded capillary column (30 m x 0.25 mm i.d. and film thickness of 0.25 µm, Sigma-Aldrich). Helium with a flow rate of 3.25 mL/ min was the carrier gas and injector and detector temperatures were set a 280°C and 325°C, respectively. Column oven temperature was programmed at 230°C and increased by 5°C/ min until 320°C was reached, where it was held for 5 min. Each alkane was identified by its retention time relative to retention times of known standards; alkane concentrations were converted to mg of alkane/kg of sample by referencing the internal standard (C-34).

Intake of animals grazing pasture was calculated by using equations detailed by (Dove and Mayes, 2006). Dry matter intake was calculated as: fecal output/ 1-forage digestibility. Fecal output was determined by: TiO2 dose rate (mg/d)/ TiO2 concentration in manure (mg/Kg). Forage digestibility was determined by: 1-concentration of C-33 alkane in forage (mg/Kg)/ concentration of C-33 alkane in manure (mg/Kg).

Statistical Analysis

Pearson partial correlations were determined by using the PROC CORR command in SAS (SAS version 9.3, SAS Inst. Inc., Cary, NC). Individual animals were the experimental unit, RFI categories were considered the independent variables and the dependent variables were RFI and RFI category for heifers, dry cows and lactating cows.

Variables with a $P \leq 0.1$ were considered different from zero. Means were analyzed with PROC GLM and mean separation between RFI categories for each variable tested was completed by least squares utilizing the PDIFF command in SAS. Variables with a $P \leq 0.05$ were considered different from zero.

Results and Discussion

Expected feed intake model determination

In an effort to best explain variation in feed intake, several prediction models for EFI were developed using stepwise regression; these are detailed in Table 2-3. While this approach provides many statistical advantages, understandably, the conclusions made are only as good as the model used to predict EFI. The use of stepwise regression against all growth, body composition and production variables led to a simple, yet effective, model that determined EFI with only 9% of the variation left unexplained. By using the 99 observations (33 animals measured three times) as opposed to the individual 33 from each individual trial, the necessary range was obtained to best explain the variation in animal intake. Additionally, the use of the same coefficients across all experiments allowed for better comparisons among the three GrowSafe trials.

Models from individual trials had weak R^2 values (Table 2-3) predicting animal intake despite using a wide range of variables. Interestingly, at least one body composition value was brought into each of these individual models suggesting a relationship between intake and body composition. The single prediction model also incorporates these variables (lipid retention, initial protein) as well as production demands. This model is appealing in that there is little need for any type of adjustments with regard to animal maturity or production stage.

Heifer trial

During the heifer trial, RFI had a range of 5.1 kg/d between the most efficient, (RFI = -2.3 kg/d) and the least efficient (RFI = 2.75 kg/d) animal; the average RFI value was -0.26 kg (Table 2-4). The heifer trial showed that ADMI was not different ($P > 0.05$) for animals in the high, average or low RFI categories. When looking at MEI/MMWT, animals in the low RFI category consumed 0.20 Mcal/kg, the average category consumed 0.24 Mcal/kg and animals in the high category consumed 0.26 Mcal/kg (Table 2-4). This is noteworthy in that even though the more efficient animals were heavier, they required less feed per unit of metabolic mass and consumed a smaller percentage of their BW. Although the heifers in the low category were heavier at trial initiation and conclusion, over the course of the trial they gained approximately 15 kg and 20 kg less than animals in the average and high categories respectively.

The same trend was observed for the protein and lipid retention estimates due to their relationship to body weight (NRC, 2000). The heifers in the high RFI category retained 21 and 50 g d^{-1} more protein than animals classified as average or low RFI, respectively. This is understandable based upon the rate at which they gained body protein over the trial. This suggests inefficient and average animals are so because they increase body protein and lipid at a higher rate than the efficient (RFI-) animals that are also increasing body protein and lipid but at a slower rate which could cause them to have lower intake requirements. This is in agreement with Basarab et al. (2003) who reported steers classified as low RFI had a slower accumulation rate of empty body fat.

Dry Cow Trial

During the dry cow trial ADMI had a range of 7.87 kg/d with an average of 0.16 kg/d; the most efficient cows ate 4.98 kg/d less than predicted while the least efficient cows ate 3.83 kg/d more than predicted (Table 2-5). The dry cow trial showed that ADMI was different between the three categories ($P < 0.01$). Cows in the high category ate 24% and 13% more feed than low and average cows, respectively (Table 2-5). These findings are similar to those of Meyer et al. (2008) who reported a difference in DMI of 21% between high and low RFI classified Hereford cows. As in the heifer trial, even though the more efficient cows were numerically heavier ($P > 0.10$), they used less feed per unit of metabolic mass ($P < 0.01$) and consumed a smaller percentage of their bodyweight. There was a trend ($P > 0.10$), for the low category cows to gain less weight over the trial when compared to the average and high groups.

Basarab et al. (2007), Lawrence et al. (2011) and Meyer et al. (2008) demonstrated animals with different RFI classifications perform similarly with regards to BW, ADG and FCR; this was also true in this study. However, initial BCS ($P < 0.01$) of cows was different (Table 2-5). Cows in the average and high RFI categories increased their BCS scores over the trial at a greater rate than cows in the low category such that all categories were similar ($P > 0.10$) at trial conclusion. This is in opposition to findings by Basarab et al. (2007), Lawrence et al. (2011) and (Meyer et al., 2008) all of whom found no differences in BCS among pregnant beef cows with differing RFI classifications.

Animals classified as low RFI have less body fat and subsequently leaner carcasses (McDonagh et al., 2001). Leading to questions regarding the reproductive efficiency of low RFI cattle due to body leanness (Lawrence et al., 2011). The dry cow study found that there were no differences between categories ($P > 0.10$) for fat thickness over the rib or rump. However, it was found that high category cows deposited more rib ($P = 0.03$) and rump fat ($P < 0.01$) over the course of the trial in relation to the other categories. There were no ($P > 0.10$) differences between number of days bred among the three categories. As in the heifer trial there was a trend ($P = 0.09$) for the low category cows to retain less protein. Similar to the heifer trial, the low category cows began and ended the trial with numerically larger BW ($P > 0.10$) and had higher initial BCS ($P < 0.01$). This leads to the supposition that low RFI cattle have the ability to partition energy more efficiently due to less lipid accreditation during physiological demands such as gestation without increasing DMI.

Lactating Cow Trial

During the lactating cow trial, the range in ADMI was slightly smaller at 7.59 kg/d (Table 2-6), than that for the dry cow trial. The most efficient cow had a RFI of -2.92 kg/d while the least efficient had a value of 4.67 kg/d; the trial average was 0.10 kg/d. As with the dry cow trial, ADMI was different between the three categories ($P < 0.01$). High RFI cows ate 14.6% and 6.5% more feed than the low and average cows, respectively (Table 2-6). While slightly greater, these findings are similar to those of Meyer et al. (2008) and Basarab et al. (2007) who reported differences in DMI of 11% and 11.6% between high and low RFI classified lactating cows, respectively. As in the previous two trials, and despite the fact that the more efficient cows carried more body mass ($P > 0.10$) throughout, they required less feed. The low category consumed 0.28 Mcal/kg of MMWT which was 0.04 and 0.07 Mcal/kg less than cows in the average and high categories, respectively.

Similar to the work of Meyer et al. (2008) and Basarab et al. (2007), our data shows that calves from cows with different RFI classifications have similar weaning weights (Table 2-6). Additionally, (Lawrence et al., 2011) reported no differences in milk yield as determined by the weigh-suckle-weigh method which was also true in the current study (Table 2-6).

The correlation between the WSW results and mechanical milking was weak ($R^2 = 0.38$). There was more reranking among RFI classifications than anticipated between the dry and lactating cow trials. The mechanical milking subset used three cows from each category based upon the RFI_{Dry} classifications; when the same cows were reclassified using RFI_{lac} there was only one cow classified as high, two classified as low the remaining six cows classified as average.

Milk component analysis of the subset showed no differences in milk composition ($P > 0.10$) between categories. These results lead to the conclusion that there was reclassification between trials and a tendency for both the RFI+ and RFI- dry cows to be reclassified in the average category as lactating cows. Due to limited animal numbers, further research should quantify these results.

There was, as in the dry cow trial, a difference ($P = 0.03$) between the high RFI category and other categories in regards to initial BCS (but not final BCS); this trend was not reflected in ultrasound data ($P > 0.10$). This agrees with findings by Basarab et al. (2007), Lawrence et al. (2011) and Meyer et al. (2008) all of whom found no differences in BCS among lactating beef cows with differing RFI classifications. The current study found no differences in back fat thicknesses determined by ultrasound ($P > 0.1$) between the three categories. This disagrees with Basarab et al. (2007) who reported low RFI cows had greater thickness of back fat when compared to medium and high RFI groups.

Pasture trial

Daily intake of cows on the pasture study were lower ($P < 0.05$) than in the GrowSafe trials (15.0 kg and 18.4 kg, respectively). Pasture DMI is likely less, due to the poorer pasture nutritive value compared to the diets used in feedlot trials. Additionally, pastures were endophyte infected tall fescue and while common to the Midwest, this forage is known to depress intake because of the ergot-like alkaloids it contains. No relationship was found between individual animal intakes from pasture and those determined in feedlot trials for both dry and lactating cows ($R^2 = 0.02$ and 0.002, respectively). Variation in pasture intake of cows and intake between the GrowSafe trials could be due to efficiency changes of animals in feedlot and pasture settings.

Energy partitioning

Herd and Arthur (2009) suggested RFI and heat production are directly correlated, leading to lower maintenance energy requirements. Data for the ME partitioning is summarized by RFI category in Tables 2-3, 2-4 and 2-5. Metabolizable energy intake can be separated into two forms: heat energy (**HE**) and recovered or retained energy (**RE**). Energy that is consumed above HE is retained energy and is available for protein and lipid deposition. In dry and lactating cow trials, the low category cows had reduced MEI ($P < 0.01$), and less RE ($P < 0.01$) compared to the high category. The low category also produced less HE ($P = 0.05$) during the dry cow trial. These findings are in agreement with those of (Basarab et al., 2003) who found similar results in steers.

For all GrowSafe trials, while cows in the low category produced less overall heat, they did partition a greater percentage of their MEI as HE. Animals classified as efficient had a greater heat increment (**H_iE**); this factor can be partitioned into heat produced for maintenance (**H_iE_m**) and the heat increment of production (**H_iE_g**). Concerning H_iE_m and (H_iE_g) among categories, the efficient animals had a higher proportion associated with maintenance as opposed to gain, this is understandable due to the fact that RFI- cows always had more body mass to maintain. Interestingly, ME_m while always numerically greater for low category cows was only significant ($P = 0.01$) for the heifer trial, in which there was a significant difference in initial body weights. Cows classified as low partitioned 77, 75 and 63% of their MEI to heat energy (HE) while those classified as high RFI apportioned only 66, 62 and 58% of their MEI to HE during the heifer, dry and lactating trials, respectively.

Williams and Jenkins, (2003) argued that H_iE_g could be further partitioned by accounting for energy cost associated with production. They propose that by separating H_iE_g into heat production associated with gain (**H_iE_r**),which represents the cost involved in RE synthesis, and ME used for support metabolism (**H_iE_v**), which represents the increased energy utilized for vital function (Williams and Jenkins, 2003).

The current study found that RFI- animals produce substantially lower amounts of heat for these processes. Perhaps this explains why they produce less overall heat and but still have a larger percentage of MEI partitioned as HE. Basarab et al. (2003) reported that the mass of the small and large intestines, liver, and stomach was greater for high RFI steers when compared to their low RFI counterparts. Cattle with increased MEI also have greater organ weights (Ferrell and Jenkins, 1998). An escalation in visceral organ weight, due to higher intakes, would explain the need for the increased levels of energy partitioned for H_iE_v in inefficient cows. Maintenance needs of low RFI animals, as a percent of MEI, are actually greater than those in other categories. At first this may seem illogical, but these findings imply that while the efficiency of energy use may be inferior for low RFI animals, this is mitigated by the low actual intake of these animals.

Reranking of cows between trials

Growing use of RFI as a selection tool to increase the efficiency of beef cattle has prompted the need for accurate classification early in the animal's life. Understanding how this classification will be affected by an animal's environment, diet and production stages is important. Recent studies report a tendency for RFI reranking in steers (Durunna et al., 2011) and heifers (Durunna et al., 2012; Kelly et al., 2010; Minton, 2010) between trials. During this study there was noticeable movement within RFI categories that occurred between trials. Of the 33 animals tested, only three (one RFI-, one Average and one RFI+) remained in the same category across all three trials. One may attribute this to way in which EFI was calculated but relatively the same amount of reclassifications between trials was found for all prediction models described in Table 2-3.

No correlation ($P > 0.5$) was found between heifer RFI and either dry or lactating cow RFI classification (Table 2-7). These results suggest postweaning RFI classification will not accurately predict the efficiency of the mature cow. Moderate correlations were found between RFI classification as a dry and lactating cow (r = 0.43), a stronger relationship was found between lactating and dry cow RFI values (r = 0.56). The stronger relationship between the individual RFI values compared to the categorical classifications demonstrates the amount of categorical shift between trials. These results are in agreement with Meyer et al. (2008) who concluded RFI changes during different production stages such as pregnancy and lactation. One explanation is that some individuals are better able to convert energy reserves to meet physiological demands, gestation and lactation, without increasing intake.

When the actual RFI values of the heifer and dry trials were compared, 61% of the cows shifted categories (Figure 2-1). Of that 61%, 18% of animals shifted a full standard deviation, resulting in their change from one category extreme to the other. While slightly greater, these findings are similar to the range of findings (54-58%) for heifer reranking reported by Durunna et al. (2012) and (Kelly et al., 2010). The majority of categorical shift between the heifer and dry cow trials were those animals that moved by one-half of the standard deviation. This shift was typically from an efficient to inefficient category, such as changing from low to average or average to high.

Evaluation of the dry vs. lactating cow trials showed reclassifications of 52%, of this 9% moved a full standard deviation, from one extreme to another. These results are similar to those of Minton (2010) who found 58% of heifers changed categories when reclassified as lactating cows. During the lactating trial a subset of nine cows were categorically separated into three equal groups based upon RFI_{dry} classifications when the same cows were reclassified using RFI_{lac} there was only one cow classified as high, two classified as low the remaining six cows were classified as average. These results suggest that during lactation there was is a tendency for both the high and low classified dry cows to be reclassified in the average category as lactating cows. Further research is needed to quantify these results due to low animal numbers.

The largest percentage of animal reclassification among trials was between the heifer and lactating trials, 82% of heifers had a change in classification when reclassified as lactating cows, but only 9% moved a full standard deviation. Forty-two percent of heifers had a reduction in efficiency from either the low to average or from average to high categories. There was a greater tendency for animals to shift from either the low (efficient) or high (inefficient) categories to the average category as opposed to the average animals reclassifying as either high or low.

The large percentage of reranking between heifer and lactating production stages classification is alarming. There have been reports that postweaning and mature RFI classifications are moderately correlated (r = 0.51 and 0.36), respectively (Archer et al., 2002; Arthur et al., 1999; Minton, 2010). These classifications were made on open, non-lactating cows. The lack of production stress, pregnancy or lactation, could explain the stronger correlations found during their research compared to the present study that found no correlation between postweaning RFI and either mature RFI classification.

Individual mean RFI classifications were made across all trials, 26 cows out of the 33 studied, had a standard deviation that was greater than the mean of their three RFI scores. This leads to the conclusion that an efficient animal at postweaning will not necessarily be an efficient animal in the breeding herd, where the majority of feed costs are realized (Montaño-Bermudez and Nielsen, 1990).

Conclusion

A major proposed benefit to RFI is that it is by definition independent of the component parameters used in its calculation like MMWT and ADG (Arthur et al., 2001b). Results reported by Minton (2010), Golden et al. (2008) and Kolath et al. (2006)

were similar in that there were no statistical differences between RFI groups in regards to MMWT or ADG measurements, while intake between groups differed by a range of 17-33%. Results from the two mature cow trials described herein support these findings; there were no significant differences between RFI category and the variables used in the intake prediction model. This was not the case for the heifer trial though, there was a significant difference in MMWT (P = 0.01); the low and average heifers were heavier than the high category heifers by 9kg and 7kg; respectively. Since both body protein and lipid estimates, used in the prediction model, are calculated on a body weight basis there is little surprise that there was a significant relationship between RFI and these two factors for this trial.

The utilization of alkanes and TiO_2 as internal and external markers to use for intake determination is promising as the idea of developing a pasture intake model is of great importance. The possibility of error introduced by various environmental, biological and individual pressures with this type of intake determination is extremely hard to qualify with just four, three day collection periods over two years. The use of a more detailed pasture trial would be better suited to mitigate these possible errors associated with pasture based intake determination. Possibly, trial duration of 60 to 80 days in which several multiday day collection periods are used could be an alternative approach to intake determination.

Energy partitioning data showed that as the efficiency of an animal increases, reductions in MEI, HE and RE are found but they do not adversely affect animal production. Additionally low RFI category cows produced less overall heat and but still had a larger percentage of MEI partitioned as HE suggesting that while they are more feed efficient they are less energy efficient than their high category counterparts.

This study documented a large amount of RFI categorical change between trials. Of the 33 animals tested, only three (one RFI-, one Average and one RFI+) remained in the same category across all three trials. There was also no relationship found for RFI classifications between postweaning and mature cows. These findings suggest that postweaning RFI classification will not accurately predict the efficiency of the mature cow.

Table 2-1. Ingredients and analysis of diets for heifer, dry and lactating cow trials.

Diet composition and analysis for heifer trial[1].	
Item	
Ingredient	
Corn, %	41.30
Soyhull pellets, %	45.00
Dry distiller's grains, %	10.00
Supplement, %	2.50
Lime, %	1.20
Analysis, DM basis	
Dry Matter, %	86.27
Crude Protein	10.97
Diet composition and analysis for dry cow trial.	
Item	
Ingredients	
Fescue baleage, %	54.50
Cottonseed hulls[2], %	41.00
Soybean meal, %	4.00
Free choice minerals, %	0.50
Analysis, DM basis[3]	
Dry matter, %	61.48
Crude protein, %	14.81
Acid detergent fiber (ADF) , %	36.99
Total digestible nutrients	58.23
Metabolizable energy, Mcal/kg[4]	2.39
Diet composition and analysis for lactating cow trial.	
Item	
Ingredients	
Alfalfa baleage, %	78.00
Corn, %	20.00
Free choice minerals[4], %	2.00
Analysis, DM basis[3]	
Dry matter, %	60.3
Crude protein (%)	17.07
Acid detergent fiber (ADF), %	30.43
Total digestible nutrients	64.10
Metabolizable energy (Mcal/kg)[4]	2.62

[1] Adapted from: Minton (2010).

[2] Monensin added at a rate of 200 mg/hd/d.

[3] Weekly samples of the total mixed diet were collected weekly, composited and analyzed monthly.

[4] Metabolizable energy (ME) Mcal/kg DM = ((TDN * .2004)*(96 - (.202 * CP))*2.2)/1000 (Clemson 1996.)

Table 2-2. Variables available for selection via stepwise regression for development of EFI prediction model.

	GrowSafe Trial[1]			
Variable[2]	Heifer	Dry Cow	Lactating Cow	All Trials Combine
Average daily gain, kg	**X**	**X**	**X**	**X**
Initial BW, kg	**X**	**X**	**X**	**X**
Final BW, kg	**X**	**X**	**X**	**X**
Δ BW, kg	**X**	**X**	**X**	**X**
MMWT, kg	**X**	**X**	**X**	**X**
Initial protein, kg	**X**	**X**	**X**	**X**
Final protein, kg	**X**	**X**	**X**	**X**
Protein retained, g/d	**X**	**X**	**X**	**X**
Initial lipid, kg	**X**	**X**	**X**	**X**
Final lipid, kg	**X**	**X**	**X**	**X**
Lipid retained	**X**	**X**	**X**	**X**
Initial BCS		**X**	**X**	
Final BCS		**X**	**X**	
Average BCS		**X**	**X**	
Δ BCS		**X**	**X**	
Initial GUM, kg		**X**		
Final GUM, kg		**X**		
Average GUM, kg		**X**		
Δ GUM, kg		**X**		
Initial back fat, cm		**X**	**X**	
Final back fat, cm		**X**	**X**	
Average back fat, cm		**X**	**X**	
Δ back fat, cm		**X**	**X**	
Initial rump fat, cm		**X**	**X**	
Final rump fat, cm		**X**	**X**	
Average rump fat, cm		**X**	**X**	
Δ rump fat, cm		**X**	**X**	
Initial %IMF		**X**	**X**	
Final %IMF		**X**	**X**	
Average %IMF		**X**	**X**	
Δ %IMF		**X**	**X**	
Initial REA, cm^2		**X**	**X**	
Final REA, cm^2		**X**	**X**	
Average REA, cm^2		**X**	**X**	
Δ REA, cm^2		**X**	**X**	
Milk Production, kg			**X**	**X**
ME Milk (Mcal)			**X**	

[1] **X**= Denotes variables available for use in prediction model for respective trial.

[2] BW= body weight; Δ= change in value over trial; MMWT= Metabolic mid weight; BCS= body condition score; GUM= gravid uterine mass; IMF= inter muscular fat; REA= rib eye area; Milk production= individual milk production; ME Milk= metabolizable energy in milk.

Table 2-3. Expected feed intake models developed from stepwise regression.

Trial	Observations	Equation	Mean RFI	R^2	SE
Heifer	33	$Y_i = β_0 + β_1 Final\ Protein + β_2 Lipid\ Retained$	0.00	0.53	0.17
Dry Cow	33	$Y_i = β_0 + β_1 Lipid\ Retained$	0.00	0.18	0.35
Lactating Cow	33	$Y_i = β_0 + β_1 Initital\ BW + β_2 Avgerage\ BCS + β_3 ΔRump\ Fat + β4 Lipid\ Retained$	0.00	0.66	0.21
All combine	99	$Y_i = β_0 + β_1 Milk\ Production + β_2 Initial\ Protein + β_3 Lipid\ Retained$	0.00	0.91	0.17
Heifer	33	$Y_i = β_0 + β_1 Milk\ Production + β_2 Initial\ Protein + β_3 Lipid\ Retained$	-0.26	0.40	0.22
Dry Cow	33	$Y_i = β_0 + β_1 Milk\ Production + β_2 Initial\ Protein + β_3 Lipid\ Retained$	0.16	0.13	0.37
Lactating Cow	33	$Y_i = β_0 + β_1 Milk\ Production + β_2 Initial\ Protein + β_3 Lipid\ Retained$	0.10	0.54	0.25

Table 2-4. Least Squares means for efficiency traits, weight, metabolizable energy partitioning, and body composition for heifers ranked low, average, and high for RFI.[1]

Traits[2]	RFI Category			
	Low (n = 11)	Average (n = 12)	High (n = 10)	*P*-value
Weight and efficiency measures				
RFI, kg/d	-1.62 ± 0.13[c]	-0.33 ± 0.12[b]	1.51 ± 0.21[a]	<0.01
ADMI, kg/d	7.47 ± 0.48	8.42 ± 0.35	8.86 ± 0.36	0.08
MEI/MMWT, Mcal/kg	0.20 ± .09 [c]	0.24 ± .09 [b]	0.26 ± .10 [a]	<0.01
ADG, kg/d	1.29 ± 0.09	1.48 ± 0.1	1.55 ± 0.04	0.11
FCR, kg/d	5.92 ± 0.29	5.96 ± 0.42	5.74 ± 0.29	0.91
Initial BW, kg/d	394 ± 12[a]	374 ± 10[a]	334 ± 7[b]	<0.01
Final BW, kg/d	484 ± 16[a]	478 ± 11[a,b]	443 ± 7[b]	0.07
Average BW, kg/d	439 ± 14[a]	430 ± 11[a]	389 ± 7[b]	0.01
MMWT, kg/d	96 ± 2[a]	94 ± 2[a]	87 ± 1[b]	0.01
Metabolizable energy partitioning				
MEI, Mcal/d	19.65 ± 1.27	22.61 ± 0.87	23.31 ± 0.96	0.08
HE, Mcal/d	15.01 ± 0.69	15.83 ± 0.48	15.27 ± 0.44	0.76
HE as % of MEI	77 ± 1.0[a]	70 ± 1.0[b]	66 ± 1.0[c]	<0.01
HiE, Mcal/d	12.65 ± 0.40[a]	12.38 ± 0.30[a]	11.19 ± 0.20[b]	0.01
HiEm, Mcal/d	10.29 ± 0.16[a]	8.94 ± 0.17[b]	7.11 ± 0.19[c]	<0.01
H_iE_g, Mcal/d	2.36 ± 0.3[b]	3.44 ± 0.2[a]	4.08 ± 0.27[a]	<0.01
H_iE_r, Mcal/d	1.78 ± 0.19[b]	2.40 ± 0.12[a]	2.66 ± 0.14[a]	<0.01
H_iE_v, Mcal/d	0.58 ± 0.11[a]	1.04 ± 0.08[b]	1.42 ± 0.13[c]	<0.01
RE, Mcal/d	4.64 ± 0.59[b]	6.78 ± 0.40[a]	8.04 ± 0.53[a]	<0.01
ME_m, Mcal/d	12.65 ± 0.4[a]	12.38 ± 0.3[a]	11.19 ± 0.2[b]	0.01
Body composition				
Initial Protein, kg	62 ± 2[a]	59 ± 1[a]	54 ± 1[b]	<0.01
Final Protein, kg	72 ± 2	72 ± 1	68 ± 1	0.07
Initial Lipid, kg	73 ± 4[a]	66 ± 3[a]	53 ± 2[b]	<0.01
Final Lipid, kg	109 ± 7	106 ± 5	91 ± 3	0.07
Protein Retained, g/d	154 ± 9[b]	183 ± 13[a,b]	204 ± 6[a]	<0.01
Lipid Retained, g/d	509 ± 48	564 ± 41	539 ± 15	0.63

[a-c] Least squares means within a row with different superscripts differ (*P* < 0.05).

[1] Values to the right of means is 2* Standard Deviation.

[2] RFI= residual feed intake; ADMI= actual dry matter intake; ADG= average daily gain; FCR= feed conversion ratio; MMWT= average weight * $^{0.75}$; FBW= full body weight; MEI= metabolizable energy intake; HE= heat energy; HiE= heat increment; HiEm= heat production of maintenance; HiEg= heat production associated with production; HiEr= heat production associated with gain; HiEv= ME used for support metabolism; RE= recovered energy; MEm= maintenance requirement

Table 2-5. Least Squares means for efficiency traits, weight, metabolizable energy partitioning, and body composition for dry cows ranked low, average, and high for RFI.[1]

	RFI Category			
Traits[2]	Low (n = 10)	Average (n = 14)	High (n = 9)	*P*-value
Weight and efficiency measures				
RFI, kg/d	-2.64 ± 0.35[c]	-0.36 ± 0.17[b]	2.62 ± 0.27[a]	<0.01
ADMI, kg/d	14.22 ± 0.55[c]	16.25 ± 0.28[b]	18.71 ± 0.5[a]	<0.01
MEI/MMWT, Mcal/kg	0.24 ± .06 [c]	0.28 ± .05 [b]	0.33 ± .06 [a]	<0.01
ADG, kg/d	0.93 ± 0.06	1.06 ± 0.07	1.04 ± 0.05	0.33
FCR, kg/d	15.71 ± 0.87	16.12 ± 1	18.43 ± 1.21	0.22
Initial BW, kg/d	718 ± 20	683 ± 12	664 ± 24	0.17
Final BW, kg/d	790 ± 22	765 ± 11	745 ± 25	0.31
Average BW, kg/d	724 ± 22	695 ± 11	673 ± 24	0.22
MMWT, kg/d	144 ± 3	139 ± 2	137 ± 3	0.20
Days Bred	180 ± 4	175 ± 4	185 ± 3	0.24
Initial GUM, kg	17.4 ± 0.9	16.2 ± 1	18.5 ± 0.7	0.24
Final GUM, kg	50 ± 2.3	47 ± 2.4	48.2 ± 3.9	0.24
Metabolizable energy partitioning				
MEI, Mcal/d	33.99 ± 1.32[c]	38.84 ± 0.66[b]	44.72 ± 1.20[a]	<0.01
HE, Mcal/d	25.28 ± 0.82[b]	26.36 ± 0.37[a]	27.91 ± 0.83[a]	0.05
HE as % of MEI	75.0 ± 1.0[b]	68.0 ± 1.0[a]	62.0 ± 0.0[a]	<0.01
HiE, Mcal/d	20.86 ± 0.62	20.03 ± 0.32	19.38 ± 0.69	0.21
HiEm, Mcal/d	16.43 ± 0.54[a]	13.7 ± 0.39[b]	10.84 ± 0.59[c]	<0.01
H_iE_g, Mcal/d	4.42 ± 0.30[c]	6.33 ± 0.20[b]	8.54 ± 0.23[a]	<0.01
H_iE_r, Mcal/d	3.27 ± 0.19[c]	4.29 ± 0.10[b]	5.32 ± 0.14[a]	<0.01
H_iE_v, Mcal/d	1.15 ± 0.11[c]	2.04 ± 0.10[b]	3.21 ± 0.10[a]	<0.01
RE, Mcal/d	8.71 ± 0.60[c]	12.47 ± 0.39[b]	16.81 ± 0.44[c]	<0.01
ME_m, Mcal/d	20.86 ± 0.62	20.03 ± 0.32	19.38 ± 0.69	0.21
Body composition				
Initial BCS	7 ± 0.2[a]	6.4 ± 0.1[b]	6.1 ± 0.2[b]	<0.01
Final BCS	7.2 ± 0.2	6.9 ± 0.1	6.8 ± 0.2	0.24
Initial Protein, kg	93 ± 1	91 ± 1	89 ± 2	0.18
Final Protein, kg	97 ± 1	96 ± 1	94 ± 1	0.30
Initial Lipid, kg	232 ± 13	210 ± 7	200 ± 14	0.18
Final Lipid, kg	280 ± 15	261 ± 7	250 ± 16	0.32
Protein Retained, g/d	53 ± 4	68 ± 6	70 ± 6	0.09
Lipid Retained, g/d	612 ± 45	666 ± 41	640 ± 41	0.69

[a-c] Least squares means within a row with different superscripts differ ($P < 0.05$).
[1] Values to the right of means is 2* Standard Deviation.
[2] RFI= residual feed intake; ADMI= actual dry matter intake; ADG= average daily gain; FCR= feed conversion ratio; Average BW= average body weight adjusted for average GUM; MMWT= average weight * 0.75; GUM= gravid uterine mass; MEI= metabolizable energy intake; HE= heat energy; HiE= heat increment; HiEm= heat production of maintenance; HiEg= heat production associated with production; HiEr= heat production associated with gain; HiEv= ME used for support metabolism; RE= recovered energy; MEm= maintenance requirement.

Table 2-6. Least Squares means for efficiency traits, weight, metabolizable energy partitioning, and body composition for lactating cows ranked low, average, and high for RFI.[1]

Traits[2]	RFI Category			*P*-value
	Low (n = 8)	Average (n = 16)	High (n = 9)	
Weight and efficiency measures				
RFI, kg/d	-1.70 ± 0.27^{c}	0.23 ± 0.12^{b}	1.76 ± 0.36^{a}	<0.01
ADMI, kg/d	18.75 ± 0.62^{b}	20.52 ± 0.6^{a}	21.96 ± 0.54^{a}	<0.01
MEI/MMWT, Mcal/kg	0.28 ± .08^{c}	0.32 ± .06^{b}	0.35 ± .07^{a}	<0.01
ADG, kg/d	0.76 ± 0.04	0.67 ± 0.08	0.73 ± 0.05	0.55
FCR, kg/d	24.82 ± 0.9	35.01 ± 3.99	31.76 ± 2.76	0.08
Initial BW, kg/d	713 ± 18	708 ± 20	691 ± 21	0.73
Final BW, kg/d	776 ± 19	763 ± 23	751 ± 21	0.74
Average BW, kg/d	745 ± 19	735 ± 21	721 ± 20	0.74
MMWT, kg/d	143 ± 3	141 ± 3	139 ± 3	0.72
CWW, kg	264 ± 7	256 ± 10	273 ± 11	0.39
Milk Production, kg^{-1}d	10 ± 1.1	10.6 ± 0.9	10.7 ± 1.1	0.88
Metabolizable energy partitioning				
MEI, Mcal/d	49.11 ± 1.61^{b}	53.77 ± 1.58^{a}	57.52 ± 1.42^{a}	<0.01
HE, Mcal/d	30.77 ± 0.76	32.15 ± 0.88	33.15 ± 0.74	0.17
HE as % of MEI	63 ± 0.01^{a}	60 ± 0.01^{b}	58 ± 0.01^{c}	<0.01
HiE, Mcal/d	21.45 ± 0.54	21.18 ± 0.60	20.77 ± 0.59	0.74
HiEm, Mcal/d	12.13 ± 0.69^{a}	10.2 ± 0.52^{b}	8.4 ± 0.71^{c}	<0.01
H_iE_g, Mcal/d	9.32 ± 0.50^{c}	10.98 ± 0.40^{b}	12.38 ± 0.43^{c}	<0.01
H_iE_r, Mcal/d	5.82 ± 0.24^{c}	6.56 ± 0.21^{b}	7.12 ± 0.19^{a}	<0.01
H_iE_v, Mcal/d	3.5 ± 0.26^{c}	4.42 ± 0.20^{b}	5.26 ± 0.25^{a}	<0.01
RE, Mcal/d	18.35 ± 0.97^{a}	21.62 ± 0.78^{b}	24.37 ± 0.84^{c}	<0.01
ME_m, Mcal/d	21.45 ± 0.54	21.18 ± 0.60	20.77 ± 0.59	0.74
Body composition				
Initial BCS	6.9 ± 0.2^{a}	6.8 ± 0.2^{a}	6.3 ± 0.2^{b}	0.03
Final BCS	7.6 ± 0.1	7.3 ± 0.2	7.2 ± 0.1	0.17
Initial Protein, kg	93 ± 1	92 ± 1	91 ± 1	0.68
Final Protein, kg	96 ± 1	96 ± 1	95 ± 1	0.59
Initial Lipid, kg	229 ± 12	226 ± 12	216 ± 13	0.75
Final Lipid, kg	269 ± 13	261 ± 15	253 ± 14	0.76
Protein Retained, g/d	45 ± 3	40 ± 5	47 ± 5	0.41
Lipid Retained, g/d	493 ± 30	431 ± 63	457 ± 36	0.66

[a-c] Least squares means within a row with different superscripts differ ($P < 0.05$).

[1] Values to the right of means is 2* Standard Deviation.

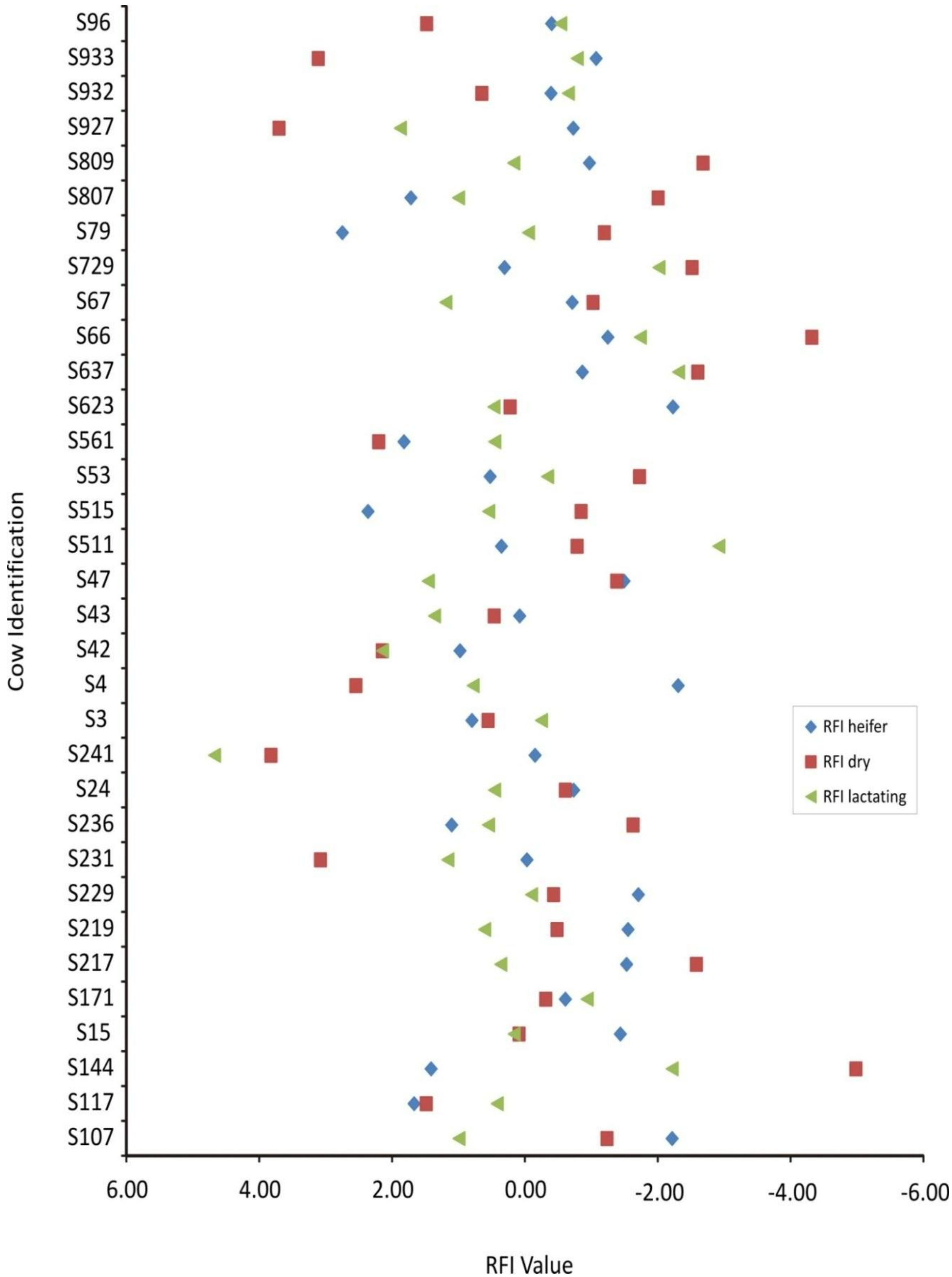
[2] RFI= residual feed intake; ADMI= actual dry matter intake; ADG= average daily gain; FCR= feed conversion ratio; MMWT= average weight * $^{0.75}$; CWW= adjusted calf 205d weight; MEI= metabolizable energy intake; HE= heat energy; HiE= heat increment; HiEm= heat production of maintenance; HiEg= heat production associated with production; HiEr= heat production associated with gain; HiEv= ME used for support metabolism; RE= recovered energy; MEm= maintenance requirement.

Table 2-7. Pearson correlations between RFI and category across heifer, dry and lactating trials for 33 cows[1].

Variable[2]	CAT_{lac}	CAT_{dry}	CAT_{hfr}	RFI_{lac}	RFI_{dry}
RFI_{hfr}	-0.10	0.02	**0.92**[c]	-0.05	-0.04
RFI_{dry}	**0.38**[b]	**0.92**[c]	0.02	**0.56**[c]	
RFI_{lac}	**0.86**[c]	**0.43**[b]	0.00		
CAT_{hfr}	0.05	0.05			
CAT_{dry}	0.28				

[1] Values in bold are different from zero (P<0.10). a,b,c indicate significance at the P < 0.1, 0.05, and 0.001 levels, respectively.
[2] RFI_{hfr}= residual feed intake as a heifer; RFI_{dry}= residual feed intake as a dry cow; RFI_{lac}= residual feed intake as a lactating cow; CAT_{hfr}= RFI category as a heifer; CAT_{dry}= RFI category as a dry cow; CAT_{lac}= RFI category as a lactating cow.

Figure 2-1. Residual feed intakes of individual animals as heifers, dry and lactating cows.



CHAPTER 3

OVERALL CONCLUSIONS

Growth and feed intake trials

Results from this study are difficult to compare to other studies due to deviation from traditional method of EFI determination. Understandably as with all RFI studies the conclusions made are only as good as the model used to predict EFI. The use of stepwise regression against all growth, body composition and production variables led to a simple, yet effective model that determined EFI with only 9% of the variation left unexplained. This is a marked improvement to the model R^2 ranges in current literature. The use of one prediction model that incorporates additional pressures placed upon mature cattle such as body condition and production demands is appealing in that there is little need for any type of adjustments as stage of maturity or production changes. To date, RFI has been phenotypically independent of the component traits used in its calculation, but the argument is made that often times the number of components used to build an intake prediction model is too few such that R^2 of the models typically range from 0.60 to 0.80. However this was not the case for this trial, and with an $R^2 > 0.9$ it is not surprising that there are correlations between the component traits and RFI classifications. To the author's knowledge, the level of variation associated with feed intake has not been accounted for as well in cattle thus far.

Milk production is a major variable in the determination of feed intake as shown by the stepwise regression analysis. Determination of individual milk production is a labor intensive and cumbersome process by either the WSW or mechanical milking. Each protocol has its benefits and drawbacks. The weigh-suckle-weigh methods benefit is number of animals that can tested at one time is only limited by personnel and facilities. Conversely it is limited by the fact that it is a measurement of available fill space and veracity of appetite of the calf during a relatively short, highly stressful, period of time. Mechanical milking has an advantage in that it measures milk production without the introduction of error presented by the calf while also having the ability for component analysis of the milk. The disadvantage to this measure of production is the amount of animals that can be tested is vastly reduced compared to the WSW method.

In retrospect there should have been a larger subset of animals chosen for mechanical milking for the current study to better represent the population. Another option would be to conduct further milk production tests prior to and after RFI has been calculated.

Pasture trial

To date there has been little research done on RFI using pasture largely because the difficulties involved in the determination of intake on pasture. The utilization of alkanes and TiO_2 as internal and external markers to use for intake determination is promising. The methodology used in analysis seems to be reliable; the technique our lab used needs to be refined to limit the amount of variation introduced during analysis.

While the idea of developing a pasture intake model is of great importance, individual intake for a cow with just one, composite, sample is impractical. The possibility of error due to various environmental, biological and individual pressures with this type of intake determination is extremely hard to qualify with just one composite or even individual samples collected over the three day collection period. The use of a more detailed pasture trial would be better suited for intake determination. A longer duration trial in which several multiday day collection periods are used should be considered to improve individual animal intake data.

It was demonstrated during this study that there was no relationship between RFI classification as a heifer and a dry or lactating cow. This leads to the conclusion that postweaning residual feed intake classifications do not necessarily reflect the efficiency of that animal when measured as a mature cow. For these reasons, if selection of replacement females based on heifer RFI is used, producers should not select for low RFI but instead select against retaining inefficient (RFI+) animals. Even though 82% of the animal shifted categories only 9% went from one extreme to the other; the largest proportion of shift was from the two extremes to the center or average category. Selection for bulls with low RFI would be beneficial due to the fact that there were a relatively small number of animals that shifted from the low category to the high category during this study. This selection process has the possibility to improve the overall efficiency of the reproductive herd by culling the most inefficient animals.

Due to the limited number of animals on this project further research should be conducted to develop a standardized intake model that is capable of predicting intakes with both high R^2 values and high confidence levels across varying levels of production.

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