THE RELATIONSHIP BETWEEN RESIDUAL FEED INTAKE, FEEDING BEHAVIORS, FEED INTAKE AND EVALUATION OF SAMPLING ERROR ASSOCIATED WITH POST WEANING GAIN TESTS

A Thesis
Presented in Partial Fulfillment of the Requirements for the
Degree of Master of Science
with a
Major in Animal Science
in the
College of Graduate Studies
University of Idaho

by
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August 2014

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Authorization to Submit Thesis

This thesis by William Kayser is submitted for the degree of Master of Science with a Major in Animal Science and titled *The Relationship Between Residual Feed Intake, Feeding Behaviors, Feed Intake and Evaluation of Sampling Error Associated with Post Weaning Gain Tests,* has been reviewed in final form. Permission, as indicated by the signatures and dates below, is now granted to submit final copies to the College of Graduate Studies for approval.

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Abstract

Feed is the largest variable cost associated with beef production, any reductions of feed inputs whilst maintaining outputs will result in direct increased profitability for the industry. Traditionally individual feed intake has been expensive and laborious to measure. Recent improvements in technologies for measuring individual feed intake have made incorporating the phenotype into breeding selection decisions possible. Residual feed intake (**RFI**) is defined as the amount of feed that an animal consumed adjusted for the expected consumption based upon requirements for maintenance and growth. RFI is independent of body weight **(BW)**, gain **(ADG)**, carcass and meat quality. RFI is highly correlated with feed intake **(DMI)** and moderately heritable (r = 0.40). There are differences in feeding behaviors amongst the divergent RFI classes, animals with low RFI tend to spend less time eating per day and have fewer overall meals per day. There are many documented differences between low and high RFI animals, by adding to the knowledge base on RFI there should be increased producer and industry adoption.

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Chapter 1

Introduction and Literature Review

Profitability of integrated beef cattle production systems is heavily dependent on the cost of inputs relative to the value of outputs (Lancaster et al., 2009). Typically the largest variable cost in beef production is feed (Lancaster et al., 2009, Arthur et al., 2004). Thus improvements in feed efficiency; an increase in pounds of production to pounds of feed would lead to reduced costs of the system while maintaining the same production therefore leading to greater overall profitability of the system (Nkrumah et al., 2006).

Previous attempts to make genetic improvements in efficiency have been centered around variations of feed conversion ratio **(FCR)**, (Bingham, et al., 2009) whether it is **G:F**; **BW** gain to feed intake or **F:G**; feed intake to BW gain. A problem associated with this methodology is that feed conversion ratio is highly correlated with growth traits. Focused selection in conversion ratio would most likely lead to larger mature cows and therefore an increased maintenance cost of cow herds (Herd et al., 2003). Residual Feed Intake **(RFI)** first proposed by Koch, (1963) is a measure of feed efficiency independent of growth traits in growing beef cattle. RFI is calculated by regressing dry matter intake **(DMI)** on mid-test $BW^{0.75}$ **(MBW)** and average daily gain **(ADG)** (Koch, et al., 1963).

Koch et al. (1963) recognized that differences in both weight maintained and weight gained affect feed requirements in growing beef cattle and that feed intake could be adjusted for BW and weight gain (Herd and Arthur, 2009) and partitioned into two components. These components were expected feed intake based upon the individuals' production and the residual portion (Herd et al., 2003). The residual could be used to identify animals that deviate from their expected feed intake. Positive residuals identify animals that ate more than expected and negative residuals identify animals that ate less than expected or were more efficient. Additionally RFI has been shown to be a moderately heritable trait (approximately 0.40; Lancaster et al., 2009, Arthur et al., 1997, Schenkel et al., 2004) and is not related to ADG (Schenkel, et al., 2004, Arthur, et al., 2001), BW (Schwartzkopf-Genswein, et al., 2011) , carcass or meat quality (Baker, et al., 2006).

By increasing the phenotypes that we include into the RFI model we can increase the R^2 value and account for portions of the variation that are not explained by metabolic mid weight and average daily gain (Lancaster, et al., 2009). Some of the phenotypes used include ultrasound measure of the 12th-rib fat thickness **(BF)**, longissimus muscle area **(LMA)** and intramuscular fat **(IMF)**. The inclusion of carcass measures into the model can explain up to 9% of the variation in DMI not explained by MBW or ADG (Lancaster et al., 2009a, Lancaster et al., 2009b). Other efforts to explain the biological basis of variation in RFI have led to an examination of the different feeding behaviors that animal's exhibit. It has been shown that certain feeding behaviors can explain up to 35% of the variation in RFI.

Certain traits are highly correlated with feed intake such as growth and body weight. Water intake has been shown to be highly correlated seasonally with feed intake on a pen level basis (r = 0.624, Utley et. al., 1970). Measures of individual water intake are new and relatively untested, but provide a means of measuring more animals at a lower cost relative to feed intake. There are reported relationships between feed intake and water intake mostly on pen level data. Season (particularly the summer months) is an important environmental factor that explains most of the variation in water intake. It has been shown that certain breeds of cattle react differently to environmental heat loads which affect their water intake.

In order to utilize water intake as a predictor for feed intake, all of these sources of variation will need to be considered.

Relationship between RFI and Feeding Behaviors

Traditionally feeding behaviors were cost prohibitive to measure, by observation or video monitoring. Newer technology such as the GrowSafe 4000E feed intake monitoring system (GrowSafe Calgary, Canada) made collecting animal feeding behavior more attainable. Most feeding trials are conducted using this system which records intake and behavior data. The system is comprised of a radio frequency identification tag (EID) on the animal, a feeding unit, a data logging panel and a personal computer that has the GrowSafe software installed. Each feeding unit consists of a feeding trough balanced on 2 load bars and an antenna embedded in the rim of each tub. The antenna detects and identifies each animal via electromagnetic waves. The system then records the amount of feed consumed as well as feeding behavior while each animal eats from the feed bunks. Data generated from the feeding units are stored in the data logging reader panel. The data are transferred wirelessly to the personnel computer. The GrowSafe data acquisition and analysis software in the computer converts the data into readable formats for subsequent analysis. The GrowSafe process routines generate 3 different intake tables; feeding events, meal events and daily intake. The feeding events table contains records of every event where an animal's EID is recorded regardless of duration or intake. Meal events are a combination of feeding events that make up a meal where the time from the previous feed event was greater than 300 seconds. Meal events span multiple feeding events and can include visits to different bunks (Basarab, et al., 2003). Daily intake contains total intake per animal per day. From these data it is possible to make observations about feeding behavior.

Feeding behavior traits found to be relevant are feeding frequency **(FF - meals/day)**, feeding duration **(FD – total time spent feeding / day)**, head down duration **(HDD - time spent with head down in trough / day)**, and feeding rate **(FR - grams consumed / min)**.

Feeding frequency is defined as the number of independent meal events recorded per day (Lancaster, et al., 2009). FF is related to ration density and particle size. Animals tested on a grow ration and then on a finish ration exhibit less FF events on the finish ration compared to the grow ration (Nkrumah, et al., 2007, Durunna, et al., 2011). Animals with low RFI values also have less FF compared to their high RFI counterparts. Nkrumah et al. (2007), Lancaster et al. (2009) and Durunna et al. (2011) all reported a decrease in FF from high to low RFI groups of 13.5%, 10.9% and 12.5% respectively. Basarab et al., (2003) reported a similar (6.67%) decrease. These findings are contradicted by Bingham et al., (2009) who showed that Brangus heifers in the low RFI group had more FF events than their high RFI counterparts 15.06 to 14.75, respectively. This may be due to study animals coming from different genetic backgrounds. Animal gender may also provide some basis for the differences in these studies since Bingham observed heifers, Lancaster observed bulls, and Nkrumah and Durunna observed steers. In addition, there were differences in the studies' observation methods. Nkrumah, Lancaster and Durunna utilized data generated by a GrowSafe system and Bingham observed video recordings on a subset of the heifers. Schwartzkopf-Genswein et al. (2011) reported differences in FF between classifications of G:F. In the first year of the study, the high G:F steers had a 15.4% decrease in FF compared to their low G:F counterparts and in year two showed a 27.5% decrease from high to low. Feeding frequency is phenotypically correlated with DMI and RFI (Nkrumah, et al., 2007, Lancaster, et al., 2009, Durunna, et al., 2011). The relationships between FF and RFI and FF and G:F suggests that the behavior is linked to animal efficiency.

Feeding duration is the sum of the difference between feeding event end-times and start-times per day for each animal. It is equal to the total number of minutes each day spent performing feeding related activities (prehension, chewing, backing away from the bunk and chewing, socializing, scratching or licking) at the feed trough (Nkrumah, et al., 2007). Animals with low RFI values spend less time performing feeding related activities than their high- and mid-RFI counter parts (Nkrumah, et al., 2007, Lancaster, et al., 2009, Durunna, et al., 2011). Feeding duration has also been shown to be positively correlated with DMI. Nkrumah et al. (2007), Lancaster et al. (2009) and Durunna et al. (2011) reported phenotypic correlations of 0.27, 0.23, 0.38 in grower phase and 0.34 in finisher phase respectively. Nkrumah et al. (2007), Lancaster et al. (2009) and Durunna et al. (2011) all reported reductions (24%, 13 %, and 12%, respectively) in FD from high to low RFI classification in the grower phase and 19% in the finisher phase respectively. Schwartzkopf-Genswein et al., (2011) reported a 4% reduction in FD in year 1 and a 3% reduction in year 2 in cross bred beef steers when classified on the G:F performance. Animals with higher gain to feed ratios had decreased FD. Feeding duration is highly correlated with DMI (Nkrumah, et al., 2007, Lancaster, et al., 2009, Durunna, et al., 2011, Schwartzkopf-Genswein, et al., 2011) and RFI (Lancaster, et al., 2009, Nkrumah et al., 2007). Research has shown the FD trait can provide value into selection criteria due to its strong relation with other relevant measures of efficiency.

Head down duration (HDD) is considered to be the number of times an animal's EID is read in the feed bunk multiplied by the scanning frequency of the GrowSafe system

(Lancaster, et al., 2009). The scanning time used in this calculation is system dependent and ranges from 1.0 to 6.3 s (Basarab, et al., 2003). Head down duration is a representation of time an animal spends with its head in the bunk feeding separate from all other feeding activity. Like the other behavior traits, HDD has been shown to be positively correlated with DMI. Nkrumah et al. (2007), Lancaster et al. (2009) and Durunna et al. (2011) reported phenotypic correlations of 0.33, 0.36 and 0.32 in the grower phase and 0.35 in finisher phase, respectively. Nkrumah et al. (2007), Lancaster et al. (2009) and Durunna et al. (2011) showed reductions in HDD from high to low RFI classifications of 24%, 13%, 12% in grower phase and 19% in finisher phase. Bingham et al. (2009) reported a 23% increase in HDD from high to low RFI classifications. This is in contradiction to the other reported results. The differences in results may be due to different methods of collecting data, differences in study animals, and differences in sample size. Head down duration may provide a stronger insight to animal efficiency than other traits discussed due to its greater correlations with DMI.

Feeding rate (FR) is a ratio of total daily DMI by total daily FD (grams/min) (Durunna, et al., 2011). Feeding rate has been shown to increase as ration particle size and density decreases (Durunna, et al., 2011). Like other feeding behavior traits, FR has phenotypic correlations with DMI. These correlations are more variable than the correlations reported for HDD and FD. Lancaster et al., (2007) reported phenotypic correlation of 0.53 with DMI and an observed relationship with RFI that was not significant. Durunna et al., (2011) reported phenotypic correlations of .13 in the grower and finisher period of the study although neither were significant. There does appear to be a trend associated with FR and RFI classifications, Lancaster et al. (2007), Bingham et al. (2009)

and Durunna et al. (2011) reported decreasing FR values from high to low RFI classifications on a roughage based diet of 3%, 39% and 4% respectively. Durunna et al, (2011) reported a 1% increase in FR from low to high RFI groups in the finisher period. Feeding rate is much more variable than the other behaviors studied and there is limited continuity between reported results. This trait may be more sensitive to ration composition, sex and pen stocking density than the other traits that are reported. Feeding rate offers less insight into animal efficiency than FF, FD and HDD.

There are considerable genetic and phenotypic variations with beef cattle in measures of feeding behavior (Nkrumah, et al., 2007). Research has shown that animals that are found to be more efficient than their peers, based on RFI or G:F, typically have less meal events per day, spend less time per day performing feeding activities, have less head down duration and eat at a slower rate. This supports the observation that efficient animals consistently have fewer behavior observations then inefficient animals (Durunna, et al., 2011). Additional research examining the impact FR has on efficiency metrics due to study variation sources needs to be conducted. By including feeding behavior traits in the RFI model, we can account for up to 35% of the variation not explained by MBW and ADG. Residual feed intake is a useful tool in discovering efficient animals. Residual feed intake allows for the selection of animals based on their ability to convert feed without affecting ADG or the mature size of the animal. Utilizing the traits that are detailed above will increase the accuracy and the value of that measurement. Further research needs to be performed on the variation within these traits in order to define what length of study is needed to generate a robust repeatable phenotype. It is also necessary to identify what implications animal management (ration composition, pen stocking density, seasonality) has on these traits so that these traits could be compared across cohorts.

The Utility of Water Intake as an Indicator Trait for Feed Intake

There is little information about individual water intakes of beef cattle. Traditionally it has been cumbersome to measure. Water delivery does not represent a large cost for beef producers and typically is provided ad libitum. With newer technology it may be possible to measure individual water intake within a pen of cattle. The value of measuring water intake is not derived by selection based off of water utilization if water doesn’t represent a large cost, rather being used as an indicator trait for traits that are directly related to profitability. It has been suggested that water intake may be a viable indicator trait for dry matter intake. Since feed represents the largest variable cost in beef production and individual feed intake is expensive to measure, it may be possible to improve the selection for efficient animals if water intake could be used as an indicator trait for dry matter intake. For water intake to be a viable indicator trait of dry matter intake it must be accurate and explain much of the variation in individual dry matter intake. The focus of this review is to identify the value of water intake as a proxy for feed intake.

Winchester and Morris (1956) concluded that water intake of cattle is a function of dry matter consumption and ambient temperature. Utley et al., (1970) showed voluntary reduction of feed intake in yearling Angus steers when water was restricted from free choice to 60% of free choice, and that feed intake was significantly correlated ($r = 0.624$) with water intake. This link between water and feed intake was confirmed by Bond et al., (1976) whom conducted deprivation studies of water and feed on steers at differing levels of dry matter. They showed that water deprivation caused a 47% reduction in feed intake regardless of the diet. When the steers were deprived of feed, the decrease in water intake was 66% in the 88% forage diet, 23% in the 30% forage diet, and 0% in the 0% forage diet. Asplund and Pfander (1972) indicated that water restriction in sheep reduced feed intake because a certain amount of water is necessary to allow normal passage of dry matter through the digestive tract. Bond et al., (1976) concluded that water intake was dramatically reduced when steers were deprived of a high roughage diet, but not when deprived of a high concentrate diet. In addition, feed intake was reduced by approximately 50% when water was withheld regardless of the type of diet. These authors suggested the dramatic reduction of water intake in the high roughage treatment was a function of the reduced dry matter intake. Based on these data, water intake models for predicting dry matter intake would need to adjust for the dry matter and roughage content of the diet.

In a study to identify management regimes that reduce heat stress, Mader and Davis (2004) exposed animals to three different feeding regimes. One group was fed ad libitum with feed being delivered in the morning which is typical of commercial feedlots, ad libitum with feed being delivered at 4 pm so that the metabolic heat generated from consumption of the feed will coincide with the cooler part of the day, and limit fed (85% of ad libitum) where the animals were fed at 4 pm. The limit fed animals had a significant reduction ($P < 0.05$) in water intake when compared to the ad libitum morning fed group. These deprivation studies suggested that there is a relationship or association between water intake and feed intake in beef cattle.

In a study of 8,209 feedlot cattle, Sexson et al., (2012) reported a significant positive relationship between water intake and dry matter intake. Similar findings were reported by Brew et al., (2009) in studies with Brahman, Romosinuano, British, and Continental bulls, steers and heifers. When adjusted for metabolic mid weights, water intake was positively correlated with feed intake. They also showed no differences between bulls, steers and heifers in water intake. The Brahman and Romosinuano cattle drank significantly less than the British and Continental cattle. The differences found between *Bos taurus* and *Bos indicus* were similar to those in the study by Winchester and Morris (1956). Their predictions for *Bos indicus* cattle had a decreased intercept as well as smaller slope coefficient when regressed on ambient temperature. These findings are contradicted by Mullick et al., (1952) who showed no association between dry matter intake and water intake in Kumauni Hill steers. The steers had no change in dry matter intake through season changes although the water intake was significantly greater during the spring and summer when compared to the autumn and winter. The animals that Mullick et al., (1952) studied were *Bos indicus* which have less water intake the than *Bos taurus* breeds coupled with the small sample size may be the reason for no significant findings between water consumption and feed intake. These results suggest that water intake would need to be adjusted for breed since there is a significant interaction present. Arias et al., (2011) reported associations between dry matter intake and daily water intake in steers and heifers although the majority of the variation in daily water intake was explained by mean ambient temperature, minimum ambient temperature and the temperature-humidity index. They also reported significant differences in daily water intake between winter and summer months. The multiple regression analysis used to identify the variables that explain the variation in daily water intake included the pooled data from the summer and winter months. The deprivation studies as well as the individual water and feed intake work have shown that there are associations present between feed intake and water intake.

There also is a pattern of seasonality and ambient temperature explaining some of the variations of water intake. The increase water intake of cattle in the summer would be mainly attributed to the direct effect of the animal attempting to reduce its thermal load (Beede and Collier, 1986, Arias and Mader, 2011). This is achieved by evaporative cooling, which is the most practical means for cooling livestock, but demands that cattle consume more water to maintain homeostasis (Morison, 1983, Arias and Mader, 2011). Arias and Mader (2011) hypothesized that daily water intake was influenced not only by dry matter intake and ambient temperature but a host of climatic factors and combinations. The climatic factors used in the regression analysis to explain the variation in water intake were daily measures of mean ambient temperature, maximum ambient temperature, minimum ambient temperature, precipitation, relative humidity percent, wind speed, solar radiation, and temperature humidity index. They generated multiple regression models using dry matter intake and the climatic factors to assess which variables explained the variation in daily water intake. They generated models for the summer, winter and overall (summer and winter combined data). Arias and Mader (2011) confirmed that water intake increases during the summer months ($P < 0.01$). The summer model explained only 23% of the variation in daily water intake and included 3 factors; solar radiation ($R^2 = 0.14$), minimum ambient temperature ($R^2 = 0.05$) and dry matter intake ($R^2 = 0.04$). Their winter model included 6 of the 7 variables with only minimum ambient temperature being excluded. The winter model also explained 23% of the variation in daily water intake with maximum temperature ($R^2 =$

0.05), wind speed ($R^2 = 0.04$), relative humidity percent ($R^2 = 0.07$), and precipitation ($R^2 = 0.05$) explaining most of the variation and dry matter intake ($R^2 = 0.01$) and solar radiation ($R^2 = 0.01$) explaining very little. The overall model which contained both seasons explained 65% of the variation in water intake. They concluded that although there was a significant relationship between water intake and dry matter intake that temperature humidity index, ambient temperature and minimum ambient temperature were the primary factors that influence water intake in finishing cattle. Due to multi co-linearity factors, minimum ambient temperature and the temperature humidity index could not be used in the same model but the minimum ambient temperature accounted for 56% of the 65% variation explained. Solar radiation and dry matter intake were found to have a smaller influence. Dry matter intake only accounted for 2% of the 65% explained variation in daily water intake. These data suggest that an animal's environment had a greater effect on daily water intake than dry matter intake. This is supported by Mader and Davis (2004) who examined the effects of sprinkling regimes on level of heat stress in animals. Animals that were sprinkled at 10:00 am and 12:00 pm drank significantly less water than animals that had water applied between 2:00 pm and 4:00 pm. There were no significant differences between dry matter intake or body weight between the two groups suggesting that these differences in water intake are related to the heat loads the animals were exposed to. Excessive heat load is known to increase the water requirements (NRC, 1996), which is exhibited in the aforementioned experiment. Animals that experienced a change in microclimate prior to the maximum heat of the day required less water to maintain thermo regulation than those that experienced microclimate change after the heat of the day. Seasonally, environmental factors account for most of the variation in water intake. For water intake to be valuable as an indicator trait these effects will need to be accounted for within models that predict DMI.

Winchester and Morris (1956) were correct in their conclusion that water intake was a function of dry matter consumption and ambient temperature. There are significant correlations between water intake and feed intake although the magnitude of those correlations varies greatly between studies. The dry matter and roughage percentages of the diet affect water consumption. There are interactions present between cattle type and ambient temperature in determining water consumption. Environmental factors such as broad ambient weather or microclimates of pens can account for over half of the variation in water intake. Currently the question of whether water intake can be used as a substitute or a predictor of dry matter intake is not substantiated and more research needs to be performed particularly on the individual animal level.

Protocol for the Measurement of RFI

By the year 2050 the world will have to produce one hundred percent more food to feed the global population (United Nations, 2009). The majority of this production will have to be generated by new technologies or improved efficiencies due to the finite amount of natural resources at our disposal (Godfray, et. al., 2010). Beef production has flourished by increasing the efficiency and gain of the animals, in 2007, compared to 1977; the US generated 12% more beef with 88% of the cattle inventory (Capper, 2011).The increases in efficiencies have come from improvements in management, technologies and genetic merit of the national beef herd. Residual feed intake is a calculation for measuring feed efficiency that is unrelated to weight or growth (Koch et. al., 1963; Archer et. al., 1999; Arthur et.al., 2001; Wang et. al., 2006).This has allowed the industry to select for animal efficiency more easily. The investment that must be made in the equipment is not trivial. Most producers cannot justify the investment needed for the equipment and must rely on centralized testing facilities. The current standard test for measuring feed intake and body weight gain is seventy days (Archer, et. al., 1997). The duration of a post-weaning test is not limited by the measurement of feed intake, but rather by the time period needed to accurately estimate gain (Archer et. al. 1997). DMI can be accurately estimated in 35 d, whereas 70 d was required to measure ADG. By changing the current feed intake and ADG measuring paradigm it would be possible to increase the number of animals that are measured through testing facilities. Ultimately reducing the cost of the test and increasing producer adoption.

Selection for feed efficiency is beneficial to the beef industry. Maintaining production while decreasing production inputs will be more profitable and require fewer resources. Inclusion of feeding behavior traits into the RFI models will increase the accuracy of those models and ultimately the selection of the animals. If proven water intake could be used as an indicator trait for feed intake allowing the industry to sample more animals at a lower cost. Changing of the test protocol would also allow for more animals to be measured through testing facilities decreasing the cost of the test. These aforementioned strategies will all ultimately reduce or increase the value of the testing process leading to producer adoption and greater efficiency of the beef herd

Literature Cited

Arias, R. A., and T. L. Mader. 2011. Environmental factors affecting daily water intake on cattle finished in feedlots. J. Anim. Sci. 89:245–251.

Arthur, P. F., J. A. Archer, and R. M. Herd. 2004. Feed intake and efficiency in beef cattle: Overview of recent Australian research and challenges for the future. Aust. J. Exp. Agric. 44:361–369.

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

Arthur, P. F., J. A. Archer, R. M. Herd, E. C. Richardson, S. C. Exton, J. H. Wright, K. C. P. Dibley, and D. A. Burton. 1997. Genetic and phenotypic variation in feed intake, feed efficiency and growth in beef cattle. Proc. Assoc. Adv. Anim. Breed. Genet. 12:234–237.

Arthur, P. F., G. Renand, and D. Krauss. 2001. Genetic and phenotypic relationships among different measures of growth and feed efficiency in young Charolais bulls. Livest. Prod. Sci. 68: 131-139.

Asplund, J. M. and W. H. Pfander. 1972. Effects of water restriction on nutrient digestibility in sheep receiving fixed water: feed rations. J. Anim. Sci. 35:1271.

Baker, S. D., J. I. Szasz, T. A. Klein, P. S. Kuber, C. W. Hunt, J. B. Glaze Jr., D. Falk, R. Richard, J. C. Miller, R. A. Battaglia, and R. A. Hill. 2006. Residual feed intake of purebred Angus steers: Effects on meat quality and palatability. J. Anim. Sci.84:938–945.

Basarab, J. A., M. A. Price, J. L. Aalhus, E. K. Okine, W. M. Snelling, and K. L. Lyle. 2003. Residual feed intake and body composition in young growing cattle. Can. J. Anim. Sci. 83:189–204

Beede, D. K., and R. J. Collier. 1986. Potential nutritional strategies for intensively managed cattle during thermal stress. J. Anim. Sci. 62:543–554.

Bingham, G. M., T. H. Friend, P. A. Lancaster, and G. E. Carstens. 2009. Relationship between feeding behavior and residual feed intake in growing Brangus heifers. J. Anim. Sci. 87:2685–2689.

Bond, J., T. S. Rumsey, and B. T. Weinland. 1976. Effect of deprivation and reintroduction of feed and water on the feed and water intake behavior of beef cattle. J. Anim. Sci. 43:873–878.

Brew, M., B. Myer, J. Carter, M. Hersom, and G. Hansen. Water intake and factors affecting water intake of growing beef cattle in North Florida. 2009. Florida Beef Report.

Capper, J. L., The environmental impact of beef production in the United States: 1977 compared with 2007, J ANIM SCI December 2011 89:4249-4261; published ahead of print July 29, 2011, doi:10.2527/jas.2010-3784H.

Durunna, O. N., Z. Wang, J. A. Basarab, E. K. Okine, and S. S. Moore. 2011. Phenotypic and genetic relationships among feeding behavior traits, feed intake, and residual feed intake in steers fed grower and finisher diets. J. Anim. Sci. 89: 3401-3409

Food Production Must Double by 2050 to meet demand from World's Growing Population, Innovative Strategies Needed to Combat Hunger, Experts Tell Second Committee, United Nations General Assembly, GA/EF/3242. Sixty Fourth General Assembly, Second Committee, Panel Discussion (AM), 10/9/2009

Godfray, Charles J., Ian R. Crute, Lawrence Haddad, David Lawrence, James F. Muir, Nicholas Nisbett, Jules Pretty, Sherman Robinson, Camilla Toulmin and Rosalind Whiteley, The future of the global food system, Phil. Trans. R. Soc. B 27 September 2010 vol. 365 no. 1554 2769-2777.

Herd, R. M., and P. F. Arthur. 2009 Physiological basis for residual feed intake. J. Anim. Sci. 87 : e64-E71.

Herd, R. M., J. A. Archer, and P. F. Arthur. 2003. Reducing the cost of beef production through genetic improvement in residual feed intake: Opportunity and challenges to application. J. Anim. Sci. 81:E9–E17.

Koch, R. M., L. A. Swiger, D. Chambers, and K. E. Gregory. 1963. Efficiency of feed use in beef cattle. J. Anim. Sci. 22:486–494.

Lancaster, P. A., G. E. Carstens, D. H. Crews, T. H. Welsh Jr., T. D. A. Forbes, D. W. Forrest, L. O. Tedeshci, R. D. Randel, and F. M. Rouquette. 2009. Phenotypic and genetic relationships of residual feed intake with performance and ultrasound carcass traits in Brangus heifers. J. Anim. Sci. 87:3887-3896

Lancaster, P. A., G. E. Carstens, F. R. B. Ribeiro, L. O. Tedeschi, and D. H. Crews Jr. 2009. Characterization of feed efficiency traits and relationships with feeding behavior and ultrasound carcass traits in growing bulls. J. Anim. Sci. 87:1528–1539.

Morrison, S. R. 1983. Ruminant heat stress: Effect on production and means of alleviation. J. Anim. Sci. 57:1594–1600.

Mullick, D. N., V. N. Murty, and N. D. Kehar. 1952. Seasonal variations in the feed and water intake of cattle. J. Anim. Sci. 11:42-49

Nkrumah, J. D., D. H. Crews Jr., J. A. Basarab, M. A. Price, E. K. Okine, Z. Wang, C. Li, and S. S. Moore. 2007. Genetic and phenotypic relationships of feeding behavior and temperament with performance, feed efficiency, ultrasound, and carcass merit of beef cattle. J. Anim. Sci. 85:2382–2390.

Nkrumah, J. D., E. K. Okine, G. W. Mathison, K. Schmid, C. Li,J. A. Basarab, M. A. Price, Z. Wang, and S. S. Moore. 2006.Relationships of feedlot feed efficiency, performance, and feeding behavior with metabolic rate, methane production, and energy partitioning in beef cattle. J. Anim. Sci. 84:145–153.

NRC. 1996. Nutrient Requirements of Beef Cattle. 7th ed. Natl. Acad. Press. Washington, DC.

Schenkel, F. S., S. P. Miller, and J. W. Wilton. 2004. Genetic parameters and breed differences for feed efficiency, growth, and body composition traits of young beef bulls. Can. J. Anim. Sci. 84:177–185.

Schwartzkopf-Genswein, K. S., D. D. Hickman, M. A. Shah, C. R. Krehbiel, B. M. A. Genswein, R. Silasi, D. G. Gibb, D. H. Crews, and T. A. McAllister. 2011. Relationship between feeding behavior and performance of feedlot steers fed barley-based diets. J. Anim. Sci. 89 : 1180-1192

Sexson, J. L., J. J. Wagner, T. E. Engle, and J. Eickoff. 2012. Predicting water intake by yearling feedlot steers. J. Anim. Sci. 90:1920-1928.

Utley, P. R., N. W. Bradley, and J. A. Boling. 1970. Effect of restricted water intake on feed intake, nutrient digestibility, and nitrogen metabolism in steers. J. Anim. Sci. 31:130–135.

Winchester, C. F., and M. J. Morris. 1956. Water intake rates of cattle. J. Anim. Sci. 15:722–740.

Chapter 2

Relationship between dry matter feed intake, feeding behaviors, performance and ultrasound carcass measurements in growing purebred Angus and Hereford bulls[1]

Abstract

Objectives of this study were to examine the growth, feed intake and feeding behaviors of Hereford and Angus bulls; identify the relationships between feeding behaviors and variation in DMI, and the value of feeding behaviors in predicting DMI. Individual DMIs were measured in Angus bulls (n = 189; initial BW = 428 ± 3.41 kg) and Hereford bulls (n = 146; initial BW = 411 ± 4.06 kg) fed a grower ration for 71 d in 2009, 78 d in 2010 and 74 d in 2011 using a GrowSafe intake monitoring system. Feeding frequency (FF, meals/d), head down duration (HDD, s/d), head down duration per meal (HDDM, HDD/FF, s/meal), average meal size (AMS, kg/(meal•d)), and feeding rate (FR, g/s) were also measured or calculated using behavior data collected by the GrowSafe system. Ultrasound measures of 12th-rib fat thickness (UFT), longissimus muscle area (ULMA) and intramuscular fat (IMF) were determined during the mid-test weight event of every trial. The data from three years was pooled to generate mean differences between the breeds. Residual feed intake (RFI) was calculated using a linear regression of DMI on ADG and MMWT (mid-test BW$^{0.75}$). Animals were classified into three RFI groups based upon their RFI score as low (> 0.5 SD below the mean), average (± 0.5 SD from the mean) or high (> 0.5 SD above the mean). Angus bulls in the low RFI group consumed 17% ($P < 0.0001$) less dry matter than the bulls in the high RFI group while in the Hereford bulls there was a 14% ($P < 0.0001$) difference in DMI between low and high RFI groups. Significant phenotypic correlations were observed between RFI and DMI (0.83, 0.77), G:F (-0.65, -0.51), HDD (0.41, 0.59), HDDM (0.40, 0.53), AMS (0.52, 0.54) and FR (-0.31, -0.51) in Angus and Hereford bulls, respectively. The HDD and HDDM were significantly correlated with DMI. The feeding behavior traits HDD, HDDM and FR when added to the RFI base model and explained 22.67 %, 42.42%, 20.06%, 32.0%, 17.18% and 22.94% of the variation not explained by ADG and MMWT in Angus and Hereford bulls, respectively. These data suggest that certain feeding behaviors are related to the feed intake of growing Angus and Hereford bulls.

Keywords: residual feed intake, feeding behavior, growing bulls

Introduction

Feed represents the largest variable cost in beef production (Arthur et al., 2004). Thus by improving feed utilization, the profitability of beef production systems can be improved (Lancaster et al., 2009 a). The traditional measures of efficiency are a ratio of feed consumed to weight gain or the inverse, typically on pen level or lot level basis. This is effective for measuring feed efficiency in a feedlot, but research has shown that selecting breeding females on the FCR merit results in an increased mature size and consequently an increased cost in maintaining females (Herd and Bishop, 2000). Residual feed intake (**RFI**) proposed by Koch et al. (1963) is a measure of efficiency that is independent of growth traits (Bingham et al., 2009). Selection to reduce RFI offers to reduce feed intake, without compromising growth performance which should allow increases to the profitability of beef production by maintaining outputs while decreasing inputs (Herd and Bishop, 2000). RFI has also be shown to be heritable (0.42±0.13 Lancaster et al., 2009 a) and strongly correlated with dry matter intake (Arthur et al., 2001) in Angus bulls, (Lancaster et al., 2009 b), Angus steers (Baker et al., 2006) and Brangus heifers (Lancaster et al., 2009 a). The evidence for genetic variation in RFI measured in young cattle, and the estimates for heritability and genetic correlations with other traits raise expectations for favorable direct and correlated responses in the next generation including, a reduction in RFI and feed intake with little change in size or growth rate for both young cattle and for cows (Herd et al., 2003). The most cost effective scenario for improving the genetics of a cow herd is by improving the quality of a bull battery. There is little information comparing differences between Angus and Hereford bulls stratified by RFI merit.

Materials and Methods

Animals and Feeding

Three hundred and thirty five purebred bulls (189 Angus, 146 Hereford) were evaluated in a three year feeding study conducted at Simplot Livestock Co. feedlot in Grand View, ID. from 2009 to 2011. These studies were conducted and reported with the approval of the owner. Upon arrival all animals were fitted with a passive half-duplex electronic identification (**EID**) ear tag (Allflex USA Inc., Dallas-Fort Worth, TX) and housed in pens equipped with a feed intake monitoring system. In 2009 and 2010, there were 2 pens each of Angus and Hereford bulls; all pens contained 4 feeding units (GrowSafe 4000E, GrowSafe Systems LTD., Airdrie, Alberta, Canada). In 2011 there were 3 pens of Angus bulls housed in pens with 4 feeding units and 1 pen of Hereford bulls housed in a pen with 8 feeding units. Pens equipped with 4 feeding units were 8.8 x 16.3 m and pens equipped with 8 feeding units were 40.9 x 30.6 m. Trials started after a 2 week acclimation period. The study durations were 71 days in 2009, 78 in 2010 and 74 in 2011. The differing yearly study durations resulted from the breeder's availability to ship and receive bulls. Bulls were fed ad libitum a grower diet 4 times/day (Table 1).

Ultrasound Measurements and Weights

The initial and final BW measurements of all bulls were measured on two consecutive days. BW was also recorded during the ultrasound event midway through the test. Ultrasound back fat thickness (**UFT**), longissmus muscle area (**ULMA**) and intramuscular fat % (**IMF**) were measured at mid-test by an Ultrasound Guidelines Council field certified technician using an Aloka SSD 500V instrument (Aloka, Wallingford CT).

Feed Intakes and Feeding Behaviors

Feed intakes were recorded with a GrowSafe 4000E feed intake system. GrowSafe data acquisition and analysis software was used to convert data into readable formats for subsequent analysis. For data integrity and quality control purposes, daily assigned feed disappearance (**AFD**) for each feeding unit was reconciled against the total daily feed delivered to each bunk versus the sum of the daily consumption for each bull. Data were considered valid for analysis for all days on which AFD and feed delivered values were > 95 % agreement. The percent of valid days from 2009 to 2011 were; 80%, 82% and 85% respectfully. Data collected on day for which this criterion was not met were excluded from all analyses.

The meal criterion used for this study has been defined as starting when the antenna detected the animal's EID and ending when the time between the last two readings was greater than 300 seconds (Basarab et al., 2003, Sowell et al. 1998, Schwartzkopf-Genswein et al. 1999). The feeding behaviors that were collected were feeding frequency (**FF**, meals/d), head down duration (**HDD**, time spent with head below the antenna in trough /d), head down duration per meal (**HDDM,** HDD/FF), average meal size (**AMS**, average amount of **DMI** per meal event) and feeding rate (**FR,** g consumed / HDD).

RFI Computations and Statistical Analysis

Statistical analyses were conducted with the SAS system (Version 9.3, SAS Inst., Cary, NC). The ADG was calculated as the response of BW regressed on DOF, using the REG procedure in SAS. The RFI value that was used to classify the bulls into three groups was calculated as the difference between actual and predicted feed intake by regressing DMI on mid-test $BW^{0.75}$ and ADG (Koch et al., 1963, Archer et al.,1997). Residual feed intake was determined within cohort (breed and year), there was no pen effect present in any of the years. The regression analysis used to determine RFI was conducted using the GLM procedure in SAS. After determination of RFI values, animals were classified into three groups High RFI (> 0.5 SD above the mean; n = 100), Average RFI (± 0.5 SD from the mean; n = 140) and Low RFI (> 0.5 SD below the mean; n = 95). The GLM procedure was used to determine the differences between the performance, behavioral and carcass metrics of the RFI classes by breed, effects of pen and year were controlled for when necessary. Means were calculated using the LSmeans statement in the GLM procedure, effects of year and pen were controlled for when necessary. For each breed, the phenotypic observations made in this study were subjected to a multi-variate analyses of variance. The analysis was designed to estimate the correlations of DMI with ADG, G:F, and the feeding behavior traits. The independent variable was year, and separate analyses were conducted for each breed. Finally, feeding behavior variables were added to a uni-variate model of DMI corresponding to the second model described above to determine if the variance of RFI was significantly reduced by accounting for differences in feeding behavior.

Results and Discussion

Mean Comparisons of Breeds

Mean performance variables for the Angus and Hereford bulls are presented in Table 2. The Angus bulls had a larger initial and final BW than the Hereford bulls, respectively their mean initial BW were 427.7 and 411.4 ($P<.0057$), mean final BW were 565.4 and 544.7 kg ($P<.0022$). Angus bulls had larger ADG of 1.9 kg/day compared to 1.8 kg/day ($P=0.0198$). The Angus bulls had larger DMI then the Hereford bulls: 11.1 kg/d compared to 9.9 kg/d ($P<.0001$). The greater intake with relatively similar ADG resulted in improved G:F for the Hereford bulls of 0.18 kg/kg compared to the Angus bulls of 0.17 kg/kg ($P<.0001$). The mean feeding behavior variables for the Angus and Hereford bulls respectively were FF, 12.4 and 12.7 meals/day ($P=0.1533$); HDD, 2479.2 and 2280.2 s/d ($P=0.1208$), HDDM, 222.4 and 193.4 s/meal ($P=0.0033$), AMS, 0.9 and 0.8 kg/meal ($P<.0001$)and FR, 5.0 and 5.1 g/s ($P=0.6517$). The Angus bulls spent more time per day eating and the mean meal size was larger than those of the Hereford bulls. The respective mean values for ultrasound measurements for Angus and Hereford bulls were UFT, 0.56 and 0.75cm ($P<.0001$), IMF, 3.66 and 2.66 % ($P<.0001$), and ULMA, 74.0 and 72.3 cm^2 ($P=0.1505$).

Comparison of RFI Classifications within Breed

Differences between RFI groups are illustrated in Table 3. The mean value for RFI for Angus bulls, low RFI versus high RFI was -1.14 and 0.92 kg/d ($P < 0.0001$), and similarly in Hereford bulls -0.71 versus 0.72 kg/d ($P < 0.0001$). These ranges are similar to the values reported by Lancaster in Brangus heifers (Lancaster et. al., 2009 b), Baker in Angus steers (Baker et al., 2006), and Lawrence in pregnant Simmental and Simmental x Holstein-Friesian heifers (Lawrence et al., 2011). There were significant differences in DMI for low versus high RFI groups for both breeds. DMI in the low RFI group was 17% lower ($P < 0.0001$) than the high RFI group in Angus bulls. In the Hereford bulls there was a 14% reduction ($P < 0.0001$) in DMI from low to high RFI groups. These results are consistent but of a larger magnitude than those reported by Basarab (2003) and Baker (2006). Both studies showed a 10% difference in DMI between low and high RFI groups for beef cross and Angus steers. Data from Durunna (2012), showed DMI of a low RFI group was 14% lower during the growing phase and 10% lower during the finishing phase compared to a high RFI group for beef cross heifers. The results of the present study are more similar to the values reported by Schwartzkopf-Genswein (2011) whom over a two year study showed DMI of Charolais sired steers in the low RFI group was 17% lower in year one and 15% lower in year two of the study. There were no significant differences between low and high RFI groups for either breed in ADG (Angus, P = 0.98, Hereford, $P = 0.81$), Initial BW (Angus $P = 0.36$, Hereford, $P = 0.36$), or Final BW (Angus, $P = 0.39$, Hereford, $P =0.25$), because the model for calculating RFI was adjusted for these traits. These findings are consistent with previous studies that found RFI was positively correlated with DMI but independent of BW and growth (Bingham et al., 2009, Herd and Bishop, 2000, Arthur et al., 2001a,b, Carstens et al., 2002). There were improvements in G:F when comparing low and high RFI in both breeds. The G:F of Angus bulls in the low RFI group was 18.8% greater ($P < 0.0001$) than the high RFI group. The G:F of Hereford bulls in the low RFI group was 17.6% greater ($P <$

0.0001) when compared to the high RFI group. These values are consistent with previous studies, Basarab (2003) showed a 9% difference in FCR and Nkrumah (2006) reported an 18% difference in FCR between low and high RFI groups of beef cross steers.

There were no significant differences in FF between low and high RFI groups in either breed. This is contrary to the findings of Nkrumah et al. (2007), Lancaster et al. (2009 a) and Durunna et al. (2011) whom all reported lower FF in low versus high RFI groups: 13.5%, 10.9% and 12.5% respectively. Basarab et al., (2003) reported similar trends but not of the same magnitude at a 6.67% difference.

Bulls in the low RFI groups spent significantly less time feeding than those in the high RFI groups. There was a 31% ($P < 0.0001$) difference in HDD in Angus bulls between low versus high RFI groups and similarly for Hereford bulls a 32% ($P < 0.0001$) difference in HDD between groups was observed. These findings are similar but of a larger magnitude than those by Nkrumah et al. (2007), Lancaster et al. (2009 a) whom showed differences in HDD between low and high RFI groups of 24% and 13%. Durunna et al. (2011) reported differences of 12% in grower phase and 19% in finisher phase cattle. Bingham et al. (2009) reported that HDD was 23% greater in low versus high RFI groups, which contrary to the other studies, although the reasons for these differences are not readily apparent.

HDDM was significantly decreased in the low RFI groups versus the high RFI groups. Angus bulls in the low RFI group, spent 33% less time per meal ($P < 0.0001$) and Hereford bulls in the low RFI group spent 32% less time per meal ($P < 0.0001$) compared to the high RFI group. These results closely parallel HDD, which may be described by the mathematical relationship between these traits. The AMS of the low RFI bulls was also significantly smaller than the high RFI groups of both Angus and Hereford breeds. The AMS of Angus bulls in the low RFI group was 19% smaller ($P < 0.0001$) and for Hereford bulls AMS of the low RFI group was 14% smaller ($P <.0001$) compared to their high RFI group. The low RFI bulls did have a greater FR than the high RFI bulls, 20 % greater ($P = 0.0056$) for Angus and 30 % greater ($P <.0001$) for Hereford bulls. The differences between the low and high RFI groups determined in the present study are contradictory to the findings of Lancaster et al. (2009 a), Bingham et al. (2009) and Durunna et al. (2011) who reported lower FR for low RFI groups compared to high RFI groups on high roughage diets of 3%, 39% and 4%, respectively. While Durunna et al (2011) reported that in the finisher period FR was 1% higher in low versus high RFI groups. In the literature there is little continuity in reported FR. It may be that this trait is more sensitive, for example, to ration composition, gender and pen stocking density than the other traits that were reported.

Previous reports have mixed results regarding the relationship between RFI and ultrasound traits. For example, Baker et al.,(2006) and Basarab et al.,(2003) showed no difference in UFT, IMF or ULMA between low and high RFI Angus steers and crossbreed steers. In Brangus heifers Lancaster et al.,(2009 b) reported no differences in the final composition of UFT, IMF or ULMA between the RFI classes, although the high RFI group exhibited increased gain in UFT. Furthermore Lancaster et al., (2009 a) reported greater UFT in the final composition of the high RFI class, as well as greater gain in UFT and ULMA in growing purebred Angus bulls. In the present study, there were no significant differences in IMF (Angus $P = 0.50$, Hereford, $P = 0.14$) and ULMA (Angus, $P = 0.36$, Hereford, $P = 0.45$) between RFI classifications for either breed. There was no difference in

UFT between RFI classifications for the Angus bulls *(P* = 0.45), although the high and average RFI groups had greater UFT than the low group *(P<.05)* in the Hereford bulls.

Phenotypic Correlations among Performance and Carcass Traits

Previous reports have shown moderately positive phenotypic correlations between RFI and DMI. Herd and Bishop (2000), Herd et al., (2003), Baker et al., (2006) and Archer et al., (2001a,b) all showed moderate phenotypic correlations between RFI and DMI in Hereford, Angus and Charolais cattle. Both breeds in the present study exhibited large correlations between RFI and DMI, (r = 0.83, $P < 0.0001$) in Angus and (r = 0.77, P < 0.0001) in Hereford bulls. Phenotypic correlations between performance and carcass traits associated with their respective p-values are found in Table 4.

There were no correlations between RFI and ADG for either breed. This was expected because the use of linear regression to compute the expected DMI for RFI forces this trait to be phenotypically independent. RFI was highly correlated with G:F in Angus (r = -0.65, P < 0.0001) and Hereford bulls (r = -0.51, P <0.0001). These findings are similar to those of Arthur et al.,(2001 a,b), Schenkel et al., (2004), Nkrumah et al., (2004, 2007) Hoque et al., (2006) and Lancaster et al., (2009 a,b) whom reported positive phenotypic correlations between RFI and FCR in growing bulls, steers and heifers. RFI has been shown to be a moderately heritable trait (Arthur et al., 1997) with reported genetic correlations ranging from r = 0.62 to 0.94 suggesting that selection for improved RFI will result in an improvement in gross feed efficiency (FCR)(Lancaster et al., 2009 b).

The ADG was moderately correlated with DMI in Angus, (r = 0.46 P < 0.0001) and Hereford bulls (r = 0.45, P < 0.0001) which is consistent with phenotypic correlations previously reported in growing steers (Carstens et al., 2002; Basarab et al., 2003; Nkrumah et al., 2004) and bulls (Arthur et al., 2001 a,b; Schenkel et al., 2004; Lancaster et al., 2009 a). In agreement with previous studies ADG was highly correlated with G:F, in Angus (r = 0.67, P < 0.0001) and Hereford (r = 0.80, P < 0.0001) bulls.

The feeding behavior traits were moderately correlated with RFI for both Angus and Hereford bulls. The phenotypic correlations between HDD and RFI were r = 0.41, $P < 0.0001$ and r = 0.59, $P < 0.0001$, for Angus and Hereford bulls, respectively. These data are similar to the findings of Nkrumah et al. (2007) whom showed a positive correlation, r = 0.33, between head down time and RFI. The HDDM was similarly correlated with RFI which was to be expected because there were no material differences between the RFI groups in FF. There were moderate, negative correlations between FR and RFI, r = -0.31, P <0.0001 and r = -0.51, P <0.0001, for Angus and Hereford bulls, respectively. Robinson and Oddy (2004) reported a low positive correlation (r = 0.16) between FR and RFI and Bingham et al. (2009) reported a significant difference between low and high RFI heifers. These findings are contradicted by Golden et al. (2008), Lancaster et al. (2009 a) and Durunna et al. (2011) all reporting the relationship between RFI and FR to be not different from zero.

Similar to previous reports (Durunna et al., 2011; Lancaster et al., 2009 a) a moderate relationship was found between HDD and DMI. The respective phenotypic correlations for Angus and Hereford bulls were r = 0.37, $P<0.0001$ and r = 0.52 P < 0.0001. The correlations among DMI and HDDM were similar. There were no significant correlations between the feeding behavior traits and ADG except for AMS; the respective values for Angus and Hereford bulls were r = 0.16, P = 0.0326 and r = 0.17, P = 0.0460.

The FF was correlated with GF in the Angus bulls *(r = 0.19, P = 0.0071)* but, not with the Hereford bulls *(r = 0.08, P = 0.3478)*. The remaining feeding behavior traits were moderately correlated with G:F in both breeds; HDD (Angus, r = -0.17, P = 0.0238, Hereford, r = -0.18, P = 0.0364), HDDM (Angus, r = -0.20, P = 0.0063, Hereford, r = -0.23, P = 0.0061), AMS (Angus, r = -0.32, P <0.0001, Hereford, r = -0.17, P = 0.0432) and FR (Angus, r = 0.15, P = 0.0440, Hereford, r = 0.17, P = 0.0439). These correlations are contradictory to the results of Lancaster et al.,(2009 a) and Durunna et al.,(2011), whom reported no significant correlations between HDD and FCR. Durunna et al.,(2011) did report a significant negative correlation among FF and FCR, which the inverse was reported here with Angus bulls.

Variation of DMI Explained by Feeding Behaviors

Individual feeding behavior traits were added to the base RFI model to quantify the value of each term in explaining variation of DMI unexplained by MMWT and ADG. Each term was added singularly to the DMI model to test if the term was significant. The mean squared error of the model with the new term was compared to the base model to identify the reduction in variation. The percentages of variation explained by the new terms are shown in Table 5. Feeding frequency was not significant when added to the model for either breed, in Angus bulls (P = 0.5602) it increased the MSE by 0.52% and explained 2.21% of the unexplained variation in Herefords (P = 0.1126). There were no differences found in FF between RFI classes in this study as a result it was an insignificant term when added to the base model. Nkrumah et al. (2007) and Durunna et al. (2011) both showed changes in FF from grow to finish rations. These findings suggest that FF can be affected by management and the environment in which the animals are tested. This may explain why the values in the present study are in disagreement with the results of Nkrumah et al. (2007), Basarab et al. (2003) and Durunna et al. (2011) whom showed differences in FF between RFI classes. The HDD explained 22.67% of the variation in DMI in Angus (P <0.0001) as well as 42.42% in Hereford (P <0.0001) bulls beyond the base model. The HHDM explained 20.06% and 32.0% of the unexplained variation in DMI in Angus and Hereford bulls, respectively. Feeding rate (FR) explained 17.18% in Angus (P <0.0001) and 22.94% in Hereford (P = 0.8052) bulls. These results are similar to the findings of Lancaster et al., (2009 a) whom included feeding behavior traits into a carcass adjusted RFI model, they reported reductions of unexplained variation of the model when meal duration, HDD and FF were added but no improvements associated with the addition of FR. The signals between feeding behavior traits, performance and residual feed intake are variable between studies. Further research is needed to understand the effects of ration, animal type, environment and location on feeding behaviors.

Implications

Technology improvements have made it cost effective to measure feed intake and feeding behavior. Rising feed costs and diminishing cow herd numbers have placed increased value on seed stock selection. In the present study, animals in the low RFI class had lower DMI and exhibited an improved G:F without compromising growth or ultrasound measures. The addition of feeding behavior traits to the base model improved the prediction of feed intake of animals tested in both breeds and inclusion of these measurements may provide improved tools toward genetic improvements in performance and efficiency. However, due to the variability of reported values across recent studies, we conclude that the use of feeding behavior traits in the RFI model needs further study.

LITERATURE CITED

Archer, J. A., P. F. Arthur, R. M. Herd, P. F. Parnell, and W. S.Pitchford. 1997. Optimum postweaning test for measurement of growth rate, feed intake, and feed efficiency in British breed cattle. J. Anim. Sci. 75:2024–2032.

Arthur, P. F., J. A. Archer, and R. M. Herd. 2004. Feed intake and efficiency in beef cattle: Overview of recent Australian research and challenges for the future. Aust. J. Exp. Agric. 44:361–369.

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

Arthur, P. F., J. A. Archer, R. M. Herd, E. C. Richardson, S. C. Exton, J. H. Wright, K. C. P. Dibley, and D. A. Burton. 1997. Genetic and phenotypic variation in feed intake, feed efficiency and growth in beef cattle. Proc. Assoc. Adv. Anim. Breed. Genet. 12:234–237.

Arthur, P.F., G. Renand, and D. Krauss.2001b. Genetic parameters for growth and feed efficiency in weaner versus yearling Charolais bulls. Aust. J. Agric. Res. 52:471-476

Baker, S. D., J. I. Szasz, T. A. Klein, P. S. Kuber, C. W. Hunt, J. B. Glaze Jr., D. Falk, R. Richard, J. C. Miller, R. A. Battaglia, and R. A. Hill. 2006. Residual feed intake of purebred Angus steers: Effects on meat quality and palatability. J. Anim. Sci.84:938–945.

Basarab, J. A., M. A. Price, J. L. Aalhus, E. K. Okine, W. M. Snelling, and K. L. Lyle. 2003. Residual feed intake and body composition in young growing cattle. Can. J. Anim. Sci. 83:189–204

Bingham, G. M., T. H. Friend, P. A. Lancaster, and G. E. Carstens. 2009. Relationship between feeding behavior and residual feed intake in growing Brangus heifers. J. Anim. Sci. 87:2685–2689.

Carstens, G. E., C. M. Theis, M. B. White, T. H. Welsh Jr., B. G. Warrington, R. D. Randel, T. D. A. Forbes, H. Lippke, L. W. Greene, and D. K. Lunt. 2002. Residual feed intake in beef steers: I. Correlations with performance traits and ultrasound measure of body composition. Proc. West. Sect. Am. Soc. Anim. Sci. 53:552-555

Durunna, O. N., M. G. Colazo, D. J. Ambrose, D. McCartney, V. S. Baron and J. A. Basarab. 2012 Evidence of residual feed intake reranking in crossbred replacement heifers. J. Anim. Sci. 2012, 90:734-741.

Durunna, O. N., Z. Wang, J. A. Basarab, E. K. Okine, and S. S. Moore. 2011. Phenotypic and genetic relationships among feeding behavior traits, feed intake, and residual feed intake in steers fed grower and finisher diets. J. Anim. Sci. 89: 3401-3409

Golden, J. W., Kerley, M. S., & Kolath, W. H. (2008). The relationship of feeding behavior to residual feed intake in crossbred Angus steers fed traditional and no-roughage diets. . J. Anim. Sci., *86*(1), 180-186.

Herd, R. M., J. A. Archer, and P. F. Arthur. 2003. Reducing the cost of beef production through genetic improvement in residual feed intake: Opportunity and challenges to application. J. Anim. Sci. 81:E9–E17.

Herd, R. M., and S. C. Bishop. 2000. Genetic variation in residual feed intake and its association with other production traits in British Hereford cattle. Livest. Prod. Sci. 63:111–119.

Hoque, M. A., P. F. Arthur, K. Hiramoto, and T. Oikawa. 2006. Genetic relationship between different measures of feed efficiency and its component traits in Japanese Black (Wyagu) bulls. Livest. Sci, 99:111-118.

Koch, R. M., L. A. Swiger, D. Chambers, and K. E. Gregory. 1963. Efficiency of feed use in beef cattle. J. Anim. Sci. 22:486–494.

Lancaster, P. A., G. E. Carstens, D. H. Crews, T. H. Welsh Jr., T. D. A. Forbes, D. W. Forrest, L. O. Tedeshci, R. D. Randel, and F. M. Rouquette. 2009 b. Phenotypic and genetic relationships of residual feed intake with performance and ultrasound carcass traits in Brangus heifers. J. Anim. Sci. 87:3887-3896

Lancaster, P. A., G. E. Carstens, F. R. B. Ribeiro, L. O. Tedeschi, and D. H. Crews Jr. 2009 a. Characterization of feed efficiency traits and relationships with feeding behavior and ultrasound carcass traits in growing bulls. J. Anim. Sci. 87:1528–1539.

Lawrence, P., D. A. Kenny, B. Earley, D. H. Crews, Jr. and M. McGee 2011. Grass silage intake, rumen and blood variables, ultrasonic and body measurements, feeding behavior, and activity in pregnant beef heifers differing in phenotypic residual feed intake. J. Anim. Sci. 2011, 89:3248-3261.

Nkrumah, J. D., J. A. Basarab, M.A. Price, E. K. Okine, A. Amoura, S. Guercio, C. Hansen, C. Li, B. Benkel, B. Murdoch, and S. S. Moore. 2004. Different measures of energetic efficiency and their phenotypic relationships with growth, feed intake, and ultrasound and carcass merit in hybrid cattle. J. Anim. Sci. 82:2451-2459

Nkrumah, J. D., D. H. Crews Jr., J. A. Basarab, M. A. Price, E. K. Okine, Z. Wang, C. Li, and S. S. Moore. 2007. Genetic and phenotypic relationships of feeding behavior and temperament with performance, feed efficiency, ultrasound, and carcass merit of beef cattle. J. Anim. Sci. 85:2382–2390.

Nkrumah, J. D., E. K. Okine, G. W. Mathison, K. Schmid, C. Li,J. A. Basarab, M. A. Price, Z. Wang, and S. S. Moore. 2006.Relationships of feedlot feed efficiency, performance, and feeding behavior with metabolic rate, methane production, and energy partitioning in beef cattle. J. Anim. Sci. 84:145–153.

Robinson, D. L., & Oddy, V. H. (2004). Genetic parameters for feed efficiency, fatness, muscle area and feeding behaviour of feedlot finished beef cattle. Livest. Prod. Sci., 90(2), 255-270.

Schenkel, F. S., S. P. Miller, and J. W. Wilton. 2004. Genetic parameters and breed differences for feed efficiency, growth, and body composition traits of young beef bulls. Can. J. Anim. Sci. 84:177–185.

Schwartzkopf-Genswein, K. S., D. D. Hickman, M. A. Shah, C. R. Krehbiel, B. M. A. Genswein, R. Silasi, D. G. Gibb, D. H. Crews, and T. A. McAllister. 2011. Relationship between feeding behavior and performance of feedlot steers fed barley-based diets. J. Anim. Sci. 89 : 1180-1192.

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

Sowell, B. F., J. G. P. Bowman, M. E. Branine, and M. E. Hubbert. 1998. Radio frequency technology to measure feeding behavior and health of feedlot steers. Appl. Anim. Behav. Sci. 59:275–282.

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Table 1. Dietary ingredients of growing rations by year (%;DM basis)

Ingredient	2009	2010	2011
Hay	20.72	32.2	20.02
Haylage	20.76	11.09	15.34
Corn silage	11.98	7.65	5.7
Fry waste	8.37	3.9	3.8
Potatoes	7.91	14.41	13.03
Flaked corn	26.3	25.53	15.84
Mineral	3.96	5.2	4.35
Dried distiller's grain	-	-	3.3
Wheat	-	-	10.38
Wheat straw	-	-	8.26
DM %	42.98	45.91	47.44
NEg	0.5	0.5	0.5
NEm	0.82	0.8	0.8

Table 2. Comparison of breed means

	Angus		Hereford		
Variable	Mean	SE	Mean	SE	P value
RFI, kg/d	0	0.87	0	0.65	-
DMI, kg/d	11.1	0.08	9.94	0.09	<.0001
ADG, kg/d	1.9	0.02	1.83	0.02	0.0198
G:F	0.17	0.002	0.18	0.002	<.0001
Initial BW, kg	427.73	3.41	411.39	4.06	0.0057
Final BW, kg	565.37	3.96	544.65	4.63	0.0022
Gain, kg/d	138.45	1.45	133.1	1.64	0.015
Feeding Behavior Traits					
FF, meals/d	12.37	0.16	12.71	0.18	0.1533
HDD, s/d	2479.24	84.35	2280.16	84.46	0.1028
HDDM, s/meal	222.39	5.79	193.41	6.77	0.0033
AMS, kg/meal.d	0.94	0.01	0.8	0.013	<.0001
FR, g/s	5	0.15	5.1	0.15	0.6517
Ultrasound Measurements					
UFT, cm	0.56	0.02	0.75	0.02	<.0001
IMF %	3.66	0.05	2.66	0.06	<.0001
ULMA, cm^2	74	0.7	72.3	0.82	0.1505

Table 3. Effect of residual feed intake group on performance, ultrasound measurements and feeding behaviors of growing Angus and Hereford bulls

Breed	**Variable**	**Low RFI**	**Average RFI**	**High RFI**	**Root MSE**	**P-value**
Angus	**No. Bulls**	46	87	56		
	RFI, kg/d	-1.14^{a}	0.01^{b}	0.92^{c}	0.44	<0.0001
	DMI, kg/d	9.96^{a}	11.05^{b}	12.06^{c}	0.92	<0.0001
	ADG, kg/d	1.9	1.89	1.9	0.26	0.9762
	G:F	0.19^{a}	0.17^{b}	0.16^{c}	0.02	<0.0001
	Initial BW, kg	435.13	427.14	437.17	44.36	0.3639
	Final BW, kg	574.19	564.82	576.33	53.14	0.3911
	Gain, kg	138.91	137.71	139.24	19.88	0.8896
	FF, *meals/d*	12.59	12.28	12.27	1.76	0.6162
	HDD, *s/d*	1879.63^{a}	2522.02^{b}	2736.59^{b}	818.28	<0.0001
	HDDM *s/meal*	155.35^{a}	210.40^{b}	233.31^{b}	70.19	<0.0001
	AMS *kg/meal.d*	0.83^{a}	0.94^{b}	1.02^{c}	0.15	<0.0001
	FR, *g/s*	5.79^{a}	4.88^{b}	4.81^{b}	1.69	0.0056
	UFT, *cm*	0.57	0.57	0.61	0.18	0.446
	IMF%	3.53	3.65	3.71	0.79	0.4977
	ULMA cm^2	75.89	73.79	75.4	8.96	0.3623
Hereford	**No. Bulls**	49	53	44		
	RFI, kg/d	-0.71^{a}	0.06^{b}	0.72^{c}	0.31	<0.0001
	DMI, kg/d	9.14^{a}	10.08^{b}	10.70^{c}	0.65	<0.0001
	ADG, kg/d	1.82	1.85	1.84	0.27	0.8112
	G:F	0.20^{a}	0.18^{b}	0.17^{c}	0.02	<0.0001
	Initial BW, kg	399.53	408.48	406.55	32.76	0.3603
	Final BW, kg	531.2	542.79	539.79	36.21	0.2548
	Gain, kg	131.96	134.22	133.04	19.79	0.8472
	FF, *meals/d*	12.71	12.6	12.84	1.79	0.8096
	HDD, *s/d*	2131.66^{a}	2884.57^{b}	3114.32^{b}	612.25	<0.0001
	HDDM *s/meal*	170.85^{a}	233.81^{b}	249.74^{b}	54.45	<0.0001
	AMS *kg/meal.d*	0.74^{a}	0.82^{b}	0.86^{b}	0.12	<0.0001
	FR, *g/s*	4.83^{a}	3.89^{b}	3.72^{b}	0.99	<0.0001
	UFT, *cm*	0.64^{a}	0.76^{b}	0.78^{b}	0.2	0.0014
	IMF%	2.56	2.73	2.77	0.55	0.1409
	ULMA cm^2	71.04	72.22	70.48	6.93	0.4479

Table 4. Partial correlation coefficients and their respective P values for performance, carcass and feeding behaviors traits between Angus and Hereford growing bulls

				Angus				
	RFI		**DMI**		**ADG**		**GF**	
RFI		1						
DMI	<0.0001	0.83		1				
ADG	1	0	<0.0001	0.46		1		
GF	<0.0001	-0.65	<0.0001	-0.33	<0.0001	0.67		1
FF	0.4197	-0.06	0.7917	-0.02	0.0656	0.14	0.0071	0.19
HDD	<0.0001	0.41	<0.0001	0.37	0.087	0.13	0.0238	-0.17
HDDM	<0.0001	0.4	<0.0001	0.34	0.2753	0.08	0.0063	-0.2
AMS	<0.0001	0.52	<0.0001	0.57	0.0326	0.16	<0.0001	-0.32
FR	<0.0001	-0.31	0.0231	-0.17	0.9774	0	0.044	0.15
UFT	0.0107	0.19	0.0002	0.28	0.0522	0.14	0.3983	-0.06
IMF	0.3256	0.07	0.4462	0.06	0.2233	0.09	0.3622	0.07
ULMA	0.2955	0.08	0.0016	0.23	0.2385	0.09	0.1834	-0.1
				Hereford				
	RFI		**DMI**		**ADG**		**GF**	
RFI		1						
DMI	<0.0001	0.77	0	1				
ADG	1	0	<0.0001	0.45		1		
GF	<0.0001	-0.51	0.0513	-0.16	<0.0001	0.8		1
FF	0.4176	0.07	0.9322	-0.01	0.4174	0.07	0.3478	0.08
HDD	<0.0001	0.59	<0.0001	0.52	0.0674	0.15	0.0364	-0.18
HDDM	<0.0001	0.53	<0.0001	0.49	0.2972	0.09	0.0061	-0.23
AMS	<0.0001	0.36	<0.0001	0.54	0.046	0.17	0.0432	-0.17
FR	<0.0001	-0.51	<0.0001	-0.37	0.4496	-0.1	0.0439	0.17
UFT	0.0148	0.2	0.0013	0.27	0.6654	0.04	0.0551	-0.16
IMF	0.1709	0.12	0.8759	-0.01	0.4554	-0.1	0.3716	-0.08
ULMA	0.862	-0.01	0.0997	0.14	0.0675	-0.2	0.0018	-0.26

Table 5. Percent reduction in the mean squared error of the model due to the inclusion of the individual trait on growing Angus and Herford bulls

Trait	Angus	Herford
FF	-0.52%	2.21%
HDD	22.67%	42.42%
HDDM	20.06%	32.00%
FR	17.18%	22.94%

Chapter 3

Evaluation of sampling error in the measurement of body weight gain and dry matter intake for the calculation of residual feed intake in growing purebred Charolais and Red Angus cattle

Abstract

The objective of this study was to determine relative contributions of sampling errors of measurements used to evaluate residual feed intake **(RFI)** and identify the possibilities of measuring body weight gain over a greater time-span than the period used to estimate feed intake. Residual feed intake is the difference between predicted and actual feed intake. Weaning weight **(WW)**, average daily gain **(ADG)**, and individual dry matter intake **(DMI)**, were recorded on 970 growing, purebred Charolais bulls (n = 519) and heifers (n = 451) and 153 Red Angus growing steers (n = 69) and heifers (n = 84) using a GrowSafe (GrowSafe, Airdrie, Alberta, Canada) system. Averages of individual DMI were calculated in 10 day increments and compared to the overall DMI, to identify the magnitude of the errors associated with measuring DMI. These incremental measurements were also used in calculation of RFI, computed from the linear regression of DMI on ADG and midtest metabolic body weight$^{0.75}$ **(MMWT)**. Residual feed intake calculated using the widely accepted approach **(RFI_Regress)** was calculated using the **(ADG_Regress)** ADG calculated as the slope of the regression of BW gain on days on feed and **(MMWT_PWG)** the metabolic mid-weight measured during the post weaning gain test. This value was considered the standard in the Red Angus cattle. For the Charolais cattle, RFI was calculated using consecutive start and finish weights taken on the initial two days and final two days of

each post-weaning RFI test period **(RFI_Calc)**. The RFI weaning weight **(RFI_WW)** was calculated using the measurement of ADG from weaning till the final out weight of the post-weaning RFI test, as well as metabolic mid-weight weaning weight (MMWT_WW) which was also calculated in an analogous manner. Overall average DMI was highly correlated with measurements of DMI taken over the abbreviated periods, with 10 days of DMI measurement being the least correlated (r = 0.85, $P < 0.0001$) and 60 days of measurement being the most highly correlated (r = 0.99, $P < 0.0001$). Although all were significantly correlated, the variation stabilized (with $r \geq 0.95$) at 30 days (r = 0.95, $P < 0.0001$). The ADG_Calc and ADG_WW were correlated (r = 0.61, $P < 0.0001$) in the Charolais cattle. The ADG_Regress and ADG_Calc were highly correlated (r = 0.92, $P < 0.0001$), and ADG_Regress and ADG_WW were moderately correlated (r = 0.26, $P < 0.0001$) in the Red Angus cattle. The standard measures of RFI were highly correlated with the RFI_WW in the Charolais (r = 0.96, $P < 0.0001$) and Red Angus (r = 0.96, $P < 0.0001$) cattle. The DMI estimates determined over abbreviated periods were included in the model with the weaning weight gain measurements, and all resulting RFI values were highly correlated with RFI_Regress and RFI_Calc. The model using only 10 d of DMI measurement **(RFI WW_10)** was the least correlated with the standard measures (Red Angus r = 0.63, $P < 0.0001$, Charolais r = 0.71, $P < 0.0001$) and the model using 60 d of DMI measurement was most highly correlated with the standard measures (Red Angus r = 0.93, $P < 0.0001$, Charolais r = 0.95, $P < 0.0001$). The fewest days to estimate DMI coupled with the weaning weight values that seemed to have an acceptable relationship for estimation of RFI was RFI_40_WW , which was highly correlated with the standard RFI measures (Red Angus r = 0.89, $P < 0.0001$, Charolais r = 0.90, $P < 0.0001$) .As previously reported in the literature,

these analyses suggest that any reduction in the standard 70d period to estimate RFI is most affected by loss of confidence in estimating ADG, while the loss in confidence in measuring DMI using only 40 days of DMI measurements is only marginally affected. Thus, we conclude that while 70 d is required to accurately estimate ADG, a shorter period, possibly as few as 40 d is needed to accurately estimate DMI for a reliable calculation of RFI.

Keywords: residual feed intake, growing bulls

Introduction

By year 2050 the world will have to produce one hundred percent more food to feed the global population (United Nations, 2009). The majority of this production will have to be generated by new technologies or improved efficiencies due to the finite amount of natural resources available (Godfray, et. al., 2010). Beef production has flourished by increasing the efficiency and gain of animals; for example, in 2007, compared to 1977, the US generated 12% more beef with 88% of the cattle inventory (Capper, 2011).The increases in efficiencies have come from improvements in management, technologies and genetic merit of the national beef herd. Newer technologies have made it possible to measure feed intake on individual beef animals on a large scale. Residual feed intake is a calculation for measuring feed efficiency that is unrelated to weight or growth (Koch et. al., 1963; Archer et. al., 1999; Arthur et.al., 2001; Wang et. al., 2006).This has allowed the industry to select for animal efficiency more easily. The investment that must be made in the equipment is not trivial. Most producers cannot justify the investment needed for the equipment and must rely on centralized testing facilities. The current standard test for measuring feed intake and body weight gain is seventy days (Archer, et. al., 1997). By changing the current feed intake and

ADG measuring paradigm it may be possible to increase the number of animals that are measured through testing facilities, ultimately reducing the cost of the test and increasing producer adoption.

Materials and Methods

Animals and Management

Data were collected using feed intake measuring troughs (GrowSafe Systems LTD., Airdrie, Alberta) at the Simplot Livestock Co. Grand View Feedyard (Grand View, ID) and at the University of Idaho Nancy M. Cummings Research Center (Salmon, ID). Nine hundred and seventy purebred Charolais bulls (n = 519) and heifers (n = 451), belonging to the Simplot Precision Genetics herd, were tested at the Grand View facility from 2011 through 2013. One hundred and fifty three Red Angus steers (n = 69) and heifers (n = 84) were tested at the Salmon facility in 2010. There were 22 cohorts that were used based upon gender, breed, test peers and to control for pen effect where present. Trial durations ranged from sixty six days to one hundred days. These trial durations were affected by the demand upon the facility and failure days of the systems. Complete descriptions of facilities and feeding management can be found in Welch et al., (2012)for the Salmon facility and in Kayser and Hill, (2013) for the Grand View facility.

Average Daily Gain Measurements

Three different calculations were used to quantify the ADG of the animals. The average daily gain standard test regression (**ADG_Regress**) was calculated as the response of BW regressed on days on feed (**DOF**). Using the REG procedure in SAS, this metric is reported only for the Red Angus cattle. The average daily gain, standard test calculation

(**ADG_Calc**) for the Charolais cattle was calculated as the difference between the average start and finish weights measured on consecutive days divided by the study duration. The average daily gain, weaning day through end of test (**ADG_WW**) was calculated as the difference between the last standard RFI test out weight and the weaning weight divided by n days between the two weights.

Feed Intake Measurements

Feed intakes were recorded using GrowSafe 4000E feed intake systems. GrowSafe data acquisition and analysis software was used to convert data into readable formats for subsequent analysis. For data integrity and quality control purposes, daily assigned feed disappearance (**AFD**) for each feeding unit was reconciled against the total daily feed delivered to each bunk versus the sum of the daily consumption for each animal. Data were considered valid for analysis for all days on which AFD and feed delivered values were > 95 % agreement. The percent of valid days on average were 91% and 82% for the Grand View and Salmon facility, respectfully. Data collected on days for which this criterion was not met were excluded from all analyses. Dry matter intake was calculated as the average of the dry matter consumed for all valid days. Averages of DMI were also calculated over abbreviated periods and compared to the standard RFI test in 10 day increments from 10 to 60 days. These values were compared against each other as well as used in the RFI model to identify the number of days required to reliably estimate DMI.

RFI Computations and Statistical Analysis

Statistical analyses were conducted with the SAS system (Version 9.3, SAS Inst., Cary, NC). The RFI values were calculated as the difference between actual and predicted feed intake by regressing DMI on mid-test $BW^{0.75}$ and ADG (Koch et al., 1963, Archer et al.,1997). Residual feed intake was determined within cohort (breed, year, gender and location), and pen effects were controlled for when needed. The regression analysis used to determine RFI was conducted using the GLM procedure in SAS. Residual feed intake values were calculated using the three different aforementioned values of ADG along with the different measures of DMI on the Red Angus cattle. For the Charolais cattle there were insufficient weights recorded to justify the ADG_Reg based calculation therefore the RFI values were calculated using only the RFI standard test calculation (**RFI_Calc**) and the RFI value determined using ADG_WW (**RFI_Wean**) values alongside the various measurements of DMI. Partial correlation coefficients were calculated using the PROC GLM procedure in SAS and were controlled for cohort. All means were calculated using PROC MEANS and were calculated for each breed and gender.

Results and Discussion

The mean values for the measured traits are shown in Table1. Mean weaning weight (**WW**), initial weight and finish weight for the Charolais bulls were 254.02 (48.28), 355.38 (51.47) and 473.00 (57.88) and heifers were 234.73 (46.06) kg, 303.17 (42.02) kg, and 389.31 (44.35) kg respectively. Similar values were measured on the Red Angus steers 268.56 (27.60) kg, 338.22 (28.84) kg, and 462.54 (38.03) kg, heifers 259.73 (24.73) kg, 312.17 (30.17) kg, and 425.10 (41.91) kg respectively. The Red Angus cattle on average were studied for longer mean duration of standard test (86.04 d) compared to the Charolais average test days of 75.98 d. This difference was due to the management differences between the facilities, however, both study period ranges fall within the standard time duration needed to estimate ADG. Recommended durations for the measurement of ADG proposed in the literature are 63 d (Wang et. al., 2006), 70 d (Archer et. al., 1997), 84 d (Swiger and Hazel, 1961; Lui and Makarechian 1993a,b) and 112 d (Franklin et. al., 1987; Kemp, 1990; Brown et. al.,1991). Both measures of ADG fit the criterion or are longer than proposed. The ADG_Calc for the Charolais bulls and heifers, respectively were 1.6 (0.28) kg and 1.09 (0.26) kg. Similarly the ADG_WW was 1.35 (0.21) kg and 1.11 (0.22) kg for bulls and heifers. The calculated ADG_Regress and ADG_Calc for the Red Angus steers and heifers were very similar. Mean values for the steers were 1.35 (0.23) kg and 1.31 (0.20) kg respectively. Mean values for the heifers were 1.48 (0.23) kg and 1.45 (0.21) kg. The ADG values calculated while on the standard test were different from the ADG values calculated from weaning to the end of the test. The ADG_WW values for the steers and heifers, respectively were 0.70 (0.38) kg and 0.58 (0.32) kg. The magnitude of the differences reported in the Red Angus amongst the test ADG values compared to the ADG_WW values is most likely due to the variation in duration of post-weaning period on which the calculation of ADG_WW was based on in the Red Angus cattle. The mean duration of days that ADG_WW was measured on the Charolais bulls and heifers respectively were 162 d and 141 d. The mean duration of days the ADG_WW was measured on the Red Angus steers and heifers were 332 d and 370 d. These differences in the span of time over which ADG_WW was measured had an effect on the value of the measurement.

As expected the mean values for all of the RFI calculations were 0. The greatest variation in DMI values for both breeds and genders were apparent for calculation models in which the abbreviated determination period was the shortest. As the animals progressed through the feeding study their BW increased and their DMI demand increased to support maintenance and growth. Similar results were reported by Brown et al., (1991) in which mean DMI values increased from day 84 to day 122 and day 112 to day 140. For the present study, performance values and derived parameter means are summarized in Table 1.The DMI for the Charolais bulls and heifers, respectively were 9.26 (1.37) kg and 7.81 (1.0) kg and for the Red Angus steers and heifers were 11.52 (1.19) kg and 11.21 (1.21) kg.

The partial correlation coefficients for the ADG measures were calculated separately for the two breeds. This was necessary due to the differences in the time-span used to calculate ADG_WW and that there was no ADG_Regress value calculated for the Charolais cattle. The partial correlation coefficient between ADG_Calc and ADG_WW for the Charolais cattle was r = 0.61 ($P < 0.0001$). The partial correlation coefficients amongst ADG_Regress, ADG_Calc and ADG_WW for the Red Angus cattle are shown in Table 2. The correlation amongst ADG_Regress and ADG_Calc was r = 0.92 ($P < 0.0001$). The strength of this association was expected given that the values were measured over the same duration. The correlation amongst ADG_Regress and ADG_WW was significant although not as strong r = 0.26 ($P = 0.0013$) given the long duration over which ADG_WW was measured on the Red Angus cattle. Much stronger relationships were reported by Brown et al., (1991) of 0.93 ($P < 0.001$) amongst ADG measured over 112 d and ADG measured over 140 d, respectively. Wang et al., (2006) reported Spearman rank correlations of 0.87 ($P < 0.01$) between ADG measured over 63 d when compared to ADG measured over 90 d. The decreased values seen in this population may be due to the experience that the calf had post weaning. The other aforementioned authors measured BW on cattle that had been weaned and therefore would be expected to show less variation. In the present study, the ADG_WW was measured from weaning to the last day of the post weaning gain test. This measurement incorporates more variation into the measurement attributable to the experiences that the calf has during and following weaning.

Averages for DMI were calculated on 10 day increments and compared to DMI. The partial correlation coefficients of the reduced measurements amongst DMI are shown in Table 3. The value that had the greatest correlation with DMI was 0-60 d DMI (r = 0.99, $P < 0.0001$) and the metric that had the lowest correlation was 0-10 d DMI (r = 0.85, $P < 0.0001$). The 0-30 DMI was strongly correlated to DMI (r = 0.95, $P < 0.0001$). For periods measuring feed intake greater than 30 d, the changes in the correlations of the averages were minimal. Wang et al., (2006) reported Spearman rank correlation of 0.93 ($P < 0.01$) between DMI measured over 35 d and DMI measured over 91d. Archer et. al.,(1997) reported a phenotypic correlation of 0.87 amongst feed intake measured over 35 d and feed intake measured over 119 d. This suggests that 30 to 35 days of daily feed intake measurement is the minimum needed to accurately estimate individual animal feed intake.

The DMI values estimated over the abbreviated time-spans were used to calculate RFI along with the ADG_Calc to identify the correlations amongst these values with the standard measurement of RFI. The partial correlation coefficients for the Red Angus cattle are shown in Table 4. The objective was to identify the relationship between RFI_Regress and RFI_Calc and then use the abbreviated period estimates of DMI along with the ADG_Calc to quantify the congruence of the derived values with those generated via the standard post-weaning RFI determination protocol. The correlation between RFI_Regress and RFI_Calc was r = 0.98 ($P < 0.001$). The models using DMI estimates over all of the abbreviated periods were all highly correlated. The correlation between RFI_Regress and RFI_Calc_30 was r = 0.89 ($P < 0.0001$), and when DMI was estimated over 40 d, the correlation improved to r = 0.93 ($P < 0.0001$). This suggests that it may be acceptable to measure ADG with two consecutive weights rather than the current standard recommendation of at least six weights for each animal taken over regularly spaced periods during a minimum of 70 d, as well as use 35 d to estimate DMI within that time-span. When this hypothesis is applied to a larger data set similar results are observed. The partial correlation coefficients of the RFI_Calc amongst the RFI_Calc calculated with DMI estimated over abbreviated periods are shown in Table 5. Overall correlations between these RFI estimates are high. When evaluation is focused on individual animals (i.e. bulls being evaluated as sires), the extraordinarily high day to day variability we observe in individual daily DMI, indicates that duplicate live weight measurements at the beginning and end of an RFI post-weaning test period are likely affected at some level by daily differences in individual gut-fill, and thus may affect individual RFI determination. This is supported by the results presented by Golden et al., (2008). However, the present analysis also indicates that when RFI is being determined for the purpose of, for example, a progeny test, the duplicate live weight measurements at the beginning and end of an RFI post-weaning test provides a useful alternative to the standard protocol.

Wang et al., (2006) suggested that 63 d was the minimum period needed to measure RFI due to the correlation of 0.90 between 63 d and 91 d measurement periods. This proposal would shorten the post weaning test by 7 d. However the duration of a post-weaning test is not limited by the measurement of feed intake, but rather by the time period needed to accurately estimate gain (Archer et. al. 1997). The analysis in the present study suggests that it is feasible to measure DMI on growing beef cattle for 35 to 40 d within the longer measurement period required to accurately estimate gain. If linearity of DMI and

ADG can be inferred and constant through careful management, it may be feasible to use such an approach to calculate accurate RFI values using the shorter DMI measurement period.

The measure ADG_WW was used in the RFI model and compared to the RFI_Regress calculation in the Red Angus cattle and the RFI_Calc calculation in the Charolais cattle. The partial correlation coefficient amongst RFI_Regress and RFI_WW in the Red Angus cattle was r = 0.96 ($P < 0.0001$). The partial correlation coefficients amongst RFI_Regress, RFI_WW and RFI_WW calculated with the reduced DMI measurements are shown in Table 6. The correlation between RFI_Regress and RFI_WW_30 was r = 0.86 ($P < 0.0001$), and the correlation between RFI_Regress and RFI_WW_40 was r = 0.89 ($P < 0.0001$). The correlation in the Charolais cattle between RFI_Calc and RFI_WW was r = 0.96 ($P < 0.0001$), very similar to the results found in the Red Angus cattle. The relationship between RFI_Calc and RFI_WW_30 was r = 0.86 ($P < 0.0001$), and similarly with RFI_WW_40 was: r = 0.90 ($P < 0.0001$). The complete sets of correlations are shown in Table 7. It should be noted that these repeatable, strong relationships amongst the RFI measurements are in part due to the relatively constant DMI between successive test periods. Thus, any adoption of an approach in which ADG is estimated over a greater time period than the estimate of DMI, will need to be conducted in a manner that ensures linearity of DMI over the entire test period.

Reducing the duration of time that animals need to be housed in pens equipped with feed intake measuring equipment has advantages (Wang et. al., 2006). Testing facilities would be able to measure more cattle and reduce data collection costs. Other costs associated with testing cattle such as feed and yardage at the facility would remain unchanged. Given the constraints and need for high accuracy in estimating DMI and ADG, ultimately the duration of the test is not likely to change since the measurement of ADG is the limiting factor and the measurement period needs to be at least 70 d. The need to maintain the animals' environment throughout the testing period, ensuring linearity of both DMI and ADG is paramount to accurately estimating RFI or other measures that require congruent collection of individual DMI and ADG. It is noteworthy that in the present study, accuracy was lost when calculating RFI with ADG_WW. The effects were minimal, but present.

Implications

There is opportunity to change the current paradigm in which DMI and ADG are determined for the calculation of RFI. The suggested strategies allow for a minimal amount of error entered into the calculation relative to the control, specifically when measuring ADG. These strategies would not be recommended for experiments identifying the differences amongst animals of different RFI classes. These strategies would however allow for testing of multiple progeny in estimating sire RFI with similar accuracy with a lower cost of the measurement, ultimately allowing the industry to test more animals for a similar cost.

LITERATURE CITED

Archer, J. A., P. F. Arthur, R. M. Herd, P. F. Parnell, and W. S. Pitchford. 1997. Optimum Postweaning test for measurement of growth rate, feed intake, and feed efficiency in British breed cattle. J. Anim. Sci. 75:2024–2032.

Archer, J. A., E. C. Richardson, R. M. Herd, and P. F. Arthur. 1999. Potential for selection to improve efficiency of feed use in beef cattle: A review. Aust. J. Agric. Res. 50:147–161.

Arthur, P. F., G. Renand, and D. Krauss. 2001. Genetic and phenotypic relationships among different measures of growth and feed efficiency in young Charolais bulls. Livest. Prod. Sci. 68: 131-139.

Brown, A. H., Jr., J. J. Chewning, Z. B. Johnson, W. C. Loe, and C. J. Brown. 1991. Effects of 84-, 112-, and 140-day Postweaning feedlot performance tests for beef bulls. J. Anim. Sci. 69:451–461.

Capper, J. L., The environmental impact of beef production in the United States: 1977 compared with 2007, J ANIM SCI December 2011 89:4249-4261; published ahead of print July 29, 2011, doi:10.2527/jas.2010-3784H.

Food Production Must Double by 2050 to meet demand from World's Growing Population, Innovative Strategies Needed to Combat Hunger, Experts Tell Second Committee, United Nations General Assembly, GA/EF/3242. Sixty Fourth General Assembly, Second Committee, Panel Discussion (AM), 10/9/2009

Franklin, C. L., W. V. Thayne, W. R. Wagner, L. P. Stevens, and E. K. Inskeep. 1987. Factors affecting gain of beef bulls consigned to a central test station. Bulletin 693, Agricultural and Forestry Experiment Station. West Virginia Univ., Morgantown.

Godfray, Charles J., Ian R. Crute, Lawrence Haddad, David Lawrence, James F. Muir, Nicholas Nisbett, Jules Pretty, Sherman Robinson, Camilla Toulmin and Rosalind Whiteley, The future of the global food system, Phil. Trans. R. Soc. B 27 September 2010 vol. 365 no. 1554 2769-2777.

Golden, J. W., Kerley, M. S., & Kolath, W. H. (2008). The relationship of feeding behavior to residual feed intake in crossbred Angus steers fed traditional and no-roughage diets. . J. Anim. Sci., 86(1), 180-186.

Kayser, W. and R. A. Hill. 2013. Relationship between feed intake, feeding behaviors, performance, and ultrasound carcass measurements in growing purebred Angus and Hereford bulls. J. Anim. Sci. 91:5492-5499

Kemp, R. A. 1990. Relationships among test length and absolute and relative growth rate in central bull tests. J. Anim. Sci. 68:624–629.

Koch, R. M., L. A. Swiger, D. Chambers, and K. E. Gregory. 1963. Efficiency of Feed Use in Beef Cattle. J. Anim. Sci. 22: 486-494.

Lui, M. F., and M. Makarechian. 1993a. Factors influencing growth performance of beef bulls in test station. J. Anim. Sci. 71:1123–1127.

Lui, M. F., and M. Makarechian. 1993b. Optimum test period and associations between standard 140-day test period and shorter test periods for growth rate in station tested beef bulls. J. Anim. Breed. Genet. 110:312–317.

Swiger, L. A., and L. N. Hazel. 1961. Optimum length of feeding period in selecting for gain of beef cattle. J. Anim. Sci. 20:189–194.

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

Welch, C. M., J. K. Ahola, J. B. Hall, G. K. Murdoch, D. H. Crews Jr., L. C. Davis, M. E. Doumit, W. J. Price, L. D. Keenan and R. A. Hill. 2012. Relationships among performance, residual feed intake, and product quality of progeny from Red Angus sires divergent for maintenance energy EPD. J. Anim. Sci. 90:5107-5117

LIST OF TABLES

Table 1. Performance values and derived parameter means by breed and gender

Breed		**Charolais**						**Red Angus**				
Gender		**Bull**			**Heifer**			**Heifer**			**Steer**	
Variable	**N**	**Mean**	**Std Dev**	**N**	**Mean**	**Std Dev**	**N**	**Mean**	**Std Dev**	**N**	**Mean**	**Std Dev**
Weaning Weight, kg	519	254	48.28	451	234.73	46.06	84	259.7	24.73	69	268.6	27.6
Start Weight, kg	519	355.4	51.47	451	303.17	42.02	84	312.1	30.17	69	338.2	28.84
Finish Weight, kg	519	473	57.88	451	389.31	44.35	84	425.1	41.91	69	462.5	38.03
Days on Study, d	519	73.43	3.11	451	78.54	8.89	84	86.19	0.99	69	85.9	1
Gain to Feed,	519	0.17	0.03	451	0.14	0.03	84	0.12	0.01	69	0.13	0.02
ADG_Regress, kg/d							84	1.35	0.23	69	1.48	0.23
ADG_Calc, kg/d	519	1.6	0.28	451	1.09	0.26	84	1.31	0.2	69	1.45	0.21
ADG_WW, kg/d	519	1.35	0.21	451	1.11	0.22	84	0.58	0.32	69	0.7	0.38
RFI_CALC, kg/d	519	0	0.64	451	0	0.66	84	0	0.66	69	0	0.77
RFI_WW, kg/d	519	0	0.64	451	0	0.66	84	0	0.65	69	0	0.76
DMI, kg/d	519	9.26	1.37	451	7.81	1.06	84	11.21	1.21	69	11.52	1.19
0-10 DMI, kg/d	519	8.18	1.34	451	7.05	1.32	84	10.72	1.35	69	10.59	1.02
0-20 DMI, kg/d	519	8.62	1.35	451	7.3	1.22	84	10.47	1.2	69	10.59	1.03
0-30 DMI, kg/d	519	8.91	1.41	451	7.4	1.18	84	10.86	1.22	69	10.92	1.14
0-40 DMI, kg/d	519	9.06	1.43	451	7.49	1.15	84	11.02	1.21	69	11.1	1.18
0-50 DMI, kg/d	519	9.16	1.43	451	7.56	1.14	84	11.11	1.21	69	11.21	1.19
0-60 DMI, kg/d	519	9.22	1.41	451	7.67	1.13	84	11.19	1.21	69	11.34	1.19

Table 2. Partial correlation coefficients of ADG measures for the Red Angus steers and heifers from the Error SSCP Matrix / *P* > |r|

	ADG_Regress		**ADG_Calc**		**ADG_WW**	
ADG_Regress		1				
ADG_Calc	<0.0001	0.92		1		
ADG_WW	0.0013	0.26	0.005	0.23		1

Table 3. Partial correlation coefficients of DMI measures from the Error SSCP Matrix / *P* > |r|

		DMI
DMI		1
0-10 DMI	<.0001	0.85
0-20 DMI	<.0001	0.91
0-30 DMI	<.0001	0.95
0-40 DMI	<.0001	0.97
0-50 DMI	<.0001	0.98
0-60 DMI	<.0001	0.99

Table 4. Partial correlation coefficients of various RFI calculations compared to RFI_Regress from the error SSCP matrix / *P* > |r|

	RFI_Regress		**RFI_CALC**		**RFI_WW**	
RFI_Regress		1				
RFI_CALC	<.0001	0.98		1		
RFI_WW	<.0001	0.96	<.0001	0.95		1
RFI Calc_10	<.0001	0.68	<.0001	0.65	<.0001	0.63
RFI Calc_20	<.0001	0.79	<.0001	0.76	<.0001	0.74
RFI Calc_30	<.0001	0.89	<.0001	0.86	<.0001	0.85
RFI Calc_40	<.0001	0.93	<.0001	0.9	<.0001	0.89
RFI Calc_50	<.0001	0.96	<.0001	0.94	<.0001	0.92
RFI Calc_60	<.0001	0.98	<.0001	0.96	<.0001	0.94

Table 5. Partial correlation coefficients of RFI_Calc compared to the RFI model calculated with DMI estimates from abbreviated measurement periods from the error SSCP matrix / *P* > |r|

	RFI_CALC	
RFI_CALC		1
RFI Calc_10	<.0001	0.73
RFI Calc_20	<.0001	0.83
RFI Calc_30	<.0001	0.89
RFI Calc_40	<.0001	0.93
RFI Calc_50	<.0001	0.96
RFI Calc_60	<.0001	0.98

Table 6. Partial correlation coefficients of RFI_Regress compared to the RFI_WW from the error SSCP matrix / *P* > |r|

	RFI_Regress		**RFI_WW**	
RFI_Regress		1		
RFI_WW	<.0001	0.96		1
RFI WW_10	<.0001	0.63	<.0001	0.62
RFI WW_20	<.0001	0.76	<.0001	0.75
RFI WW_30	<.0001	0.86	<.0001	0.87
RFI WW_40	<.0001	0.89	<.0001	0.92
RFI WW_50	<.0001	0.92	<.0001	0.95
RFI WW_60	<.0001	0.93	<.0001	0.97

Table 7. Partial correlation coefficients of RFI_Calc compared to the RFI model calculated using ADG_WW and the DMI estimates from abbreviated measurement periods from the error SSCP matrix / *P* > |r

	RFI_CALC		**RFI_WW**	
RFI_CALC		1	<.0001	0.96
RFI_WW	<.0001	0.96		1
RFI WW_10	<.0001	0.71	<.0001	0.7
RFI WW_20	<.0001	0.8	<.0001	0.81
RFI WW_30	<.0001	0.86	<.0001	0.88
RFI WW_40	<.0001	0.9	<.0001	0.93
RFI WW_50	<.0001	0.93	<.0001	0.96
RFI WW_60	<.0001	0.95	<.0001	0.98

Chapter 4

Conclusion and Future Directions

There is considerable economic benefit for the beef production system to improve feed efficiency. RFI is a measurement that is well suited to accomplish this task integrated within a selection index. The independence of RFI from other production traits would allow for selection of improved feed efficiency without unintentionally increasing mature size. RFI is shown to be moderately heritable, highly correlated with feed intake and independent of gain. There are no differences between low and high RFI animals with regards to the finished product (yield, grade, carcass wt.). Yet beef animals have the poorest feed efficiency relative to the other protein species most consumed in the United States (Poultry & Swine). For beef to remain competitive in the U.S. the animals must become more efficient. The lack of vertical integration within the beef industry makes accomplishing this task more challenging. The U.S. beef industry needs to measure feed intake on more animals that are destined for seed stock than it is currently. In order to increase producer adoption the test needs to be affordable. This can be accomplished by changing the current test so that gain is measured over a greater time span than feed intake. This would reduce the data costs associated with the test and allow central testing stations to run more cattle through the same facility. The correlations between RFI_Regress and RFI_WW in Chapter 3 are strong enough that the recommendation could be made to do this when testing progeny for sire evaluations. There needs to be more research investigating the effects of changing the animals' environments during a post-weaning gain test on individual animal performance. This paradigm could be applied to all classes of animals tested if there were no deleterious effects on the animals by moving them from a standard feed bunk pen into a pen equipped with feed intake monitoring equipment or vice versa. The addition of feeding behaviors traits to the base model improved the prediction of feed intake of animals tested. Inclusion of these measurements may provide improved tools toward genetic improvements in performance and efficiency. Incorporating feeding behaviors into the model will improve the r^2 of the models and account for up 35% of the variation not explained by ADG and MMWT. Furthermore the feeding behaviors measured by time spent at the feed bunk could be used as a proxy for feed intake of progeny to inform the accuracy of sire efficiency. This would allow the industry to perform progeny testing and sire evaluations at a fraction of the current cost. The ability to measure feeding behavior traits is a recent technological advance; the inclusion of feeding behaviors needs to be further studied. It is unknown whether these traits are heritable or repeatable also there is evidence that animal management plays a role on feeding behaviors so comparison across locations may be unattainable. The most cost effective solution for a proxy of feed intake could be measuring water consumption of the animals. The water intake measurement equipment currently available is untested and fraught with water delivery problems. When animals are in their thermo-neutral zone water intake is a function of animal size and dry matter consumption. With advances in the measurement equipment and research performed on the effects that breed, gender, and environment have on water intake it would certainly be feasible to measure water intake in lieu of feed intake. The conclusions made here should improve the protocol of how we test cattle, the accuracy of the measurement and solutions for more economical measurements in the future.

Appendix A:

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