Characteristics of Feed Efficiency and Use for Selection of Heifers and Cows

Phillip Lancaster[1]
Range Cattle Research and Education Center
Institute of Food and Agricultural Sciences
University of Florida

Introduction

A significant challenge facing the world today is the expected 34% increase in the human population by 2050, which will require 70% more food from existing natural and land resources (FAO, 2009). Thus, the efficiency of natural resource use must be improved to meet the food security goals for a growing population while protecting the environment (FAO, 2009). Due to their ability to utilize cellulose for production of meat, cattle can be used to produce human food from land that cannot be used to grow food crops. However, cattle have a low conversion rate of feed to meat. Therefore, considerable research has focused on nutrient use efficiency or feed efficiency in cattle.

Typically, feed conversion ratio (**FCR**; i.e., feed to gain) has been used as the measure of feed efficiency in beef cattle. However, more efficient animals can either have lower feed intake for the same gain or faster gain for the same feed intake indicating that selection pressure may not be consistently placed on either feed intake or rate of gain making genetic improvement difficult. Feed conversion ratio is strongly negatively correlated with growth rate such that selection for faster growth rate will improve FCR (Bailey et al., 1971; Irgang et al., 1985; Mrode et al., 1990). However, other studies (Thompson et al., 1985; Aaron et al., 1986; Herd et al., 1991) reported no improvement in FCR between genetic lines selected for fast or slow growth rate. Thus, selection for faster growth rates may not improve feed efficiency, but will significantly increase mature weight (Herd et al., 1991; Archer et al., 1997; Herd et al., 1997), thereby increasing feed required to maintain the cow herd. Given that the cow herd accounts for 65% of feed required to produce a pound of beef, selection for improved feed efficiency based on FCR or growth rate may be detrimental to feed efficiency of beef production.

Recently, considerable research has focused on evaluating residual feed intake (**RFI**), also referred to as net feed intake or net feed efficiency, as a trait for use in selection programs. Koch et al. (1963) suggested RFI as an alternative trait to FCR that is independent of growth rate and mature weight, and will not result in greater maintenance requirements of the cow herd. Residual feed intake is calculated as actual feed intake minus expected feed intake based on growth rate and body weight; animals that consume less than expected have low RFI and are more efficient. The use of RFI

[1] Contact at: Range Cattle Research and Education Center, University of Florida, Ona, FL, Email: palancaster@ufl.edu

to measure feed efficiency identifies animals that consume less feed for the same growth rate and body weight, putting selection pressure directly on feed intake. Therefore, consistent genetic improvement in feed efficiency can be made using RFI.

Relationships of RFI with production traits

Average correlation coefficients of RFI with other production traits from several published studies (Arthur et al., 1997; Herd and Bishop, 2000; Arthur et al., 2001a; Arthur et al., 2001b; Basarab et al., 2003; Nkrumah et al., 2004; Brown, 2005; Nkrumah et al., 2007; Lancaster et al., 2009a; Lancaster et al., 2009b) are presented in Table 1. As expected, RFI is not correlated (phenotypically independent) with body weight and average daily gain indicating selection for improved RFI (low RFI) will not result in increased mature weight. However, RFI is positively correlated with feed intake and FCR indicating that animals with low RFI consume less feed and are more efficient based on FCR. Thus, selection for lower RFI will improve feed efficiency by reducing feed intake for the same growth rate and body weight.

The impact of selection for low RFI on carcass merit has been studied extensively. From the published studies mentioned above, RFI was not correlated with ribeye area, but was positively correlated with rib fat thickness in all studies. Additionally, RFI is positively correlated with marbling score or ultrasound intramuscular fat in some studies but not others. The correlations of RFI with rib fat thickness and marbling score are very weak relationships indicating that the correlated response in rib fat thickness and marbling score to selection for low RFI is expected to be small. However, Herd et al. (2003) and Arthur et al. (2005) reported less rib fat thickness in finished steers and mature cows, respectively, from a low RFI selection line compared with a high RFI selection line. McDonagh et al. (2001) and Baker et al. (2006) reported no difference in Warner-Bratzler shear force values between low and high RFI steers, but Baker et al. (2006) found lower sensory panel scores for juiciness and off-flavor in low RFI steers. Residual feed intake can be calculated to be independent of carcass fat by including measurement of 12^{th}-rib fat thickness in the regression model to calculate expected feed intake (Basarab et al., 2003; Lancaster et al., 2009a; Lancaster et al., 2009b). Given these relationships, RFI should be computed using ultrasound estimates of 12^{th}-rib fat thickness to reduce any correlated responses in carcass fat, but no studies have evaluated the impact on beef sensory characteristics.

Relationships of RFI with Reproductive Performance

Body condition score or body fat is known to impact reproductive performance and pregnancy rates in beef cows; cows of low body condition with less body fat have lower pregnancy rates and longer postpartum interval. Given this relationship, selecting cattle with low RFI and the correlated decrease in body fat could negatively impact reproductive performance in heifers and mature beef cows. Although, previous studies (Lancaster, 2008; Basarab et al., 2011; Shaffer et al., 2011) have reported no difference in age at puberty between low and high RFI heifers, even though differences in body fatness were evident. Lancaster (2008) reported no difference in pregnancy, calving or weaning rate, but Basarab et al. (2011) found that low RFI heifers had lower pregnancy and calving rates. However, when RFI was adjusted for rib fat thickness the difference in calving rate between low and high RFI heifers was eliminated (75.5 vs. 81.5%; P = 0.31), but when the rib fat adjusted RFI was used, low RFI heifers were older and heavier at puberty than high RFI heifers indicating that including rib fat thickness in the calculation of RFI may negatively impact attainment of puberty in heifers (Basarab et al., 2011).

Only 2 studies have evaluated reproductive performance in mature cows (Table 3). Arthur et al. (2005) found no difference in pregnancy, calving, or weaning rate between cows from the low and high RFI selection lines. These authors did report a tendency for cows from the low RFI selection line to calve 5 days later in the year indicating that these cows were bred later in the breeding season compared with cows from the high RFI selection line. There was no difference in milk yield or pounds of calf weaned per cow exposed between cows from the low and high RFI selection lines (Arthur et al., 2005). Basarab et al. (2007) evaluated the effect of RFI on cow productivity retrospectively by evaluating performance of dams of steers with low and high RFI; RFI was not measured on the cow. These authors also found no difference in pregnancy, calving, or weaning rate between dams based on RFI of their steer calves. Similar to Arthur et al. (2005), Basarab et al. (2007) found that dams of steers with low RFI calved 4 days later in the year than dams of steers with high RFI, but these authors found no difference in calving interval indicating that the dams of steers with low RFI were bred later in the breeding season as heifers and continually bred later in the breeding season in subsequent years. There was no difference in pound of calf weaned per pound of cow body weight between dams of steers with low and high RFI (Basarab et al., 2007). Additionally, Crowley et al. (2011) found a negative genetic correlation (-0.29) between RFI and age at first calving again indicating selection for improved RFI may result in heifers that conceive later in the breeding season. Collectively, these results suggest that selection for more efficient cattle using RFI may negatively impact age at puberty and pregnancy rates of heifers, but have little impact on reproductive performance and productivity of mature cows.

Relationships of RFI Measured as Growing and Mature Cattle

Selection for improved RFI typically occurs in young growing bulls measured shortly after weaning in performance test stations utilizing high energy diets. However, mature cows consume a low energy diet and produce milk rather than deposit nutrients into tissue. This raises a significant question: “Will selection of young growing bulls with superior RFI fed high energy diets translate to improved feed efficiency in mature cows consuming low energy diets?”

Several studies have evaluated the relationship between RFI measured in growing and finishing phases in cattle fed a moderate energy growing diet followed by a high energy finishing diet. Crews et al. (2003) and Durunna et al. (2011b) reported genetic correlations of 0.55 and 0.50, respectively, between RFI measured in the same steers fed a growing diet then a finishing diet. Brown (2005) reported a phenotypic correlation of 0.47 between the same steers fed a growing versus finishing diet. These data suggest that either diet or stage of maturity impacts feed efficiency.

Arthur et al. (2001b) found a strong genetic correlation (0.75) between RFI measured in weanling bulls and again as yearling bulls fed the same diet. Archer et al. (2002) reported a strong genetic correlation of 0.98 between RFI measured in growing heifers and again as non-pregnant, non-lactating 3 yr-old cows fed the same diet. Durunna et al. (2011a) found that the Spearman rank correlation between RFI measured in steers fed a growing diet then a finishing diet was 0.33 compared with 0.44 and 0.42 between RFI measured in steers fed either the growing or finishing diet, respectively, for the entire study. These studies indicate that both stage of maturity and diet impact ranking of cattle for RFI suggesting that selection for improved RFI in young growing bulls fed high energy diets may not translate to improved efficiency in mature cows fed low energy diets.

To further evaluate the relationship between RFI in young growing cattle compared with mature cattle, several studies have compared RFI in growing heifers and again as mature cows. Nieuwhof et al. (1992) reported a genetic correlation of 0.58 between RFI measured in growing heifers and again in lactating first-calf heifers fed similar diets, but the phenotypic correlation was not different from zero (0.07; Table 4). Similarly, Archer et al. (2002) reported a very strong genetic correlation (0.98) between RFI measured in growing heifers and again as 3-yr-old non-pregnant, non-lactating cows fed the same diet, but the phenotypic correlation of 0.40 was much lower. These results suggest that RFI measured at different stages of maturity is genetically the same trait, but that expression of that genetic potential may be altered.

Other studies have determined the phenotypic relationship between RFI in growing heifers and mature cows. Arthur et al. (1999) and Herd et al. (2006) found phenotypic correlations of 0.36 and 0.39 between RFI measured in growing heifers and again as 3-yr-old non-pregnant, non-lactating cows fed the same diet (Table 4). Hafla et al. (2013) reported a similar correlation (0.42) between RFI measured in growing heifers and again as pregnant, non-lactating first or second calf heifers fed a different diet. Adcock et al. (2011) found a slightly lower correlation (0.30) when cows were non-pregnant, but lactating and fed the same diet. However, Black et al. (2013) reported no significant relationship (0.13) between RFI measured in growing heifers and again as 3-yr-old non-pregnant, lactating cows fed a different diet. Collectively, these results suggest that different physiological state (growing versus pregnant or lactating) and diet can combine to drastically reduce the relationship with feed efficiency of growing cattle, which indicates that selection for improved RFI in young growing bulls fed high energy diets will most likely result in minimal improvement in feed efficiency of mature lactating cows.

Energy Efficiency Index: A Trait to Measure Feed Efficiency of Mature Cows

As outlined above, selection of cattle with superior RFI measured as growing cattle is not likely to significantly improve feed efficiency of the mature cow. Thus, RFI may be better suited to selection of cattle for improved feed efficiency in the feedlot rather than the breeding herd.

Efficiency of the mature cow is complex. Feed has to be used for lactation and conceptus growth, as well as body fat and muscle reserves. The cow must have the ability to use nutrients from feed and body reserves to produce milk early in lactation, then shift nutrients toward conceptus growth and rebuilding body reserves later in the production cycle. Thus, the efficient cow must have the genetic ability to efficiently produce milk in the mammary gland, transport nutrients across the placenta, and synthesize/breakdown lipids and protein in fat and muscle. Moreover, she must do all this with the feed resources available. Ferrell and Jenkins (1985) indicated that the most efficient cows in one environment are not necessarily the most efficient cows in another environment. For example, a cow with genetic ability to efficiently produce milk when high quality forage is available will struggle to maintain body condition and rebreed when only low quality forage is available. This stresses the importance of measuring efficiency of the cow in the conditions in which she will have to perform (i.e., on the ranch).

Recently, Tedeschi et al. (2006) developed a model to calculate an energy efficiency index (**EEI**) for beef cows on the ranch based on body condition score and body weight of cows, weaning weight of calves, and forage nutritive value. The amount of metabolizable energy required per pound of weaned calf, EEI, can be calculated for each cow in the herd. The use of EEI to evaluate efficiency of mature cows has some advantages compared with RFI. First, this calculation does not require measurement of feed intake making it less difficult to evaluate efficiency of mature beef cows and allowing evaluation on the ranch. Additionally, the calculation is based on energy metabolism of the mature cow taking into account lactation, conceptus growth, and body reserves rather than that of growing animals as with RFI. However, one potential disadvantage is that estimating the metabolizable energy required rather than actually measuring feed intake may lead to erroneous classification of efficient and inefficient cows.

Currently, there is little data evaluating EEI. Bourg (2011) found that EEI was negatively correlated with milk expected progeny difference (**EPD**) of cows indicating that the most efficient cows produced more milk. However, EEI was not correlated with weaning weight EPD, average daily gain EPD, hot carcass weight EPD, ribeye area EPD, marbling EDP, or residual feed intake EPD. These results suggests that more efficient cows could be selected based on EEI without correlated responses in growth, body weight, or carcass merit of offspring. Energy efficiency index was not related to RFI EPD, which suggests that these traits are not measuring the same biological processes and supports the idea that RFI measured in growing animals does not translate to improved energy metabolism and efficiency of mature beef cows.

Conclusions

Residual feed intake is a measure of feed efficiency that is independent of growth rate and mature body weight indicating that selection for improved residual feed intake would not negatively impact mature cow size and maintenance requirements of the cow herd. Limited research indicates that selection for improved residual feed intake would have minimal impact on cow productivity. However, residual feed intake is weakly correlated with body fat content such that more efficient cattle are leaner. Additionally, more efficient heifers as measured by residual feed intake may achieve puberty at older age and conceive later in the breeding season as heifers, which may be related to differences in body fat content. Additional research is needed on the relationship of residual feed intake with female reproductive performance.

Several studies have reported a weak relationship between residual feed intake measured in growing cattle and again as mature cows. This suggests that even though selection for residual feed intake will not impact cow productivity, it likely will not result in much improvement in feed efficiency of the mature cow either. This is most likely due to the differences in energy metabolism between growing cattle and mature lactating cows. Energy efficiency index is based on energy metabolism of mature beef cows and allows evaluation of the beef cow in her production environment. Very little data is available evaluating energy efficiency index in beef cows, but energy efficiency index shows potential as a trait to identify efficient beef cows.

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Table 1. Average correlations of residual feed intake with production traits in growing beef cattle from published studies.[1]

Trait	r_p[2]	No. of studies[3]
Body weight	0.00	0 of 10
Average daily gain	-0.01	0 of 10
Feed intake	0.65	9 of 9
Feed conversion ratio	0.55	9 of 9
Ribeye area	0.00	0 of 10
12th-rib fat thickness	0.21	7 of 8
Marbling score or IMF%	0.12	2 of 6

[1] Arthur et al., 1997; Herd and Bishop, 2000; Arthur et al., 2001a; Arthur et al., 2001b; Basarab et al., 2003; Nkrumah et al., 2004; Brown, 2005; Nkrumah et al., 2007; Lancaster et al., 2009a; Lancaster et al., 2009b.
[2] r_p = phenotypic correlation coefficient.
[3] Number of studies where correlation coefficient is different from zero ($P < 0.05$).

Table 2. Reproductive performance of beef heifers with low and high residual feed intake.

	Lancaster, 2008		Shaffer et al., 2011		Basarab et al., 2011	
Trait	Low RFI	High RFI	Low RFI	High RFI	Low RFI	High RFI
Age at puberty, d	279	271	425	411	353	347
Pregnancy rate, %	89	79	62	66	77[a]	86[b]
Calving rate, %	81	78			73[a]	84[b]

[ab] Means within a row and study with different superscripts differ ($P < 0.10$).

Table 3. Reproductive performance and productivity of mature beef cows with low and high residual feed intake.

	Arthur et al., 2005		Basarab et al., 2007	
Trait	Low RFI	High RFI	Low RFI	High RFI
Pregnancy rate, %	90.5	90.2	95.6	96.0
Calving rate, %	89.2	88.3	84.9	86.3
Weaning rate, %	81.5	80.2	81.5	82.3
Calving date, Julian day	215[a]	210[b]	92[a]	88[b]

[ab] Means within a row and study with different superscripts differ ($P < 0.10$).

Table 4. Relationships of residual feed intake measured in growing and mature cattle.

Study	Cattle Description: Age 1	Cattle Description: Age 2	r_p[1]
Nieuwhof et al., 1992	Growing dairy heifer	Non-pregnant, lactating 1st-calf heifer fed similar diet	0.07
Arthur et al., 1999	Growing heifer	Non-pregnant, non-lactating cow fed same diet	0.36*
Archer et al., 2002	Growing heifer	Non-pregnant, non-lactating cow fed same diet	0.40*
Herd et al., 2006	Growing heifer	Non-pregnant, non-lactating cow fed same diet	0.39*
Adcock et al., 2011	Growing heifer	Non-pregnant, lactating cow fed same diet	0.30*
Black et al., 2013	Growing heifer	Non-pregnant, lactating cow fed different diet	0.13
Hafla et al., 2013	Growing heifer	Pregnant, non-lactating 1st or 2nd-calf heifer fed different diet	0.42*

[1] r_p = phenotypic correlation coefficient.
* Correlation coefficient is different from zero ($P < 0.05$).

SESSION NOTES