Genetic improvement of feed efficiency

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Improvement of the economic position of the farm or ranch is an ongoing process for many commercial cow-calf producers. Profitability may be enhanced by increasing the volume of production (i.e. the pounds of calves you market) and/or the value of products you sell (improving quality). The reduction of production costs, and thus breakeven prices, can also improve profitability. For commercial beef producers, the implementation of technologies and breeding systems that increase the quality and volume of production and/or reduce input costs is essential to maintain or improve the competitive position of the operation. Profitability is influenced by these factors concurrently. Efficiency is the proportion of outputs to inputs and is frequently used by beef producers. There are many different 'efficiencies' that affect beef production, especially at the cow-calf level. Some of these efficiencies are observed at the individual animal level and some observed at the system or herd level. The various efficiencies can be categorized into with measures of biological or economic efficiency. Improvement in individual animal efficiency, especially during the post-weaning growing or finishing phases, may or may-not improve efficiency at the herd or system level, and may have undesirable correlated response in traits of cows.

So, why is improvement in feed efficiency important and why does the beef industry focus on it? During the growing and finishing phase of production, a 1% improvement in feed efficiency has the same economic impact as a 3% increase in rate of gain. The traits that beef producers routinely record are outputs which determine the value of product sold and not the inputs defining the cost of beef production. The inability to routinely measure feed intake and feed efficiency on large numbers of cattle has precluded the efficient application of selection despite moderate heritabilities ($h^2 = 0.08\text{-}0.46$). Feed accounts for approximately 65% of total beef production costs and 60% of the total cost of calf and yearling finishing systems. The cow-calf segment consumes about 70% of the calories; 30% are used by growing and finishing systems. Of the calories consumed in the cow-calf segment, more than half are used for maintenance.

Table 1 shows the potential cost savings to the US beef cattle industry that could occur with selection for feed intake, feed efficiency, growth, and carcass traits. Calves and yearlings selected for residual feed intake (RFI) have the same average daily gain (ADG) but eat less feed thus saving feedlot operators money. Assuming 27 million cattle are fed per year and that 34% of cattle in the feedlot are calves and 66% are yearlings, the beef industry could save over a billion dollars annually by reducing daily feed intake by just 2 lb. per animal.

Table 1. Estimated cost savings to the US beef cattle industry from selection for a 2 lb. reduction in residual feed intake.

In Wt.	**Out Wt.**	**Lb. Gain**	**ADG**	**Days on Feed**	**RFI**	**Reduced Feed Intake**	**Feed Cost Savings**	**% of Fed Mix**	**Feed Cost Savings**
					Calf Feds				
600	1,250	650	3.5	186	0.0	0			
600	1,250	650	3.5	186	-2.0	-371	$ (54.72)	0.34	$ (502,620,656)
					Yearling Feds				
775	1,300	525	4.0	131	0.0	0			
775	1,300	525	4.0	131	-2.0	-263	$ (38.67)	0.66	$ (689,539,820)
							Total Savings:		**$(1,192,160,476)**

Annual fed slaughter: 27 million head; Delivered feed cost: $294.62 as fed

Weaber, 2011

Different measures of efficiency

There are a variety of measures of efficiency discussed and utilized in beef production. Some may or may-not be important to cow-calf producers. For improvements in 'efficiency' to positively impact profitability of a cow-calf producer, the efficiency improvement must be realized prior to the marketing endpoint of progeny. While that may seem rather obvious, members of a production sector in the beef industry often get caught up in selection for outcomes for which they have no or limited opportunity to capture the value of the genetic gain. Often that selection pressure is at the cost of selection for traits that are economically relevant to the enterprise's market endpoint. In the following sections a variety of 'efficiency' measures are discussed including their applicability and limitations for improvement in efficiency of the cow herd. These measures or their component traits have been shown to be heritable, so selection for improvement is possible but anticipated to be slow, requiring a decade or more to move the population a meaningful distance. A number of the measures, especially measures of biological or economic efficiency are also favorably impacted, typically, by the improvements in lowly heritable traits like longevity and fertility due to heterosis generated in structured crossbreeding systems. System efficiency improvements due to crossbreeding can be realized in three to five years depending on replacement rate in the herd.

Feed efficiency or feed conversion ratio

Many cow-calf producers and, certainly cattle feeders, are familiar with the term *feed efficiency* (FE) or its reciprocal, *feed conversion ratio* (FCR). Both of these measures are indicative of differences in the efficiency of feed utilization and are most commonly associated with animals during the growing or finishing phases. They represent a gross efficiency measure of the conversion of feed to gain. Both measures are suitable for managerial use during feeding but are poor selection tools. Their utility is limited in selection due to two issues. First, the measures are ratios of inputs and outputs, so improvement in the ratio can be achieved by changing the numerator, the denominator or both. Therefore breeders don't have control over which parameter in the ratio changes due to selection. In practice the parameter improved in selection tends to be the one with the largest genetic variance. Selection tools like an index that consider each input and output separately are more effective. Second, FCR or FE is strongly related to ADG and composition of gain. Leaner biological types and larger, faster growing animals tend to have better FE and FCR. Selection based on FE or FCR results in larger, later maturing and leaner cows. This type of cow tends to have higher maintenance energy requirements.

Residual feed intake

Recently, RFI has been reintroduced as an efficiency measure for beef production. Residual feed intake was first proposed by Koch et al in 1963, so RFI is not a new idea. It is a residual computed by deviating actual average daily feed intake (AFI) from the predicted daily dry-matter intake. Predicted daily dry-matter intake is computed from a multiple regression model by regressing AFI on ADG and body weight (BW) scaled to the ¾ power (est. of metabolic weight). By regression, RFI is independent (i.e. zero correlation) from differences in ADG and BW. Recall the problems with FCR and FE centered around their undesirable association with other growth parameters. When RFI is computed on the phenotypic scale independence is assured for predictor variables. However, this does not assure genetic independence. In fact research shows underlying genetic correlations between RFI with FI, ADG and BW as well as measures of composition. Computing RFI on the genetic scale as an index of EPDs assures a selection tool with fewer antagonisms. That said, RFI is not a perfect tool. The data used to compute it are quite expensive to gather as it requires individual feed intake monitoring systems. Additionally, RFI can and does identify efficient animals that also have slow growth and low feed intake making these candidates undesirable for selection and use in the commercial beef industry. So, RFI must be used with other measures like ADG to assure that industry acceptable animals are selected. Some research suggests that selection for RFI produces slightly larger and leaner cows over time and cows that have older ages at first calving. In general, selection for favorable (negative) RFI results in animals with equivalent performance, but achieves that output with less feed consumed.

Residual average daily gain

A concept closely related to RFI is residual average daily gain (RADG) which was proposed at the same time as RFI as a potential tool for selection for improved feed efficiency. It is the residual from regression of ADG on AFI and BW raise to the ¾ power (metabolic body weight). Selection for RADG seeks to find animals that consumed equivalent AFI but resulted in better performance. RADG, like RFI, is a transformation of the data and can be computed on either the phenotypic or genetic scales. Differences in ADG are controlled for differences in AFI and BW. Like RFI it is typically computed on growing animals and is indicative of difference in efficiency of feed utilization for growth. It may have limited utility for prediction of differences in maintenance efficiency of cows. Residual average daily gain should not be used alone in selection for feed efficiency. Data reveal that some animals with favorable RADG have sub-par feed intake and consequently undesirable ADG. Feed intake and growth, not surprisingly, have a strong positive genetic association. Input drives output. One additional challenge with RADG, and RFI for that matter, is that these measures are computed on growing animals. In the case of cows, growth is not desired endpoint, reproduction, maintenance and lactation are the principle energy sinks.

Average daily feed intake

Also known as AFI. Average daily feed intake is a gross measure of nutrient input. While it cannot be used alone as a predictor of feed efficiency, it provides a useful data input for computation of selection index. Feed intake represents an economically relevant measure of cost that can be associated with a variety of output or endpoint measures. Average daily feed intake could be measured on animals during different phases of production and used to capture input:output (efficiency) information. A selection index for AFI or an AFI expected progeny difference (EPD) can be reliably produced analyzing performance records for a variety of growth traits. An AFI EPD produced without actual feed records but based on genetic associations between growth and intake can account for nearly 75% of the variation in observed feed intake.

Weaning weight per cow exposed

This is a gross measure of biological efficiency and relates the importance of reproductive success, longevity, calf survival and other factors on system output. Improvements in maintenance efficiency of cows (or a reduction in maintenance or production requirement under stressful environments) would likely improve this efficiency metric. Clearly, both production potential (growth and lactation) and heterosis from crossbreeding can substantially affect this measure.

Weaning weight per cow exposed per unit of energy consumed

Another measure of biological efficiency that includes accounting of nutrients consumed for both production and maintenance of cow and calf. This metric should point to best combination of genetic merit for economically relevant traits to a weaning market endpoint including calving ease, growth, lactation, and mature cow weight among other. Researchers (Ferrell and Jenkins, 1994) have conducted a number of studies to evaluate different sire breeds for biological efficiency under low, average and high nutrient availability. In this experiment, they found little difference in efficiency across biological type (growth, lactation and leanness) at moderate nutrient availability. Under low nutrient availability, smaller breeds with lower lactation potential were more efficient. At high nutrient availability, large, high milk breeds were more efficient. The primary difference was the impact of nutrient availability on fertility for a given biological type.

Value ($) output per $100 of total input

This is a measure of economic efficiency and the results are highly dependent upon selection of appropriate endpoint. Nielsen and colleagues (1993) demonstrated the differences in economic efficiency for three different levels of milk production from cows of three different breed crosses but of similar body size. The weaning endpoint favored the low and medium lactation groups over the high milk group. If progeny were sold as finished calves the group ranks were the same, but the range between them widened. Kress and others (1988) demonstrated the importance of longevity to both biological and economic efficiency.

Selecting to improve efficiency

Role of growth and lactation potential on ME efficiency and ME requirements

Mature cow weight and lactation potential play a key role in determining annual nutrient requirements for cows. Increasing average cow mature weights from 1,000 lb to 1,400 lb, approximately the change we have observed over the last 30 years, increases nutrient requirements by 27%. Increasing lactation potential from 10 lb. to 30 lb. per day at peak results in a 16% increase in nutrient requirements. These increases in potential have the opportunity to be associated with increases in output, but they also have the potential to undermine a cow's fitness in a given production environment. Increases in mature weight and lactation drive up maintenance requirements. Optimization of growth and lactation genetics, and ultimately profitability, requires understanding the marginal revenues and marginal costs associated with these attributes.

The associated change in maintenance requirement due to mature weight change is distinctly different from the change increased weight has on maintenance energy or metabolic efficiency. Metabolic rate does not scale linearly with mass or weight. Instead, it increases exponentially by the ¾ power. Thus, warm blooded animals with larger mass are more metabolically efficient than ones of small mass. The principal reason for these phenomena is relationship between surface area of the animal and it's mass. Large animals have less surface area per unit mass enabling them to conserve heat more effectively. So, large cows are more efficient users of maintenance energy but have higher requirements.

The key then is finding cows with appropriate levels of mature weight and lactation potential (or biological type) for your production environment. Note that managerial (i.e., reducing supplemental feedstuffs) or environmental (i.e. drought) changes that alter nutrient availability may substantially change the fitness of your existing cows. Care should be taken in sire selection for production of replacement females such that their growth, mature weight and lactation potential are appropriate.

Current tools

At present several selection tools are available for selection to improve feed efficiency in beef cattle. These include the RADG EPD published by the American Angus Association. The EPD leverages a variety of molecular and phenotypic data to produce a genetic prediction describing differences in expected post-weaning gain given some level of intake. More positive values are indicative of higher levels of efficiency. A number of other breeds, including Simmental, Gelbvieh, Hereford and Limousin have active breeding programs and data collection efforts to gather individual feed intake records with goals of producing genetic predictors for efficiency of gain. A large USDA-funded integrated research and extension project is focused on the genetic improvement of feed efficiency in beef cattle and will leverage a variety of methods to achieve this goal.

The American Angus Association and the Red Angus Association of America both produce selection indexes that describe differences in maintenance energy requirements. These tools rely on the genetic associations between maintenance energy required with mature size and milk genetic predictors. As before, animals with higher potentials for these traits generally have higher maintenance energy requirements.

Unfortunately, little work has been done to address the additive genetic improvement of maintenance efficiency in beef cattle. Researchers know differences exist across breeds and individuals but accumulation of a substantial number of records has been elusive. Clearly this parameter would benefit from the development of genomic selection tools to enable genetic improvement.

Value of heterosis in improving biological efficiency

One of the only, yet very effective ways, to improve biological efficiency of beef cattle production systems is through the use of planned crossbreeding systems to leverage heterosis, especially maternal heterosis, and breed complementarity.

Heterosis refers to the superiority of the crossbred animal relative to the average of its straight bred parents. Heterosis results from the increase in the heterozygosity of a crossbred animal's genetic makeup. Heterozygosity refers to a state where an animal has two different forms of a gene. It is believed that heterosis is the result of gene dominance and the recovery from accumulated inbreeding depression of pure breeds. Heterosis is, therefore, dependent on an animal having two different copies of a gene. The level of heterozygosity an animal has depends on the random inheritance of copies of genes from its parents. In general, animals which are crosses of unrelated breeds, such as Angus and Brahman, exhibit higher levels of heterosis, due to more heterozygosity, than do crosses of more genetically similar breeds such as a cross of Angus and Hereford.

Heterosis generates the largest improvement in lowly heritable traits. Moderate improvements due to heterosis are seen in moderately heritable traits. Little or no heterosis is observed in highly heritable traits. Heritability is the proportion of the observable variation in a trait between animals that is due to the genetics that are passed between generations and the variation observed in the animal's phenotypes, which are the result of genetic and environmental effects. Traits such as reproduction and longevity have low heritability. These traits respond very slowly to selection since a large portion of the variation observed in them is due to environmental factors and a small percentage is due to genetic differences. Heterosis generated through crossbreeding can significantly improve an animal's performance for lowly heritable traits. Crossbreeding has been shown to be an efficient method to improve reproductive efficiency and productivity in beef cattle.

Improvements in cow-calf production due to heterosis are attributable to having both a crossbred cow and a crossbred calf. The two tables below detail the individual (crossbred calf) and maternal (crossbred cow) heterosis observed for various important production traits. These heterosis estimates are adapted from a report by Cundiff and Gregory, 1999, and summarize crossbreeding experiments conducted in the South-eastern and Mid-west areas of the US.

The heterosis generated in calves that are the progeny of straight bred parents of different breeds or crossbred parents is called individual heterosis. While this type of heterosis has import effects on economically important traits, it only accounts for approximately one-third of the total economic benefits of having crossbred cows and calves. Thus if you only have crossbred calves (i.e. straight bred cows) you're missing the biggest share of economic benefit from crossbreeding. Individual heterosis improves performance in a number of traits measured on calves including survival and growth (Table 2.). For example, individual heterosis can improve weaning weights by nearly 4% which on a 500 lb. weaned calf is 20 lbs.

Table 2. Effects of individual heterosis on performance of crossbred calves

Trait	Units	% Heterosis
Calving Rate, %	3.2	4.4
Survival to Weaning, %	1.4	1.9
Birth Weight, lb.	1.7	2.4
Weaning Weight, lb.	16.3	3.9
Yearling Weight, lb.	29.1	3.8
Average Daily Gain, lb./d	0.08	2.6

Why is it so important to have crossbred cows?

The production of crossbred calves yields advantages in both heterosis and the blending of desirable traits from two or more breeds. However, the largest economic benefit of crossbreeding to commercial producers comes from having crossbred cows. Maternal heterosis improves both the environment a cow provides for her calf as well as improves the longevity and durability of the cow. The improvement of the maternal environment a cow provides for her calf is manifested in the improvements in calf survivability to weaning and increased weaning weight. Crossbred cows exhibit improvements in calving rate of nearly 4% and an increase in longevity of more than one year due to heterotic effects (Table 3). Heterosis results in increases in lifetime productivity of approximately one calf and 600 pounds of calf weaning weight over the lifetime of the cow (Table 2). Crossbreeding can have positive effects on a ranch's bottom line by not only increasing the quality and gross pay weight of calves produced but also by increasing the durability and productivity of the cow factory. Crossbred cows may be the only free lunch in the world.

The effects of maternal heterosis on the economic measures of cow-calf production have been shown to be very positive. The added value of maternal heterosis ranges from approximately \$50/cow/year to nearly \$100/cow/year depending on the amount of maternal heterosis retained in the cowherd (Ritchie, 1998). Maternal heterosis accounted for an increase in net profit per cow of nearly \$75/cow/year (Davis et al., 1994). Their results suggested that the benefits of maternal heterosis on profit were primarily the reduced cost per cow exposed. Crossbred cows had higher reproductive rates, longer productive lives, and required fewer replacements than straight bred cows in their study. All of these factors contribute to reduced cost per cow exposed. Further, they found increased outputs, including growth and milk yield, were offset by increased costs.

Table 3. Effects of maternal heterosis on calf traits affected by maternal environment, cow productivity and longevity.

Trait	Units	% Heterosis
Calving Rate, %	3.5	3.7
Survival to Weaning, %	0.8	1.5
Birth Weight, lb.	1.6	1.8
Weaning Weight, lb.	18.0	3.9
Longevity, years	1.36	16.2
Lifetime Productivity		
Number of Calves	0.97	17.0
Cumulative Weaning Wt., lb.	600	25.3

How can I harness the power of breed complementarity?

Breed complementarity is the effect of combining breeds that have different strengths. When considering crossbreeding from the standpoint of producing replacement females, one could select breeds that have complementary maternal traits such that females are most ideally matched to their production environment. Matings to produce calves for market should focus on complementing the traits of the cows and fine tuning calf performance (growth and carcass traits) to the market place.

There is an abundance of research that describes the core competencies (biological type) of many of today's commonly used beef breeds. Traits are typically combined into groupings such as maternal/reproduction, growth and carcass. When selecting animals for a crossbreeding system, their breed should be your first consideration. What breeds you select for inclusion in your mating program will be dependent on a number of factors including the current breed composition of your cow herd, your forage and production environment, your replacement female development system, and your calf marketing endpoint. All of these factors help determine the relative importance of traits for each production phase.

What are the keys to successful crossbreeding programs?

Many of the challenges that have been associated with crossbreeding systems in the past are the result of undisciplined implementation of the system. With that in mind, one should be cautious to select a mating system that matches the amount of labor and expertise available to appropriately implement the system. Crossbreeding systems range in complexity from very simple programs such as the use of hybrid genetics, which are as easy to use as straight breeding, to elaborate rotational crossbreeding systems with four or more breed inputs. The biggest keys to success are the thoughtful construction of a plan and the sticking to it! Be sure to set attainable goals. Discipline is essential.

Modify cows or modify environment?

Historically, supplemental feedstuffs have been relatively inexpensive compared to current costs. In fact, much of the early motivation to develop farmer owned confinement feeding systems, common in the Midwest, was to add value to coarse grains by feeding it to cattle. Present costs for supplemental feedstuffs, fertilizer and fuel inputs have many producers reconsidering their production model and moving towards systems with reduced inputs. Indeed producers are evaluating modification of the cow rather than modification of the production environment.

It seems that in the short run, the most effective way to improve efficiency at the production or herd level is through selection for cows of the appropriate biological type that fit their production environment. Further, these cows should likely be crossbred cows to leverage the benefits of maternal heterosis and breed complementarity. In the intermediate to long run, seedstock and ultimately, commercial producers, should select for animals, via selection index, that optimize efficiency to the enterprise's market endpoints. Such a two pronged approach leverages efficiency gains due to additive and non-additive genetics that affect animal efficiency of feed utilization as well as biological efficiency, respectively.