Development of Genetic Evaluations and Decision Support to Improve Feed Efficiency

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Introduction

The National Beef Cattle Evaluation Consortium (NBCEC) receives federal funding from a USDA special grant in order *to develop and implement improved methodologies for genetic evaluation of beef cattle*. The intent of such research is *to maximize the impact genetic programs have on the economic viability, international competitiveness and sustainability of U.S. beef cattle producers*. An important component of NBCEC endeavors include actively seeking out new traits and technologies to include in breeding programs. Many breeders and producers comment on the fact that there are no existing tools for improving feed efficiency. This paper considers the current scope for improving cow-calf and feedlot feed efficiency and identifies some opportunities for near- and long-term developments.

Breeding Goals and Breeding Objectives

The first step in the logical development of a breeding program is to determine the goal or *purpose toward which an endeavor is directed*. What is the goal for the nation's cow-calf herds, or for all the feedlots, or for the total production system? The answer is probably not straightforward, nor is it something that should be solely developed by a commentator such as myself. However, it will have something to do with *satisfaction* and will typically include profit. One thing is for sure, the goal is unlikely to be biological efficiency per se.

Given a profit-based goal, the next logical step in developing a breeding program is to consider the list of traits that influence the goal (Harris *et al*., 1984). Broadly speaking, these traits will influence income, or costs, or perhaps both income and costs. This will be the case for the cow-calf sector, the feedlot sector, or both sectors considered as an integrated system. Different spectators may come up with different lists of traits, according to their particular perspective. Some lists might focus on concrete factors such as heifer pregnancy, rebreeding success, calving ease, calf survival, growth rate, feed costs, veterinary costs that have direct relevance to output or input line items in financial budgets or accounts. Others might construct lists that include *cow efficiency* or *feed efficiency*. One problem in the development of such lists of traits is that it is easy to double count. More on this later.

The next consideration in a breeding program is determination of the relative importance of each of the traits in the list. The naïve breeder might hope to avoid this step and simply identify individuals that are perfect for every attribute. However, in real life, this does not occur unless you have a very low definition of perfection. In practice, individuals may be outstanding for some attributes, and average or even inferior for others, especially if some traits are antagonistic. Most livestock breeding programs include a number of antagonistic relationships.

The formal means of determining the relative emphasis for a profit-based goal is to quantify *the partial derivative of the profit function*. This statement probably doesn't mean much unless you are mathematically or econometrically inclined. It involves answering the question, one at a time for each of the traits in your list that influence the goal, *what is the value of a unit change in that trait, all other traits held constant?*

Suppose our list of traits includes output, input and efficiency, defined as either the ratio of output per unit of input or the ratio of input per unit of output. We would need the answer to the question, *how does profit change with a unit increase in output, with no changes in input or efficiency*. The answer would be the value of the output, for example, the beef price. We would then ask *what is the change in profit for a unit change in input, with no change in output or efficiency*. The answer would be the cost of the input, for example the feed price. We would then ask *what is the change in profit for a unit change in efficiency, with no change in output or input*. The answer would be that there is no change in profit. Accordingly, the economic value of efficiency is zero, if input and output traits are already in the objective. Of course, it is not possible for a change in input or output without a change in efficiency, but this simply reflects that fact that we are double-counting when we attempt to have all three traits, namely output, input and efficiency simultaneously in the objective. We would therefore determine that only output and input traits are required in the objective, and therefore we only require EPDs for output and input traits.

In contrast, suppose our list of traits included only output and a measure of efficiency, but not input. In that case, we could determine an economic value for output and an economic value for efficiency and would conclude that we need EPDs for output and for efficiency, but not for input. Determining an economic value for efficiency is not as straightforward as determining economic values for output and for input in the previous paragraph. Suppose our existing feed conversion ratio is 6 lb feed intake per 1 lb gain. We need to answer the question *what will happen to profit if conversion ratio improves by say one unit, to 5 lb feed per 1 lb gain*? We can't answer that question without knowing how much gain we make. This is the case because the value of efficiency is not independent of the actual output or input. This just further reflects some of the difficulties of using ratio traits.

Finally, suppose our list of traits included only input and a measure of efficiency. We would conclude we need EPDs for input and efficiency, but not output. I doubt that many readers would be comfortable with such an approach, but it is just as logical (or illogical) as the former suggestion of only output and efficiency.

There are therefore four possible scenarios for the national evaluation system, as given in Table 1. Any of these scenarios could be adopted. Scenario 1 would involve the national generation of EPDs that could be used to predict outputs and inputs and therefore be very naturally used to generate predictions of profit. Scenario 2 may appeal to those more interested in biological rather than economic efficiency. Scenario 3 may appeal to those who believe in low inputs. Scenario 4 would appeal to those who like more EPDs than are needed. I will argue that scenario 1 is the most sensible approach as it allows selection to readily account for the value of changes in output and the costs of changes in inputs. The difference between the value of outputs and the cost of inputs is the profit. Selection for profit is likely to change the outputs and the inputs, with the amount of change in each being determined by the extent of genetic variation in outputs and inputs, the covariation between outputs and inputs and the relative ratios of beef returns to feed costs. Typically, selection on profit would increase both outputs and inputs, while improving biological and economic efficiency.

Table 1. Alternative lists of traits in the national breeding objective.

	Outputs[A]	Inputs[B]	Efficiency[C]
Scenario 1	Yes	Yes	
Scenario 2	Yes		Yes
Scenario 3		Yes	Yes
Scenario 3	Yes	Yes	Yes

[A]Outputs can be predicted from EPDs for sale weights, reproductive performance and carcass attributes.
[B]Inputs can be predicted from EPDs for maintenance energy, growth, feed intake and residual feed intake.
[C]Efficiency could be defined as ratios of either inputs per unit output or outputs per unit input.

In contrast to selection on profit, where the breeder can select the emphasis to be placed on outputs and the emphasis on inputs, selection on efficiency leaves the emphasis on these two components to be determined biologically, without any regard to the ratio of the value of outputs to the cost of inputs (Gunsett, 1987). Table 2 demonstrates some of the problems with EPDs for efficiency, as can be shown by comparing the two bulls Oscar and Papa. Papa is much more efficient than Oscar, but no more profitable. Selection on efficiency could increase efficiency without changing profit. Furthermore, animals that vary in profit may share the same efficiency. For example the bulls Oscar and Romeo have the same efficiency, but Romeo has greater profit.

Table 2. Output, input, profit and efficiency ratios of three candidate sires for selection.

Bull ID	Output ($/dtr[A])	Input ($/dtr)	Net Income[B]	Efficiency[C]
Oscar	$500	$200	$300	2.5
Papa	$400	$100	$300	4.0
Romeo	$750	$300	$450	2.5

[A]Output and input are expressed in financial terms, per daughter (dtr).
[B]Net income is the value of the outputs column less the cost of inputs column and may not be the same as profit which typically includes other fixed costs.
[C]Efficiency is defined here as the ratio of outputs to inputs ($/$). In this case, higher ratios are desirable. It could equally be defined in other units such as lb/lb or as its reciprocal, inputs/outputs, in which case lower values would be desirable.

The distinction between selection towards a profit-based goal derived from an index of EPDs on inputs and outputs, as compared to selection using an efficiency EPD can be graphically demonstrated in a more thorough manner than the simple example in Table 2. Consider a graph depicting the amount of output (e.g. sale weight) on the y-axis and the amount of input (e.g. feed provided or consumed) on the x-axis. Suppose this figure is populated with progeny averages for various sires. It might appear as depicted in Figure 1, with a positive (economically antagonistic) relationship reflecting the fact that getting offspring to heavier sale weights typically requires greater feed inputs. However, the relationship is not strong for several reasons. First, some animal get to heavier weights by growing faster than others and therefore require less maintenance feed up until the point of harvest than do slower growing animals. Second, animals vary in the composition of their gain, and the feed costs associated with laying down lean and laying down fat are not identical. Third, animals may vary in the extent of feed wastage. Fourth, animals do not all exhibit identical levels of activity. Fifth, there is inherent variation in the efficiency of energy utilization, after accounting for the four previous factors. The physiological and biochemical mechanism for such variation is still unknown, but the existence of such a phenomenon is the basis for heritable so-called "residual feed intake" or RFI.

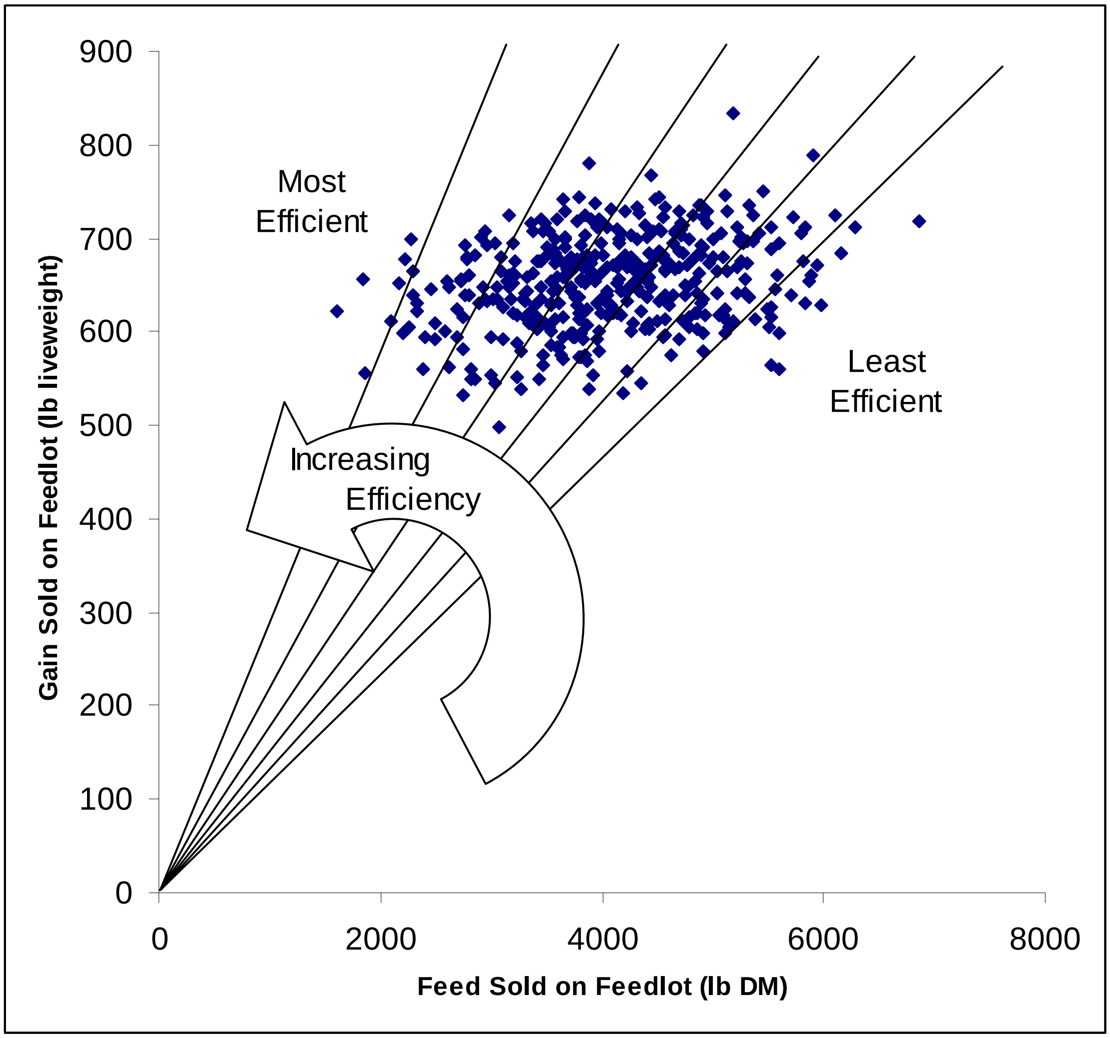

Figure 1. Outputs, inputs and iso-efficiency lines for progeny groups of a number of sires.

Superimposed on Figure 1 are iso-efficiency lines, where every point on the line has identical feed efficiency. These lines can be drawn without any consideration of the value of outputs (i.e., the beef price) or the cost of inputs (i.e., feed costs), nor their relativity. The lines are not parallel as they all pass through the origin and become progressively steeper to the left of the Figure. The large arrow indicates the direction of increasing efficiency, and the animals in the top left-hand corner represent the progeny groups with the highest biological efficiency.

The same sire groups are shown on Figure 2, with iso-profit lines superimposed. These lines represent the net income of each sire group, defined as the value of the gain, less the cost of the feed. Suppose the beef price was $1.38 per lb carcass weight. At a dressing out percentage of 62.5%, this relates to a price of $0.86/lb liveweight. At that price, a 116 lb increase of liveweight would correspond to a $100 increase in per head return. Suppose the feed cost was $5.70 per 100 lb on a dry matter (DM) basis. An increase in feed inputs of 1750 lb would decrease per head return by $100. Compared to an average progeny group, a sire whose progeny weighed 116 lb more at harvest, but had consumed 1750 lb more feed, would have the same profit as the average sire group. In contrast to the iso-efficiency lines, the iso-profit lines are parallel. The beef price to feed price index determines the slope of the iso-profit lines. These lines have a horizontal increase of 1750 lb feed for every vertical increase of 116 lb weight.

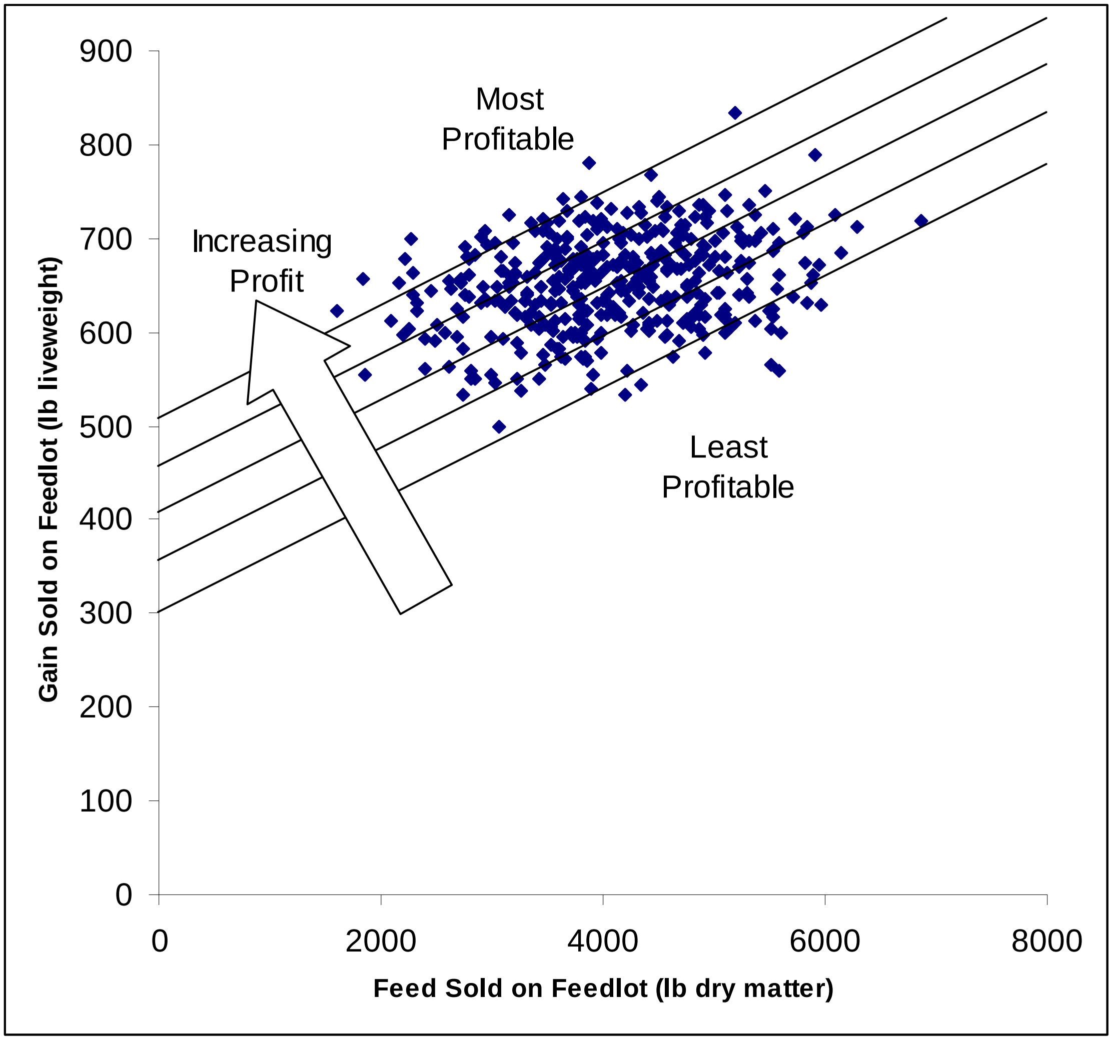

Figure 2. Outputs, inputs and iso-profit lines for progeny groups of a number of sires.

Comparing Figure 1 and Figure 2 it is apparent that although there is overlap, the sires with the highest efficiency identified on Figure 1 are not the same sires as those with the highest profit identified on Figure 2. Some of the sires with the highest profitability have intermediate efficiency. Conversely, the sires with the lowest efficiency do not coincide with the sires with the lowest profit. Some of the least profitable sires have moderate efficiency. Whereas the efficiency lines are unaffected by the economics associated with beef to feed price-cost ratios, the most profitable animals require some knowledge of this relativity. At certain price-cost ratios, the most efficient sires may correspond to the most profitable. However, because the iso-profit lines are parallel whereas the iso-efficiency lines represent rotations, it is not generally possible for an efficiency index to simultaneously correctly identify both the most and the least profitable groups of sires.

Some commentators find appeal in efficiency measures because of the vagaries of costs and prices and the difficulties in assessing what these might be in the future. However, it is not the actual values for beef or feed but the price-cost relativity that is important. Trends in price-cost relativity may be more consistent than actual prices and costs. Using biological efficiency does not get around the problem that economics determines profit. Unless biological efficiency rather than profit is the goal for selection, livestock managers would make better decisions using predictions of output value less input value rather than using predictions of efficiency.

Current Status for Predicting Outputs, Inputs, Efficiency and Profit

Predicting Outputs. National evaluation has long been based on some measures of outputs, notably weaning and yearling weights, and more recently measures of carcass attributes that relate to output value. However, system outputs are determined by the number of animals available for sale, as well as their sale weights. Although the prediction of sale weights is well advanced, prediction of sale numbers leaves considerable room for improvement. In a herd breeding their own replacements, the heifer pregnancy rate, cow fertility, length of productive life and calf survival rate are critical factors. The length of productive life has a major impact on the number of first calvers required. Herds whose cows stay longer (for more parities) need a smaller fraction of first calvers than do herds where the cows have a higher probability of being open and are therefore culled at a younger age. The heifer pregnancy rate determines the number of weanlings that need to be retained in order to meet the requirements for first calvers. The fertility of the cow herd determines the number of calves produced and the calf survival rate dictates the proportion that survive to sale. Heifer pregnancy and stayability represent two EPDs that can be used to predict sale numbers in a system context. However, many breeds are yet to adopt these EPDs, or even to modify their performance recording practices in order to ensure they collect data that can be meaningfully used for such predictions. Inventory recording systems are prerequisite for reliably predicting some output factors.

Predicting outputs in a feedlot setting on the basis of existing EPDs is probably more difficult that predicting outputs in a cow-calf system. Animals with higher yearling weight EPDs typically have higher mature sizes and can therefore grow faster and to heavier weights before achieving the same level of fatness as animals with lower yearling EPDs. EPDs for carcass fatness and for carcass marbling can be used to get some idea of the relative abilities of offspring of different sires to lay down fat or to marble, but prediction of the actual weight at which this will be achieved is not obvious from EPDs. Additional decision support tools that utilize growth and carcass EPDs in the context of a feedlot model is currently being developed at Colorado State University. Such models need to simultaenously account for the growth trajectories of alternative sires in terms of liveweight and its components, including, total fat, fat thickness and marbling. The desired outputs from such models need to include *value at finish*, *days to finish* and *feed to finish*.

Predicting Inputs. Feed requirements represent the most important input in the beef industry although inputs related to veterinary needs (e.g. based on calving difficulty) and animal health (e.g. pink eye, shipping fever etc) should not be overlooked. In a cow-calf system, feed inputs are required for replacements (maintenance and growth), the cow herd (maintenance, gestation, lactation and growth) and for the calves from birth to sale (maintenance and gain). In mature cows, most of the annual requirements are for maintenance. In growing animals, the relative importance of maintenance and gain varies with the growth rate and the composition of the gain. The amount of feed required by the cow herd and its replacements can be predicted from knowledge of the numbers, weights, rate of gain and milk production potential. This is achieved by determining the feed requirements for maintenance, for gestation, for lactation, and for growth (e.g. using NRC, 1996).

Maintenance requirements are principally determined by the weight, fat content and lactation potential of the cow. Lactation potential can be determined from the weaning weight maternal EPD, whereas cow weight and fatness can be predicted from weighing and condition scoring mature cows, preferably at weaning. The Red Angus Association of America uses this information to predict mature weight and maintenance energy EPDs. The American Simmental Association and the North American Limousin Foundation are also developing maintenance energy EPDs.

Gestation requirements can be predicted from birth weight EPDs. Lactation requirements can be predicted from weaning weight maternal EPDs. Growth requirements can be predicted from body weights, including birth, weaning and yearling weight EPDs. Requirements for replacements can be predicted from the age structure of the herds, influenced by heifer pregnancy and stayability.

Some individual animals consume more than we expect them to require, based on their maintenance and growth and, in the case of breeding cows, requirements for gestation and lactation. Such differences often result from variation in activity between animals, or variation in requirements to maintain temperature, for example in very cold conditions. However, even when all these factors are taken into account, some animals eat more or less than we would expect them to given their level of production. This difference is known as residual feed intake. Differences in residual feed intake will give the impression that some animals have lower maintenance requirements or higher efficiencies of gain, although it is technically problematic to determine the underlying cause of variation in residual feed intake. The only way to phenotypically determine residual feed intake is to measure individual feed intake.

Measuring feed intake is not altogether informative, as much of the variation in feed intake between animals can be predicted from their weight, growth rate and composition of gain. Furthermore, measuring feed intake is prone to a number of errors, from animals selecting among their feed, and wasting feed, for example dropping it on the ground or in the water trough. It is particularly problematic to measure it in grazing circumstances, although various methods do exist based on indigestible compounds such as alkanes or chromate. The real value of measuring feed intake is to predict residual feed intake, because that is the only component of feed intake that cannot be predicted from performance alone.

In order to generate measures of residual feed intake, not only is intake required, but also a method of predicting the amount of feed that should have been required. This can be achieved in two broad ways, from regression of intake on weight, gain and perhaps composition (e.g. ultrasound measures of backfat) or from prior knowledge using feed tables or nutritional models (Tedeschi *et al.*, 2004).

Prediction of inputs from a cow-calf perspective could be considerably improved if we had better predictions of certain outputs, principally, mature weights, condition scores, heifer pregnancy, fertility and stayability. Collecting more of these phenotypes represents an obvious opportunity that we should be exploiting. Measuring residual feed intake accurately and cost-effectively on these extensively managed foraging animals is technically some way off. In contrast, in feedlots, individual intake for at least a portion of the growing period is technically much more straightforward.

Pooled records on intake, for example from a small pen of animals may be more cost-effective to obtain than attempting individual observations. Pooled records can be used in genetic evaluations (Olson *et al.*, 2006), and can contribute to EPDs for RFI. However, whereas a considerable infrastructure exists for collecting growth and ultrasound information, the infrastructure to collect feed intake measures is sadly lacking. This will need to be remedied.

Guidelines for collecting feed intake data and corresponding performance need to be developed or adopted from existing guidelines elsewhere in the world and incorporated in the BIF guidelines.

Predicting Efficiency. Efficiency measures are useful key performance indicators for comparing the management of alternative feedlots or cow-calf production systems. However, as a tool to improve efficiency by selection, EPDs for measures of input and for measures of output are more effective than a new EPD based on some ratio of inputs and outputs. Genetic trend estimates for outputs and for inputs could be used to predict the genetic trend in biological efficiency. Decision support models that predict output and input could readily predict current and future efficiency, but the use of such measures as the basis for selection is not advisable for profit-based goals for the reasons demonstrated in Figures 1 and 2. Accordingly, the NBCEC has no current plans to develop an EPD for cow-calf or feedlot biological efficiency per se.

Predicting Profit. Given a profit-based goal, the most effective means of selection is based on an index that predicts profit. One approach to this problem would be to measure phenotypic profit on every animal, and then undertake genetic evaluation to construct an EPD for profit. However, the components of profit vary greatly in the extent of non-genetic effects (e.g. sex or age of dam). Furthermore, the heritability of the records after accounting for non-genetic effects also varies greatly. The consequence of varying heritability is that individual measurement is more informative of EPD for some traits than it is for others. The preferred approach to generate an EPD for profit is to combine the EPDs for economically relevant traits according to their contribution to profit, known as their relative economic value. Such an index is a great selection tool if the index is properly constructed and the user has a high level of confidence in the underlying assumptions. An equivalent method is to use EPDs to predict phenotypic performance, and then to combine predicted phenotypic performance with expected costs and prices in order to generate index values. This approach, known as sire selection by simulation (Bourdon, 1998), has the advantage that it can readily demonstrate the ramifications of selection (Garrick, 2006), can provide justification of the basis for the animals' index values and readily extends to mating systems that involve both pure- and cross-bred individuals (Garrick, 2005). The NBCEC web-based tools for predicting profit from predicted outputs and predicted inputs on the basis of existing national EPDs are available at *http://ert.agsci.colostate.edu*. The current version supports multiple breeds of sires in the context of a cow-calf model. A prototype feedlot model will be added to the software over the next twelve months.

Summary

Selection to improve profit will be more effective when based on predicted outputs and predicted inputs than on ratios such as efficiency. Predicted outputs and inputs can be used in conjunction with economic information to predict expected financial outcomes. Short- and long-term opportunities exist to improve the prediction of both outputs and inputs in cow-calf and feedlot scenarios.

In the cow-calf system, improved prediction of reproductive performance is needed. In most cases, modified recording practices will be required to generate phenotypes or inventory information that will enable a broader portfolio of economically relevant traits (heifer pregnancy, stayability, mature size and maintenance energy) to be evaluated. This will take some time and will therefore provide long- rather than short-term benefits. In the immediate future, better use needs to be made of correlated information (weights, scrotal circumference, condition scores) to predict such EPDs while breeders need to be educated as to the industry benefit of improved recording practices.

In the feedlot system, improved predictions of both inputs and outputs are required. Existing phenotypes (primarily ultrasound measures of live animal composition) need to be used in more innovative ways, accounting for knowledge of growth and composition trajectories. That information needs to be used in order to predict phenotypic outcomes (value at finish, days to finish and feed to finish) in the context of particular user-defined feeding strategies. New but not novel phenotypes, such as feed intake, may provide opportunities for faster rates of improvement in selection for feedlot performance. Collecting these phenotypes may not be cost-effective from the sole viewpoint of genetic improvement but should be harnessed when being collected in the context of monitoring and improving feedlot management. However, guidelines and infrastructure for collecting such intake data in national performance databases will need to be developed.

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