Rick Bourdon, a Red Angus breeder currently involved in teaching and research at CSU, has designed this series (continued from last month's Journal) to help breeders understand and use available performance information.

A Series

Beef Cattle Breeding

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Part Three

Breeding Value, Heritability and Genetic Correlation

In the first two articles in this series (see the November issue), I discussed the various ways that an individual performance record can be manipulated in order to better represent the genetic component of a trait. Adjusted weights, deviations from contemporary group averages or means, and ratios are all results of calculations designed to help us compare animals for genetic value. They are still measures of observed performance of individuals, however. They are related, but are not equivalent to the genetic component itself. In fact, the genetic component, or breeding value, is not something which can be directly measured on an individual. It is a theoretical quantity which can only be estimated.

Two definitions

What is breeding value? Let's look at two definitions, first that of the population geneticist. With few exceptions, economic traits in beef cattle are **quantitative,** meaning they are affected by many genes-tens, hundreds, perhaps thousands. (Examples of non-quantitative or **qualitative traits** are red/black coat color and the horned/polled character, each of which is affected by a single pair of genes.)

Imagine that for every gene an animal possesses, we could assign a value representing the effect of that gene on a particular trait. Some genes would have relatively large positive values. Others might have negative values. Most genes would probably have small values or no value at all. If all the assigned values or independent effects of an individual's genes on a given trait were summed, the sum would be that individual's breeding-value for the trait.

An animal can have as many breeding values as there are traits to be measured, and the effect of each gene can vary greatly depending on the trait being considered. For example, a particular gene might be very important for growth traits, but have absolutely no influence on mothering ability.

An animal can also have breeding values for traits not expressed in the individual. Bulls do not produce milk, yet they possess genes for milk production and therefore have a breeding value for that trait.

A second, perhaps more practical definition of breeding value is the definition implied by the phrase "breeding value" itself-the value of an animal as a parent. In our breeding programs, we try to cull out the worst parents and select replacements which we expect will make the best parents with regard to a particular trait or set of traits. So we are really selecting for breeding value, and in seed stock operations we sell breeding value as well.

Just as weights gain meaning when expressed as deviations from contemporary group means, breeding values are best written as deviations from the means of breeding populations. (A breeding population could mean a closed herd, or for most purebred breeders, an entire breed.) Some possible breeding value ratios for weaning weight might then be 98 or 103.

On the average

Breeding values have one very useful mathematical property: on the average the breeding value of an offspring will be the mean of the breeding values of its parents. For example, if a bull with a breeding value ratio of 108 for birth weight were mated to a cow with a breeding value ratio of 92, we would expect a calf with a breeding value ratio of 100 for birth weight. I emphasize on *the average,* however.

A parent contributes only a sample half of its genes to an offspring, and that sample, being random, might contain many genes with large favorable effects on the trait under consideration (a good sample) or it might contain genes which on balance are unfavorable (a poor sample). This **random assortment** of genes is much like a poker

hand-some hands are winners, others aren't, but they all come from the same deck. So even though a sire with a breeding value ratio of 110 for yearling weight bred to a cow with a breeding value ratio of 100 will produce, on the average, calves with breeding value ratios of 105, the same mating could result in a calf with a breeding value ratio of, say, 98 or 112.

As breeders, we often compliment ourselves when particular matings turn out as expected, and we scratch our heads when they do not. Considering that we don't know the breeding values of parents, but have only educated guesses; that the random assortment of genes allows a whole range of possible breeding values in the offspring; and that the breeding values of the offspring will be masked to a greater or lesser extent by environment, it's a wonder that we don't scratch our heads more often.

Since breeding values cannot be measured directly, how are they estimated? Before this question can be answered, we need to understand a few more terms. The balance of this article will deal with two concepts important to both breeding value estimation and selection in general-heritability and genetic correlation.

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Heritability

Most of us have an intuitive feeling for what heritability means; it is a measure of how "inheritable" a trait is. Without using statistical terms, however, it is hard to define it more precisely and yet more understandably, so the following definition of heritability should probably be read over a few times. For any given trait, we observe differences in the performance of individuals. Heritability is the fraction of those differences which is caused by differences in the breeding values of those individuals for that trait.

For example, consider the traits yearling weight and age at first calving. Yearling weight is highly heritable, meaning that differences in yearling weight seen in contemporaries reflect to a large extent differences in the breeding values of those animals for yearling weight, Age at first calving, on the other hand, is lowly heritable, meaning that differences in this trait seen among contemporaries are largely due to environmental effects or vary ing amounts of hybrid vigor, but not to differences in breeding value.

With a highly heritable trait, an animal's own performance tells us a lot about his breeding value, so we can expect much of that animal's superiority or inferiority to be passed on to his offspring. With lowly heritable traits, however, individual performance and breeding value are only vaguely related, and performance of parents will be a poor predictor of performance of offspring.

Heritability is expressed either as a decimal fraction with a range of 0 to 1, or as a percentage with a range of 0 to 100. A heritability of 0 would indicate that a trait is not inherited, while a heritability of 1 would indicate that an offspring's performance is completely determined by its parents' performance. Heritability values of 0 to .2 are commonly considered low, .2 to .4 moderate, and .4 and above high. Yearling weight in the above example is

from 40 to 70 **percent heritable,** while the heritability of age at first calving is from 0 to 10 percent.

You have probably noticed that a cow with high individual performance will tend to produce better-than-average calves, but that the average performance of the calves rarely matches the cow's performance. Likewise, calves from a poor performing individual are rarely as poor as that individual. This is because no trait is perfectly heritable. In fact, if we mated bulls and cows whose own weaning weights were all 100 lb. above average (to ratio 120 in a herd where weaning weights average 500 lb.), we would expect their calves to weigh only about 30 lb. above average at weaning (to ratio 106). Weaning weight is approximately 30 percent heritable, so only about 30 percent of the superiority of the parents represents superiority in breeding value. The breeding value ratios of the parents will average about 106 (not 120), and the average breeding values of the offspring will be the mean of their parents' breeding values.

When genes that have positive effects on one trait routinely have positive effects on another, the genetic correlation between the two traits will be positive.

This example suggests a way of estimating breeding value ratios: simply multiply the superiority of an animal's own performance by the heritability of the trait and add it to the average (100 + (.3 x 20) = 106). The example also demonstrates the main reason why estimated breeding values are almost always closer to average than are measures of individual performance.

Genetic correlation

To **understand genetic correlation we must first define the concept of correlation.** A correlation is a statistical term which measures the relationship between two variables and which has a range of – 1 to + 1. A correlation of + 1 is considered "perfect" and indicates that an increase in one variable is associated with a perfectly predictable increase in a second variable, A correlation of – 1 is also "perfect," only an increase in the first variable dictates a **decrease** in the second variable. A correlation of 0 is no correlation at all, in other words, no relationship. Typically, correlations have intermediate values, indicating intermediate degrees of relationship.

A genetic correlation is the correlation between breeding values for two different traits in a single individual. The genetic correlation between birth weight and yearling weight is positive and quite high (approximately .6), suggesting that calves with high breeding values for birth weight are also likely to have high breeding values for yearling weight and vice versa. In contrast, the genetic correlation between birth weight and age at first calving is near zero, indicating that a heifer's breeding value for birth weight tells us little about her breeding value for age at first calving.

Genetic correlations occur because some genes affect more than one trait. When genes that have positive effects on one trait routinely have positive effects on another, the genetic correlation between the two traits will be positive. When those genes routinely have negative effects on another trait, the correlation will be negative, And when those genes have no effect or unpredictable effects on a second trait, the genetic correlation will be near zero.

Knowledge of genetic correlations is important because it allows us to use information on one trait to predict a breeding value for another trait. For example, if we have yearling weights for a bull and his contemporaries, we can use that information along with a genetic correlation estimate to predict the bull's breeding value for birth weight.

With a highly heritable trait, an animal's own performance tells us a lot about his breeding value, so we can expect much of that animal's superiority or inferiority to be passed on to his offspring.

Genetic correlations also affect the results of selection. If two traits are genetically correlated, selection for one will cause change in another. Selection for increased yearling weight will increase birth weight.

We must be careful not to confuse genetic correlations with the correlations we observe between actual measures on individuals. Remember that genetic correlations are correlations between breeding values, not between actual observations. Observed correlations can differ from genetic correlations because of environmental effects. Weaning weight, for example, has a high genetic correlation with postweaning gain; the same genes are involved in the same way for both traits. However, the calculated correlation between actual performance for weaning weight and postweaning gain is only slightly positive. This correlation is weaker than the genetic correlation because a good environment for weaning weight (lots of mother's milk) is related to a poor environment for postweaning gain (more body fat caused by lots of mother's milk). Calves that have heavy weaning weights because of high breeding values for growth will probably grow fast after weaning, but calves that have heavy weaning weights due only to their dams' milk production will not. AJ

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NEXT
Relationship, Inbreeding, Hybrid Vigor and "Nicking"