Breeding for Beef Production

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INTRODUCTION

The steady expansion of the Canadian beef industry in the past 20 years is expected to continue in the future. In fact, production levels must be doubled by 1980 if the supply of beef is to keep pace with the predicted consumer demand.

Three ways to accomplish this increase are:

- Expand the national breeding herd and increase the area and productivity of land used for raising beef cattle.
- Improve feeding methods, rations, management, and disease and parasite control procedures to make most use of the available land and animals.
- Improve the inherent ability of the beef animal to efficiently produce the product demanded by consumers.

The simplest and fastest way to increase beef production is to increase the breeding herd. Feed for the increased national herd could be grown by cultivating new land, by extended and more effective use of fertilizers, cover crops, and crop rotations with forage production, and by breeding more productive hay and pasture species. The sciences of nutrition and veterinary medicine must also play an important role if productivity is to be increased.

Demands for other agricultural products will limit the area of land that can be used for beef production. And, while improved rations and other details of animal management are important, the extent of the increase in production is basically determined by the inherent capacity of the cattle to reproduce and develop. Thus the long-range approach to increased beef production must be through genetics. The beef industry will meet the challenges of the future only if the national breeding herd can be improved genetically to produce more and better beef on less feed.

Every breeder knows that genetic change in his herd is inevitable. Breeding animals that die or are culled because they fail to produce must be replaced if herd size is to remain constant. Since the animals chosen as replacements will not have exactly the same characteristics as those they replace, some degree of genetic change is natural and inevitable. To guide this genetic change in a desired direction the breeder must follow a consistent selection program. This publication provides information on which a sound selective breeding program must be based. It is not a book of methods or generalities that must be accepted on faith. Rather, it develops the essential principles of animal breeding from a background of the science of genetics. When traditional concepts of selection, breeding or testing procedures are challenged, an explanation of the scientific facts that support the recommendations is given.

GENETIC BASIS OF SELECTION

Progeny are expected to bear some resemblance to their parents. For this reason, breeders try to select breeding stock that have the characteristics of performance they want in the offspring. Thus, if a specific color pattern is desired in the calves, parents with that pattern are chosen. If weight for age is desired, this trait should be present in the stock selected for breeding.

The success of this process of selection is well known to breeders of beef cattle. It is successful because it is based on proven and simple principles of inheritance. Knowledge of these principles, though not necessary for successful breeding operations, will help the breeder to develop a sound selective breeding program for his herd.

Genes — The Factors of Inheritance

The genetic makeup or *genotype* of each animal consists of sets of genes, which are found in every body cell. These gene sets are in pairs because they are part of large structures called *chromosomes,* which occur in pairs.

This paired nature of the genetic material is the basis of the process of inheritance. An individual receives one chromosome of each pair from each parent. This means that an individual receives one-half of its genes from each parent. (The one exception to this rule is associated with sex determination.) Further, the sample half of chromosomes received from each parent is entirely a matter of chance. Thus the genotype of an individual is a result of the chance sampling of the genetic material contributed by both parents. This explains why related individuals differ from one another. For example, full brothers will each receive a sample half of the genetic material from their parents but the samples, having been decided by chance, are unlikely to be the same.

The two members of any gene pair affect the same trait of the animal, but they may affect it in different ways. For example, the presence or absence of horns in cattle is determined primarily by a single pair of genes. This gene occurs in two different types, one permitting and the other preventing horn development. If both members of the gene pair are of the first type, the animal is horned. If one or both genes are of the second type, the animal is polled. This explanation is oversimplified but it illustrates the genetic principle involved.

Animals with two genes of the same type are said to be *homozygous.* In this example, they may be homozygous for either the horned or the polled condition. But there is a third possibility. An individual may have one gene of each type in the gene pair. In this case it is said to be *heterozygous.*

Sometimes the heterozygote is intermediate. Shorthorns, for example, may be red, white or roan. These three colors are the results of a single gene pair of which one gene type produces red color and the other produces white. Homozygotes, therefore, will be either red or white but the heterozygote has a mixture of both colors and is roan.

Few inherited traits show this blending effect. Usually one member of the gene pair dominates. This is illustrated by the gene pair involved in determining presence or absence of horns. The gene for polledness is *dominant,* that for horns is *recessive.* Thus the heterozygote with one gene of each type will be polled.

Animals homozygous for either the horned or the polled conditions will breed "true" because they can transmit only one type of gene to their progeny. But heterozygous animals will transmit two types of genes and therefore will not breed true.

It is impossible to distinguish between animals that are homozygous for the dominant gene and those that are heterozygous. This fact is important because several defective conditions in cattle result from recessive genes. Since the normal condition is dominant, heterozygotes that carry the undesirable recessive may be selected for breeding. The first indication that this has happened will be when two heterozygotes or carrier animals are mated and the resulting calf, by the chance sampling of inheritance, receives the recessive gene from both parents.

Some defective conditions of beef cattle, with comments on their genetic basis, are described on page 54. The breeding procedure used to try to identify the heterozygous "carriers" of undesirable recessives will be found on page 22.

Undesirable recessive genes may remain in a population because the heterozygote is unknowingly preferred. This was the reason for the spread of the dwarf gene in beef cattle about two decades ago. In some cases the heterozygote may be superior in survival ability or have other advantages that allow him to leave more offspring than either homozygous type. This provides a supply of recessive genes for future generations. Chance can also spread a recessive gene throughout a population. For example, if a "fashionable" bull happens to be a carrier, the deleterious genes he carries will be widely disseminated.

Although major genes influence many characteristics of cattle, other genes called modifiers also have a significant influence on the final traits. For example, in the horned and hornless case cited earlier, the absence of horns is determined primarily by the polled gene. However, modifier genes can reduce this effect slightly and cause scurs to develop on a genetically polled animal. There is a further complication in that the development of scurs is also influenced by sex; scurs show greater development in males than in females. Other modifiers will influence the size of horns in genetically horned animals with extremes of mature horns ranging from less than a foot long to over 3 feet.

Other examples of modifier genes are the brockle faces of some Hereford crosses and the amount of white on the back and sides of Hereford cattle.

Quantitative Traits

Most of the performance traits of interest in beef cattle are quantitative; that is, they vary continuously over a wide range, for example, body size. Part of the reason for the continuous variability of such traits is the fact that they are controlled by many pairs of genes. Each gene pair may, and usually does, have only a small effect, but when these small individual effects are added together for all gene pairs, the net result can be large.

Differences in performance among animals are the joint product of their inheritance (the specific genes that an individual has) and the environmental conditions in which they developed (management, nutrition, climate). Since only the genetic portion affects genetic improvement, the breeder must have some way to decide the relative importance of the genetic and environmental contributions to the variation observed. Further, he must know the proportion of the genetic contribution that will be useful to him in selection. This proportion is known as the heritability.

Heritability estimates for some important traits are given in Tables 2 and 3. Two points must be emphasized about heritability estimates. First, they apply to variation observed among animals treated reasonably alike. Where the animals being compared have not been treated alike, the heritability applicable to any of the important performance traits will be lower than those given in the tables. Secondly, they are averages and can be expected to apply only in terms of predicting the average response over several years of selection. They do not apply equally to every herd or to every selection made within a herd.

The meaning of heritability might be clarified by an example. Consider a large herd from which a bull and 10 heifers are chosen for breeding. If these selected animals averaged 440 pounds at weaning and the herd average in the year they were weaned was 400 pounds, the amount of selection applied for weaned weight would be 40 pounds. Since weight at weaning is 30 percent heritable, the genetic improvement expected from this selection will be 30 percent of 40 pounds or 12 pounds. In other words, the progeny of the selected animals should wean approximately 12 pounds heavier than if there had been no selection.

Selection differential or *reach* is the amount of selection applied to a trait. In the preceding example, the selection differential was 40 pounds and the genetic progress expected was estimated by multiplying the reach by the heritability. The rate of genetic improvement can be increased by increasing the selection differential. There are two general rules that make selection differentials large:

- Select for few traits. The greater the number of traits in the selection program, the lower the selection pressure that can be applied to each one. This means limiting selection to traits of moderate to high heritability that have economic meaning in production. Selection for traits of low heritability is unrewarding; further, there are more efficient ways to improve them (see page 19). Selection for traits of low economic importance is of little value to the industry.

- Select replacement animals from the largest population possible. In general terms, the number of replacements needed each year will be reasonably constant for a given herd size. The larger the population from which these are selected, the greater the opportunity to choose outstanding animals.

Again it is important to emphasize that the animals being compared for selection should have been reared under the same environment. Unless the animals are from the same herd and their performance has been adjusted for known environmental variation such as age of dam, it is impossible to establish the proportion of the selection differential that is due to genetic effects. Comparison of animals from different herds should be based on their within-herd index (see page 29).

PREDICTION OF GENETIC IMPROVEMENT RESULTING FROM SELECTIVE BREEDING

The theory of animal breeding has been based on statistical mathematics. Since the theory does not take account of all the factors involved, it falls short of perfection, but for characteristics such as growth rate in beef cattle it is useful for estimating the results of selective breeding.

For convenience in discussing this theory three symbols are used:

ΔG — genetic improvement.

I — selection differential or reach. This is the difference between the average performance of animals selected for breeding and the average performance of the herd from which they came.

H — heritability. This is the proportion of the total selection differential that is attributable to the genetic superiority of the selected animals, and therefore inherited by the next generation.

When selection is practiced, the resulting genetic improvement may be estimated by the following equation:

$\Delta G = IH$ (This means that the genetic improvement is equal to the product of the selection differential and the heritability of the trait.)

Selection Differential

When a group of animals has been chosen for breeding from a larger group of tested animals, the selection differential may be computed as the difference between the average performance of the selected animals and that of the entire group of tested animals, including those selected.

This approach is of little value in planning a breeding program, since the selection differential cannot be calculated until the test results are available. Therefore, another approach has been worked out, which is based on the proportion (P) of the tested animals that are selected and the normal variation found in the trait being considered. For most traits, the sexes differ in average performance levels, so the selection differential must be computed separately for males and females, then averaged to give the overall selection differential.

The procedure for estimating selection differentials and for predicting expected genetic improvement is given in Table 1. The interpretation of the table is provided in the following paragraphs.

Table 1. Estimated selection differentials per year and genetic improvement per year under different intensities of selection among bulls for weight at 1 year of age

1* Number of cows mated to each bull	2 P_B	3 I_B (pounds)	4† I_B per year (pounds)	5 I per year (pounds)	6 $\Delta G = IH$ (pounds)
250	0.01	133.5	66.8	37.4	18.7
50	0.05	103.0	51.5	29.8	14.9
25	0.10	87.5	43.8	25.9	13.0
12	0.20	70.0	35.0	21.5	10.8
8	0.30	58.0	29.0	18.5	9.2
6	0.40	48.5	24.2	16.1	8.0
5	0.50	40.0	20.0	14.0	7.0

* Assuming 80% calves reared to breeding and a sex ratio of 1♂ : 1♀.
† Using yearling bulls.
P — Proportion selected of those tested.
I — Selection differential.
ΔG — Genetic improvement.
H — Heritability.
B — Referring to bulls.

Selection of bulls — The estimated selection differentials for bull (I_B) corresponding to the proportion of the tested bulls selected for breeding (P_B) are given in Table 1 for weight at 1 year of age. It is assumed that yearling bulls, which will be 2 years old when their offspring are born, are used. Therefore it takes 2 years to achieve the selection differential (I_B). In terms of selection per year (I_B per year; column 4, Table 1), I_B must be divided by 2. When a herd is closed and sires are replaced each year, the maximum intensity of selection that can be achieved is determined by the number of cows mated to each sire, since this determines the number of bull calves from which the replacements may be chosen. The number of cows mated to each sire is unlikely to exceed 25 unless A. I. is used.

Selection of females — Intense selection among the females in a cattle herd is not possible because a high proportion of the heifer calves must enter the breeding herd to compensate for normal losses due to age and unsoundness. To estimate the maximum possible selection intensity in the cow herd, assume the following:

- The sex ratio among calves is 1♂ : 1♀.
- For every 100 cows bred, 80 calves (40 heifers and 40 bulls) are reared to breeding age.
- The average age of the cows at calving is 6 years. Heifers enter the herd at 1 year of age and, *on average,* are bred 5 years before being discarded. Thus, one-fifth of the cow herd must be replaced each year, so 20 replacement heifers are needed each year for every 100 breeding cows.

With every 100 cows producing 40 heifers per year, and 20 of these required for replacements, the highest possible selection intensity among heifers is 20/40 = 0.50, with corresponding selection differential for heifers of 40 pounds. But the selected group of heifers to which this applies constitutes only one-fifth of the cow herd, so the selection differential applicable to the whole cow herd each year is only one-fifth of this, or 8 pounds. It is not possible to increase this intensity of selection and nothing is gained by reducing it, so for the purpose of Table 1 the selection differential for females is considered to be fixed at 8 pounds per year for each herd size.

Selection differential, sexes combined — Since each parent makes essentially the same contribution to the genetic makeup of the offspring, the annual selection differential applicable to the entire herd (I per year) is the simple average of those for the two separate sexes [$(I_B + 8)/2$] as given in column 5, Table 1.

Heritability (H)

The annual selection differential for the whole herd (I per year), as developed in the preceding section, is an estimate of how much the average performance records of the *breeding herd* can be improved each year. But only a fraction of this outward improvement in breeding stock will be transmitted to their calves, this proportion being given by the heritability (H) of the trait. Heritability estimates are usually based on the degree of physical similarity among animals of known genetic relationship. The method of computation is not given here, but heritability estimates for many traits of importance to beef breeders are tabulated (Table 2). For the example given in Table 1, yearling weight, the heritability is about 0.50.

Annual Genetic Improvement ($\triangle$ G per year)

When the annual selection differential (I per year) has been estimated from the breeding structure in the herd, and the heritability (H) of the trait is known, the actual genetic improvement expected ($\triangle$G per year) can be calculated by multiplying the two together (column 6, Table 1).

$$\triangle G = IH$$

The preceding sections show how to estimate the expected gain when a particular breeding plan has been followed. These expected gains are only estimates, and are not expected to apply beyond the first 10 years or so, since the I and H estimates will change under constant selection. However, the method is sound and is the best way for a cattleman to set up a selection program. For example, in the Shorthorn herd at the Research Station at Lacombe, an improvement of 10 pounds per year in yearling weight would have been predicted from these calculations and an improvement of 8 pounds per year was actually realized over a 5-year period.

Generation interval, which is determined by the proportion of the breeding animals replaced each year, will directly influence the rate of change that may be expected from a given selection differential. If few animals are replaced, the generation interval is long and the change per year small. For maximum rate of change the generation interval must be kept as short as possible.

GENERATION INTERVAL

The generation interval is the period between generations or the average age of the parents when the offspring are born. The annual rate of change for a given selection differential depends on the proportion of animals that are replaced each year. If few animals are replaced, the generation interval is long and the rate change per year small. A cow herd will reach an equilibrium situation in which the proportion of cows of each age class, and therefore the average age of the cow herd, does not change from year to year. At this point the average age may be about 5 years. This is the generation interval for cows. Also, the generation interval for bulls is their average age when their calves are dropped (weighted by the number of calves sired by each bull). The generation interval for bulls may be as low as 2 years (if only yearling bulls are used) but more often it is 4 years or more.

Since the generation interval is the time needed for one generation's improvement, it affects the rate of improvement per year, which is the final measure of the effectiveness of a

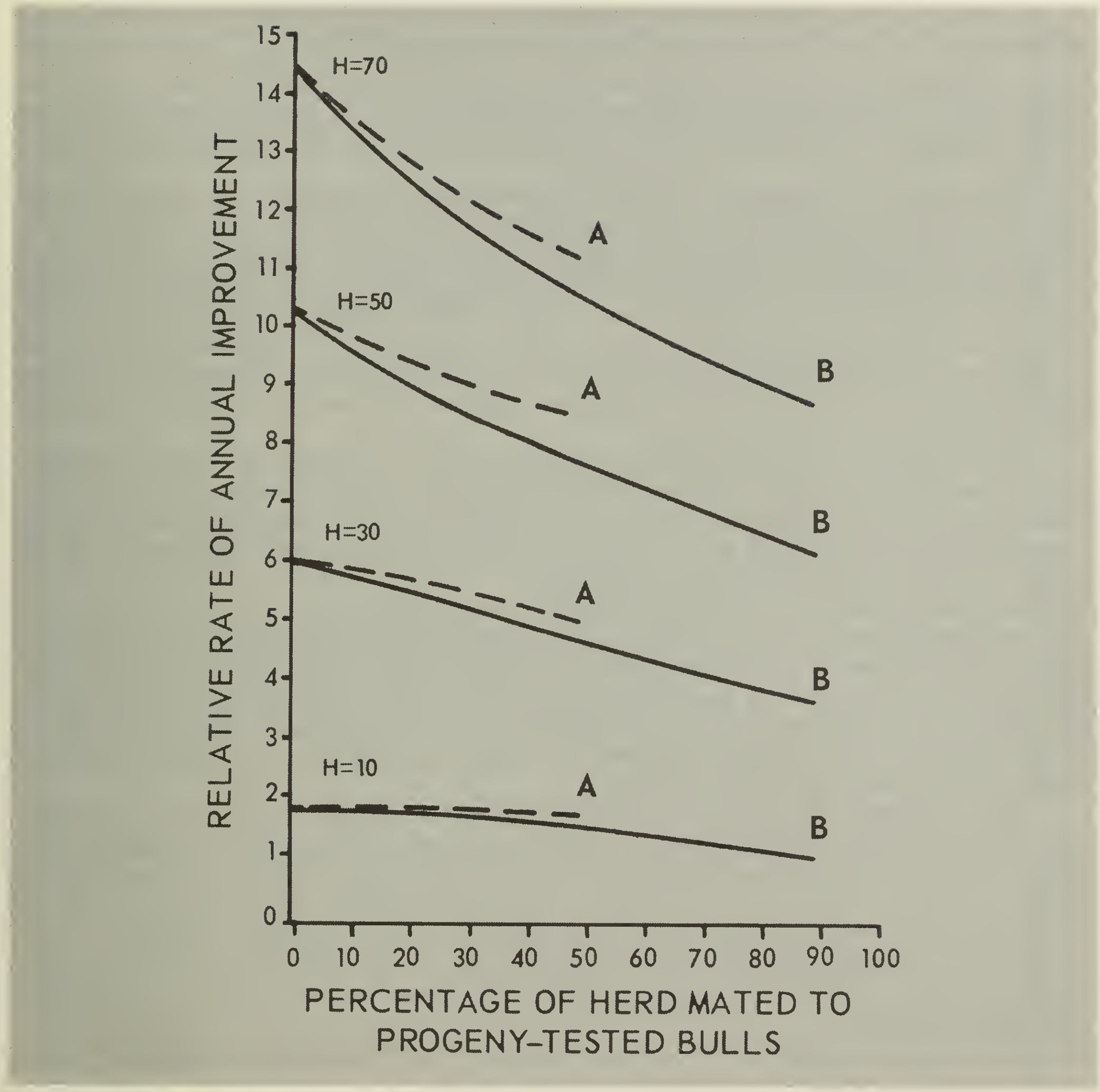


Figure 1. Male contribution to annual genetic improvement in yearling weight as affected by the proportion of the cow herd mated to 2-year-old, progeny-tested yearlings. The remainder of the herd is mated to young bulls selected for their own performance only. The assumptions made in this example are:
The herd consists of 100 cows.
Eighty percent of the calf crop is raised to maturity.
The sex ratio is 1♂ : 1♀.
All bull calves but no heifers are performance tested.
There is no selection among females.
The best 10 percent (four) of the yearling bulls are progeny tested.
The best one (line *A*) or two (line *B*) of the progeny-tested bulls are kept for further use as 2-year-olds.
Yearling bulls can be used on as many as 25 cows, and 2-year-old bulls on as many as 50 cows per season. When only one progeny-tested bull is used (*A*) he cannot handle more than 40 percent of the herd.

selection program. In general terms, where A is the generation interval in years,

$$\Delta G \text{ per year} = (\Delta G \text{ per generation})/A.$$

Therefore, the longer the generation interval, the lower the annual rate of improvement. This is a good reason to keep the generation interval short.

Little can be done to shorten the generation interval of the females, since this is mainly determined by the rate of natural loss from the breeding herd. The generation interval for males can be kept as low as 2 years, but if the progeny test is used to increase the accuracy of assessment of the bull's transmitting ability, 4 years in the minimum. The advantage of progeny testing must, then, be measured against the disadvantage of increased generation interval.

In practice, some portion of the herd must always be mated to young, nonprogeny-tested bulls to obtain a progeny test on them. The pertinent question is what porportion of the herd should be mated to progeny-tested bulls. In Figure 1 a method of approaching this question, supplied by Dickerson and Hazel (J. Agr. Res. 69:459–475, 1944), is applied to a typical selection program with beef cattle. Four examples are shown representing levels of heritability (H) from 0.10 to 0.70. The example with H=0.50 applies specifically to weaning weight. For this trait, the figures for the relative rate of annual improvement are given in pounds per year. The assumptions made in constructing this example are listed below the figure.

The first point on each line, corresponding to zero percent of the females mated to progeny-tested sires, means that all cows in the herd are mated to young bulls that have been selected on the basis of their own performance alone. The remaining points represent a gradual increase in the use of progeny-tested bulls with a corresponding decrease in the number of cows mated to young, unproven bulls.

Returning again to the specific example of weaning weight (H=0.50), the use of only performance-selected yearling bulls, that is zero percent of the herd mated to progeny-tested bulls, provides a male contribution to genetic improvement of about 10.6 pounds per year. With 50 percent of the herd mated to the two best progeny-tested bulls (line B), the genetic contribution from sires is reduced to 8.1 pounds per year. And with 90 percent so mated the gain is only 6.6 pounds per year. When only the one best progeny-tested bull is used (line A), the decrease is a bit slower.

The conclusion from Figure 1 is that in closed herds, the extensive use of progeny-tested sires generally reduces the rate of annual improvement below that obtainable when young bulls, selected on the basis of their own performance alone, are used only as yearlings. This is because the increased accuracy with which progeny-tested bulls are evaluated is more than offset by the corresponding increase in generation interval.

Traits that cannot be measured on breeding animals (for example, the carcass traits) can best be improved by use of progeny testing. But the generation interval should be kept as short as possible.

Heterosis

Estimates of heritability apply only to genetic effects that can be used in selection. There are other types of genetic effects that do not respond to selection. These result from specific gene combinations, which, when in a heterozygous state, produce hybrid vigor or heterosis. The term hybrid vigor comes from the observed fact that crossbreds frequently possess greater vigor than their parents.

The traits that show the greatest hybrid vigor are those with the lowest heritabilities. Therefore, while crossbred calves may grow more rapidly than straightbreds, the traits benefiting most from crossing are associated with reproductive and preweaning performance. The amount of heterosis produced depends on the genetic dissimilarity of the parents. The more widely separated the parental breeds, the greater the heterosis that may be expected from crossbreeding.

The potential benefits of heterosis should be evaluated in terms of net economic returns from the breeding herd. There is little point in undertaking a cross from which the net returns, including all aspects of productivity from reproduction to carcass merit, are no greater than would have been obtained by straightbreeding the better parent breed. There is no simple way to predict the amount of heterosis to be expected from crossbreeding, and each cross must be evaluated on its own merits.

TRAITS OF ECONOMIC IMPORTANCE

Performance traits of greatest importance in economical beef production are:

- Reproductive performance
- Cow productivity
- Postweaning performance
- Carcass merit

Reproductive Performance

Efficient production must be based on a high level of reproductive performance. This is a complex trait combining calving interval, conception rate, calf survival, and other factors that influence the number of calves weaned per 100 breeding cows maintained in the herd. These factors are influenced to a large extent by environmental conditions such as nutrition, management methods, and disease, and the apparent influence of heredity on each is small (Table 2). Therefore, special attention given to the reproductive performance of the dam when selecting herd replacements will have little effect on this trait and will decrease selection pressure on more highly heritable characteristics. Poor reproductive performance is partly self-eliminating, as poor reproducers leave few offspring for selection. However, cows that fail to conceive regularly and wean strong healthy calves should not be kept in the herd. A sound procedure is to cull open females and use nutrition and management that will maintain high reproductive performance.

Reproductive performance shows considerable heterosis. Therefore, use of crossbred females in commercial breeding operations is the most promising procedure for achieving high reproductive performance.

Table 2. Heritability and repeatability estimates for items relating to reproductive performance and cow productivity

Item	Heritability (percent)	Repeatability (percent)
Reproduction		
Services per conception	3	Not repeatable
Nonreturns to first service	Not heritable	3
Calving interval	Not heritable	Not repeatable
Milk production	20	40
Weight and gain		
Weaning weight	30	45
Gain birth to weaning	40	40

Cow Productivity

Cow productivity, measured in pounds of calf weaned, is determined by the cow's milking ability and by the calf's inherent ability to grow. Preweaning average daily gain is the simplest measure of milking ability.

Weaning weight is moderately heritable and can be improved by selecting replacements that weigh above average at weaning. It is also a repeatable characteristic of the cow. Therefore, the ability of a cow to wean large calves can be judged from the weaning weight of her first calf. The initial improvement in average weaning weight of a herd results from culling cows that wean lightweight calves. Long-term improvement will require a combination of such culling with the selection of heifers of above-average weight as replacements.

Lifetime productivity of a cow will depend, to some extent, on her longevity. Of greater importance, however, are items already considered under reproductive performance, particularly regularity of calving. Cows that start producing early in life (as 2-year-olds) and continue to wean a calf each year thereafter will have the greatest value to the herd.

There is evidence, both experimental and practical, that crossbred females are more "durable" than straightbreds. Further, the crossbred cow weans calves that are considerably heavier than those from straightbreds (Table 4). For these reasons, the breeding use of crossbred females offers commercial cattlemen considerable potential for maximizing cow productivity.

Postweaning Performance

Ability to grow rapidly is a highly desirable characteristic of the beef animal. Rapid gains in the feedlot mean a more rapid turnover through the feeding facilities, and reduction in the costs per head for labor and other investment charges. There is a favorable correlation between growth rate and feed efficiency, so selection for increased growth rate tends to improve economy of gain. This is most helpful to the breeder because of the difficulty and cost involved in obtaining individual feed records.

Average daily gain after weaning is a highly heritable trait (Table 3), and an effective selection procedure is to choose breeding animals that have grown rapidly themselves. Weight at 12 or 18 months of age is also highly heritable. The use of weight for age as a single trait for selection is a practical way to combine selection for birth weight, pre- and post-weaning gain, and pounds of trimmed retail product produced per day of age. An added benefit is that heifers in weight-selected herds have the genetic potential for high pre- and post-weaning gain. Therefore, if reared on a standard feeding program, these heifers will reach puberty at a younger age, conceive earlier in their yearling breeding season, be larger at their first calving, and be more likely to conceive again as 2-year-olds.

Although rapid gains and heavy weight at 1 year of age are desirable characteristics, extreme mature weights of breeding animals are not necessarily an economic advantage. Feed requirements for maintaining the cow herd are obviously related to mature size and the long-range goal of the industry may be maximum early growth rate combined with moderate mature weight.

Table 3. Heritability estimates of some of the important postweaning traits

Trait	Heritability (percent)
Postweaning feedlot daily gain	45
Postweaning pasture daily gain	30
Efficiency of feedlot gain	40
Weight at 12 months	50
Days to finish	25
Rib eye area	70
Tenderness (shear value)	60
Carcass cutout	25–50
Thickness of fat over rib eye	40

Carcass Merit

Carcass merit involves proportions of lean, fat, and bone conducive to high retail cutout yield and value. Methods of predicting carcass value from carcass measurements are evolving. The most satisfactory method for assuring good retail yield from live animal appraisal is by de-emphasizing fatness because a high degree of fatness is associated with poor cutout yield. Cutout yield from widely differing types of cattle such as beef and dairy breeds is similar when evaluated at the same degree of fatness. Conformation, as traditionally appraised, shows no relationship to cutout yield or to relative proportions of the high-priced cuts.

Retail cutout yield can be predicted with reasonable accuracy from the carcass measurements of area of rib eye, thickness of fat over the rib eye, weight of kidney fat, and carcass weight. The first three of these traits have fairly high heritabilities and are improved by the selection of sires whose progeny test shows superior merit. There is some indication that the proportions of muscle and bone in the shank, or perhaps some other cut, may be useful in predicting carcass merit. However, a breeder should begin his selection program by emphasizing growth rate and, when this is under way, consider the inclusion of carcass merit.

Eating quality is an important consideration in appraising carcass merit. It involves such items as color, tenderness, texture, and taste. Fatness, up to a point, improves some of these measures of quality, at least in the view of the average Canadian consumer; however, fatness beyond a certain level is undesirable. Quality can be assured by slaughtering bulls, steers, and heifers at less than 20 months of age, by finishing them to at least minimum levels of fatness, and by taking care that stress is minimized during marketing.

Heterotic Response of Performance Traits

The amount of heterosis or hybrid vigor varies for different performance traits. In general, traits with high heritabilities show little heterosis. Conversely, traits with low heritabilities do not respond to selection but they show large amounts of heterosis.

Table 4. Average heterotic effect (advantage over straightbred performance)

Trait	Two-breed cross	Three-breed cross (dams crossbred)
Percentage calf crop	14 percent	14 percent
Weaning weight	5 percent	10 percent
Daily gain	3 percent	3 percent
Slaughter grade	5 percent	2 percent
Age at puberty (heifers)	30 days	30 days

Crossbred calves have an advantage in calf livability, particularly in the first few days after birth, and they grow slightly faster both before and after weaning. Carcasses from crossbred and straightbred calves, when compared at the same weight, are similar in pounds of edible meat and percentage of boneless trimmed retail cuts from the round, loin, rib, and chuck. However, crossbreds tend to produce more pounds of lean meat per day of age because of their superior growth rate.

The potential for increased productivity through systematic crossbreeding is large because the modest improvement in growth rate is *multiplied* by the increase in fertility and survival.

Summary

Present knowledge about the main performance traits of economic importance in beef cattle can be tabulated as follows:

Trait	*Heritability*	*Heterosis*	*Method of Improvement*
Reproductive performance and cow productivity	Low	High	Selection of little value. Nutrition and management of great importance. Crossbreeding, specifically the use of the crossbred cow, very important.
Weaning weight and postweaning performance	Medium	Medium	Selection important. Should be based on own performance. Direct selection for feedlot gain will tend to improve feed efficiency. Crossbreeding of some value.
Carcass merit	High	Low	Selection should be quite effective. No practical and efficient method known for live animal evaluation. Heterosis of little value but crossbreeding useful as a means of introducing desired carcass traits.

PERFORMANCE OF THE INDIVIDUAL AND ITS RELATIVES FOR SELECTION DECISIONS

Selection is the process of deciding which animals shall become parents. If the animals saved for breeding have superior inheritance to those culled, the net result will be genetic improvement of the herd. The information needed to identify the animals that have superior inheritance, that is, to estimate their potential breeding value, may be obtained from their own performance, their full- and half-sib performance, the performance of their progeny, or from information on their pedigree relatives.

Own Performance

Selection on the basis of own performance is particularly useful for traits of moderate to high heritability measurable directly on the individual. Weight for age is a good example. This trait is highly heritable in cattle and can be thoroughly evaluated before the animal reaches breeding age. Own performance for reproductive traits is also used in culling the breeding herd. Although reproductive traits are of low heritability and therefore are unlikely to show much response to selection, simple economic considerations require that the poor producers be discarded.

Full- and Half-sib Performance

The average performance of sibs or half sibs is of some use in selecting for traits that cannot be measured on the animal that is to be used for breeding. One example is carcass merit, for which reasonably detailed information can be obtained only after slaughter. Therefore, if carcass merit is emphasized in the selection of replacement stock, the necessary information may be obtained from slaughtered half sibs. Information on half sibs will also augment the information available on own performance. For example, if selection within a herd has been narrowed down to two young bulls that are similar in terms of their own performance, the bull with the higher half-sib average for the desired traits is likely to have superior genetic merit.

Progeny Performance

Progeny test information is used to:

- Cull mature breeding stock that leave inferior progeny.
- Select for traits of low heritability.
- Select for traits measurable only on one sex (mothering ability or milk production).
- Select for traits measurable only after slaughter (carcass).
- Identify carriers of undesirable recessives (dwarfism).

The first point applies to any herd and requires only an annual summary of the individual performance records of calves produced by each cow and bull in the herd.

In the selection of breeding stock, the primary application of the progeny test is to evaluate sires intended for wide use through artificial insemination (A. I.). For such tests to be reliable, they must be carefully planned to ensure a uniform environment for all the progeny groups being compared.

Selection based on a progeny test increases the interval between generations. Therefore, when used as a basis of selection for traits of moderate to high heritability, progeny testing reduces the rate of genetic improvement compared with selection based on own performance. However, if progeny tests are conducted to provide information on carcass traits or traits of low heritability, data on growth rate and other traits of high heritability should also be obtained to complete the record.

Detection of bulls carrying inherited defects by means of the progeny tests has specific application for bulls standing for service in A. I. centers. For the simplest case, that of a single recessive gene, the number of matings required to ensure 90 percent detection of carrier bulls is eight if the cows are all carriers and 17 if the cows are all daughters of the bull being tested. To increase the odds to 99 percent (that is, of all *carrier* bulls tested, 1 percent would not be detected) 16 and 34 matings, respectively, are required. Carrier cows are used to test for specific recessives, whereas daughters are used to test for all recessives.

PROGENY TESTING FOR HERD IMPROVEMENT AND A. I. STUD USE

Progeny testing of bulls has limited use in within-herd improvement because it takes too long and therefore increases the generation interval and reduces the rate of annual improvement. Further, most of the traits that can be improved by selection have high heritabilities and can be readily improved by direct selection for own performance.

However, bulls intended for A. I. use may serve many thousands of cows, and detailed proof of their genetic worth assumes greater importance. Therefore, A. I. units must have a system for proving the worth of replacement bulls. Indeed, the ultimate success of an A. I. unit depends not on its proven bulls (these do not last forever) but on the extent and soundness of its testing program for new bulls.

Test Procedure

Yearling bulls with outstanding performance records should be taken into the bull stud for progeny testing. Semen should be drawn from each bull immediately and used on at least 50 females, preferably in 10 or more different herds (with a carefully planned pattern of matings to ensure that the various sires can be genetically evaluated).

These matings must be recorded, the resulting calves identified, and all progeny performance tested as described on page 25, with the exception of male calves, which should be finished and slaughtered and their carcasses identified and evaluated after chilling (page 18).

All young sires whose progeny do not attain the average performance of their contemporaries for growth and carcass merit should be discarded.

The remaining young sires should now be mated to their yearling daughters to test for recessive genetic defects. There should be about 20 yearling daughters from which perhaps 15 calves may be expected. If any calf shows a genetic defect, the sire should be discarded. Nine-tenths of the carriers of recessive genetic defects should be eliminated by this test. Outstanding sires that will be widely used should be further tested by taking another 15 of their calves from 20 more daughters. With 30 normal calves from at least 30 daughters, and none abnormal, the chance that a carrier of a genetic defect will escape detection is about one in 100 — low enough for all practical purposes. In addition to recognized genetic defects, all deformities and unexplained stillbirths and abortions should be regarded with suspicion, and considered cause for further testing, since they may be caused by genetic defects.

Responsibilities of the Herd Owner

To function effectively, the A. I. unit must have access to a substantial number of individually identified cows for progeny testing young sires, and the offspring in these herds must be performance tested. These testing herds do not need to be purebred. Commercial herds are highly suitable, but they must be prepared to use one or more unproven bulls on a representative sample of their own cows and to keep the required records on the offspring. The A. I. unit might provide fieldmen to undertake most of the record work, but the obligation of providing cows to be mated to unproven bulls remains with individual herd owners as one of the costs of having superior proven sires available for use on the rest of the herd. The more "tester" cows available to the A. I. unit, the more young bulls can be tested each year, and the better will be the average quality of the proven bulls in the stud.

Information on Pedigree Relatives

For traits of low heritability the performance of relatives more distant than the sire and dam merits little or no consideration in selection. Pedigree information has long been given special emphasis in the selection of lines of breeding that are free of defective traits, for example dwarfism. Even if the pedigree record is assumed to be accurate and complete, a "clean" pedigree tells little about the animal in question, and discrimination against an animal several generations removed from a known carrier cannot be justified.

Combination Selection

For certain traits, particularly those of low heritability, the accuracy of selection might be improved by joint consideration of own performance, sib performance, and progeny performance. But such combination selection is not generally recommended because it complicates decision making, lengthens the generation interval, and weakens the overall intensity of selection. For postweaning traits, heritability is high and the emphasis in selection should be on own performance. Sib records are useful in choosing between two animals that are essentially equivalent in terms of their own performance, while progeny records can be used to cull mature breeding stock.

A detailed comparison of the usefulness of own performance and information on various relatives is given on pages 23 and 24.

THE VALUE OF INFORMATION ON RELATIVES

A cattle breeder who is buying breeding stock is generally advised to base his opinion of an animal's value on the apparent merit of its most illustrious relative. Indeed, there are some traits (such as carcass characteristics) for which assessment of breeding animals can be based only on information from relatives, since the traits cannot be measured on breeding animals. Probably most decisions on the choice of breeding animals are influenced by the apparent merit of relatives. It is, therefore, important to know the accuracy with which the true breeding value of an animal can be estimated from the average apparent merit of relatives.

To determine the precise value of information on relatives, it is necessary to assume the following:

- All relatives under consideration have had the same normal management.
- There has been no special attempt to mate best to best (assortative mating) or best to poorest (disassortative mating).
- The trait is affected by many genes with individually small effects.
- The effect of one gene is not greatly changed by the presence or absence of another.

If these assumptions apply, the value can be calculated by precise mathematical functions of the number of relatives averaged (n) and the heritability of the trait (H). The most important of these functions are given and illustrated in Figure 2. In practice, the assumptions are never all met completely, but even where there is considerable departure from them, the functions in Figure 2 give a good indication of the predictive accuracy of information on relatives.

Own performance is the most accurate single measure of an animal's potential breeding value.

Sire-progeny performance is a measure of actual breeding value. The accuracy of this measure is high and increases rapidly as the number of progeny (from different dams) increases from two to six. The rate of increase declines with larger groups but useful improvement in accuracy may be obtained by increasing progeny group size to 10 to 15. Progeny information is most useful for traits that cannot be measured on the breeding animal itself.

Full-sib performance (full sisters and brothers) has limited application because beef animals have few full sibs. Information on two or three full sibs, adequately adjusted for the fact that each record will have been made in a different year, has greater predictive value than any reasonable number of half sibs; is equal in value to information on both parents; but is less accurate than information on the same number of progeny.

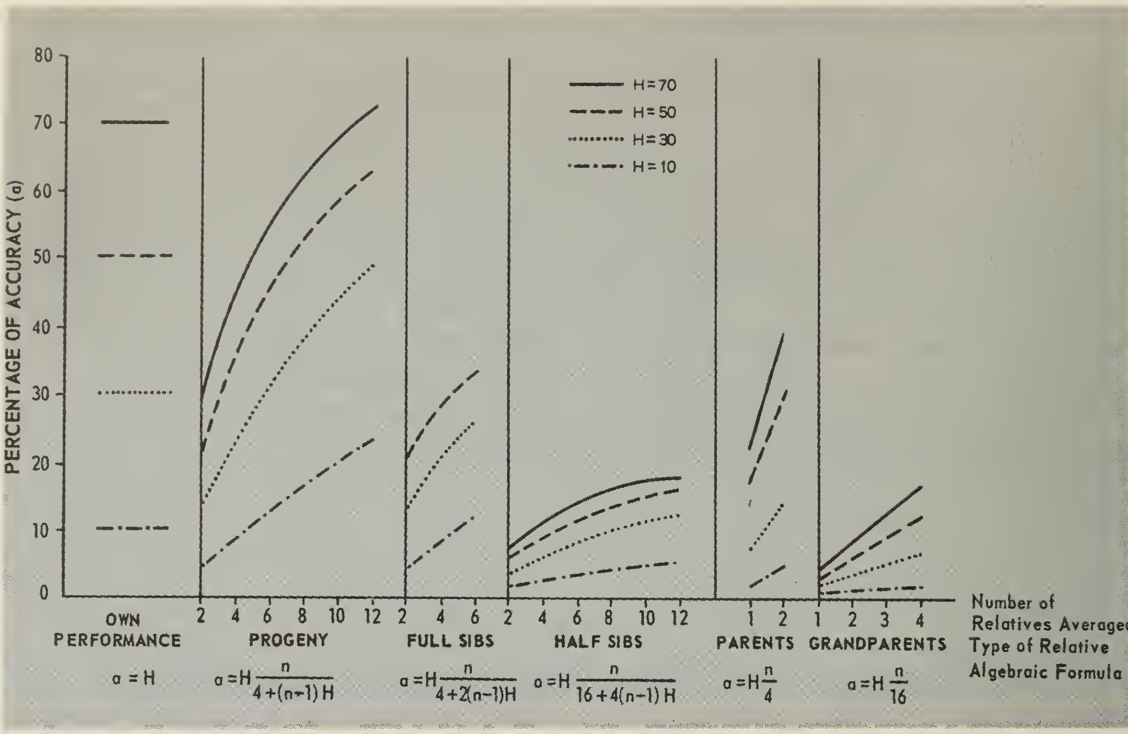


Figure 2. The accuracy with which the breeding value of an animal can be predicted from information on relatives.

Half-sib performance (half sisters and brothers) is of low predictive value and is unlikely to be useful unless nothing else is available. Accuracy increases slowly as the number of half sibs increases but test group sizes above 10 give little additional benefit.

Parent performance has enough predictive accuracy to be useful if information on the animal itself is not available. Information on both parents has about the same predictive value as information on two progeny or two to four full sibs (depending on heritability). Even with low heritabilities, information on the parents is as useful as information on 12 half sibs. Information on one parent has half the value of information on both.

Grandparent performance has one-quarter the predictive value of parent information. Therefore, information on all four grandparents is equal to information on one parent. Only rarely will information on grandparents be worthy of much attention in selecting replacement stock.

Summary

An animal's own performance will generally be the most useful indicator of his breeding value for any trait that can be measured on the live animal (for example, weight for age). When this information is available, little is gained by considering information on any of the relatives. Progeny testing provides accurate genetic information and is particularly useful for traits that cannot be measured on the animal itself (such as carcass traits). Except in the special case of testing for undesirable recessive genes (see page 22) little useful information is gained by increasing progeny group size beyond 10 to 15. In information on neither the individual animal nor its progeny is available, information on one or both parents should be used. Information on half-sib groups or grandparents is of limited value and should be considered only as a last resort.

PERFORMANCE RECORDS AND THEIR INTERPRETATION

The purpose of performance and progeny testing is to assist in recognizing animals that have superior breeding value. By systematically measuring and recording the performance of animals, by adjusting performance as required to eliminate known environmental differences, and by comparing animals in terms of standardized records, a basis is provided for a sound program of genetic improvement. Information obtained through performance testing may be used to estimate the genetic worth of the individual, it may be summarized by progeny groups to give a progeny record or it may be used in other ways. Whatever the intended use, the records must start with the individual animal, the records must be accurate and, if comparisons are to be valid, every effort must be made to provide the same environmental conditions for the animals under test.

Individual identification of every animal in the herd is needed in any system of records. Each calf in a pedigreed herd must be identified at birth by ear tattoo, and the same method is used by many commercial producers to ensure permanent identification of every animal. However, tattoos are impractical for ready identification of animals in a large herd and other methods such as brands, ear tags, and neck chains or straps must be used. With all these methods, it is important to number calves in numerical sequence as they are born and to include a year number, or letter, to designate the year of birth.

Another basic requirement is the written record. Even where few traits are involved, dependence on memory alone may lead to costly errors of judgment. Record-keeping takes time and should be limited to items of performance that have real economic importance. Otherwise records become more hindrance than help.

Essential Data in a Comprehensive Individual Performance Record Program

- Individual identification
- Sex
- Birth date
- Identification of sire and breed
  (In some breeding operations where several sires are allowed with the herd, i.e., multiple sire, identification of the sire may not be known.)

- Identification of dam
- Age of dam when the calf was born
- Date and weight at weaning
- Complete information concerning physical soundness, defects, or problems such as bloating that appear pre- or post-weaning
- Date and weight at approximately one year of age
  (The latter weight may be replaced — or supplemented — by 18-month weight. The important point here is to choose an age appropriate for each herd that will permit a reasonable evaluation of post-weaning gain.)

All these records, taken on each calf produced in the herd, should be summarized annually to provide a basis for individual selection and progeny test information for the cows and bulls used. Dam progeny records will reveal any cows that are irregular breeders, wean lightweight calves, or for other reasons are below average in productivity. When you compare progeny records for preweaning traits, be careful to adjust for differences due to age of dam. Appropriate adjustments for age of dam effects are described on page 28. Progeny records may also include information on special, central tests for feedlot growth, carcass merit, and genetic defects (see page 21).

Measurement of feed requirements has not been included among the records proposed for comprehensive testing. Experience has demonstrated that accurate feed records are difficult to obtain and difficult to interpret in terms of actual efficiency. Because growth rate and feed efficiency are favorably associated, emphasis is placed on growth rate, which can be interpreted with fewer reservations (page 17).

Testing Programs

Many producers with a genuine interest in the steady improvement of their cattle have developed their own performance testing programs. Such programs can be highly successful. However, enrollment under a recognized performance testing program has certain advantages such as provision of forms for the maintenance of systematic records, assistance in summarizing and tabulating results, and advice on the interpretation and effective use of results. Fieldmen whose views and comments may be helpful in establishing a selection program and in appraising the strengths and weaknesses of a herd through impartial eyes are provided through these programs. The main purpose of testing programs is to provide accurate information for performance selection within each breeder herd.

Federal–provincial ROP testing program — This is a Canada-wide testing program for breeding herds. The tests are supervised and detailed regulations regarding the test program are established by each province according to a broad framework laid down by an advisory committee to the Canada Department of Agriculture. Preliminary processing, summarizing, and printing is done at Ottawa and more detailed studies may be undertaken and reported by provincial departments of agriculture.

Government and industry sponsored central testing programs — Central testing stations are used to evaluate cattle from several herds under uniform feeding conditions. Several stations are operated either by the government or industry or through cooperative effort. Specific information on these testing facilities can be obtained from agricultural extension offices, research centers, and universities. Some breeders have developed their own system of post-weaning testing in their own feedlot or by feeding a moderate amount of grain with hay or pasture. It is important to feed at a rate sufficient to stimulate expression of genetic differences in growth rate and to ensure successful breeding of yearling heifers.

Central test station appraisal is limited to evaluating postweaning growth rate for breeding bulls and obtaining growth and carcass data for slaughter cattle. Four uses of central testing, listed in order of potential value to the cattle industry, are: acquainting breeders with testing procedures, progeny test comparisons of sire groups, comparing the performance of individual young sires from different herds, and estimating genetic differences between herds.

Certain factors must be considered in evaluating the contribution of central testing stations. Pretest environment before and immediately after weaning has a major influence on the growth and development of a calf to yearling age. Therefore, it is most important to restrict the age range and the length of time after weaning during which calves are entered on test. An adjustment period of at least 28 days at the station should be followed by a minimum test period of 140 days. Weight per day of age should be emphasized, not just average daily gain during the test period. An adequate sample of a herd must be tested to estimate herd differences. A breeder will gain far more information for his own improvement program if progeny from two or more sires from one herd are tested simultaneously.

INFORMATION REPORTED BY ROP PROGRAM

Reports issued to breeders participating in the Federal–Provincial ROP testing program should include the following performance information:

- Age and weight at weaning
- Average daily gain, birth to weaning
- Average daily gain, birth to weaning, adjusted for age of dam
- Age and weight at end of feeding period
- Average daily gain on feed
- Average daily gain, birth to end of test
- Index (within-herd rank) for preweaning, postweaning, and gain from birth to end of test
- Average daily gain (A.D.G.) from birth to weaning, calculated as follows:

$$\frac{\text{weaned weight} - \text{birth weight}}{\text{age in days at weaning}} = \text{A.D.G.}$$

Other gains are calculated in a comparable manner. Birth weight, if not available, is assumed to be the breed average for the sex involved.

Adjustment of A.D.G. from birth to weaning is given by the formula

$$\text{A.D.G.} \times \text{adjustment} = \text{adjusted A.D.G.}$$

The adjustments, designed to equate performance of all calves to a level equal to that expected from a mature dam, are as follows:

Age of dam	*Male calves*		*Female calves*	
(years)	Noncreep	Creep	Noncreep	Creep
2	1.18	1.10	1.11	1.13
3	1.09	1.09	1.07	1.08
4	1.04	1.05	1.03	1.04
5	1.02	1.03	1.01	1.02
6	1.01	1.01	Mature	Mature
7	Mature	Mature		

For example, the A.D.G. of a creep-fed male from a 3-year-old heifer is multiplied by 1.09 to give adjusted A.D.G.

Weaning index or within-herd rank is calculated as follows:

$$\frac{\text{adjusted A.D.G. to weaning} \times 100}{\text{average adjusted A.D.G. for sex subgroup}} = \text{Index}$$

Averages are provided for both sex groups so that the information may also be used as a progeny test.

In terms of computations alone, this program can be quite helpful to the producer. Full details of the program may be obtained from provincial departments of agriculture.

Interpretation of Performance Records

The performance of every animal is the joint product of its inheritance and its environment. Therefore, valid genetic comparisons cannot be made among animals unless they have been raised under the same environment or, alternatively, the environmental differences can be measured and effectively accounted.

The only unqualified comparisons are those made among animals born and raised during the same season and year within one herd. These conditions permit reasonably complete standardization of such environmental factors as feeding and management. Adjustments are still required for differences in age of dam and age of calf when weighed (at weaning or at 1 year of age). Adjustment for sex of calf (males grow more rapidly than females) may be required when progeny groups are compared unless this is done by using accumulated average herd-index values. Adjustment is not necessary for creep feeding if all calves in the herd are treated alike. Obviously the weaning weight of creep-fed calves is not a valid basis for evaluating the milking ability of the dam. However, milking ability can be estimated by calf gains from birth to 90 days of age (before creep feeding begins). Inbreeding may cause some reduction in fertility, survival, and growth rate. But the levels of inbreeding in most herds are likely to be low and do not require use of special adjustment factors. A low level of inbreeding should not be considered an excuse for substandard performance.

Adjustment of records for these specific environmental factors and calculation of within-herd rank or index are integral parts of performance testing a herd. By ranking all animals available for selection in order of their performance index, the breeder can make accurate and maximum selection for the economic traits he wishes to improve. This focuses attention on the primary function of a herd performance test, for example, augmenting selection decisions within the environment of one herd.

Between-herd Comparisons

When cattlemen consider buying breeding stock from other herds, they must try to assess the proportion of the differences they observe that is really hereditary, because feeding and management practices on different ranches can have a marked influence on growth and development. The following questions and comments may serve as guidelines for making more accurate decisions among herds and the individual animals within them:

Are individual performance records available? A buyer can afford to consider purchases only in herds where the individuals offered for sale are "known quantities" for weaning weight and postweaning growth. A reliable guide is whether a breeder's herd is part of a public or private herd performance testing program.

How long has the herd been under a performance testing program? The longer a breeder has been testing, the more opportunity he has had to appraise the performance of his herd and the greater the likelihood that selection will have had an impact on herd performance.

Is the herd under performance selection or simply under performance testing? In other words, are the best performing bulls and heifers selected for herd replacements? The answer to this question will determine whether a breeder's testing program has really influenced his selection decisions. The only insurance a buyer has that he will be able to purchase stock of higher genetic merit in the future is when breeders are consistently selecting their highest performing young cattle for herd use.

Is other comparative performance information available? Central tests of progeny from several herds can be an aid to selection decisions. This information is regularly available on few herds. These herd comparisons are most meaningful if the same herds have been represented in the same test during more than 1 year. Participation in central testing is an indication that a breeder has a special interest in acquainting the industry with the performance of samples of cattle from his herd.

What is the herd rank of each individual purchase candidate? After choosing a herd from which purchases will be made, the buyer must then use within-herd rank as a basic performance guide for selection. An increasing number of breeders are establishing a price scale according to performance level.

How do the progeny of introduced cattle compare with progeny of "home-raised" progeny? This is the final test. Regardless of any previous performance data, the critical issue is how breeding stock will perform under the buyer's own conditions. Some buyers introduce individuals from two or more herds simultaneously, compare their home-herd progeny performance, and return to purchase further stock from the herds yielding the highest progeny record.

Between-herd performance comparisons for selection purposes becomes a process of elimination. By using the guidelines outlined above, the list of potential sources can be narrowed substantially. The buyer who is conscientiously attempting to improve his herd performance will often find gaps in the performance information. Then his only alternative is to visit prospective herds and make subjective judgments on how management and nutrition may have influenced individual and herd performance.

The final phase of judgment involves objective comparisons of progeny performance. This is an all-important phase because a wrong decision will have a long-term effect on the herd. Sires of low genetic merit should be recognized and eliminated as soon as possible, preferably as soon as their first calf crop has been weaned. To delay the decision on culling until their first calves have gone to slaughter might result in a number of their female progeny being chosen as breed replacements. Under these circumstances, several more years might elapse before all the progeny of an inferior bull can be eliminated from the herd.

Summary

- Inherited differences in performance ability are shown in actual differences in performance.
- Accurate written records of performance permit assessment of inherited differences and hence of potential breeding value.
- Records should be limited to the traits of economic importance.
- Performance should be adjusted for known environmental differences before comparisons are made.
- Own performance is the most reliable guide to genetic potential for traits of high heritability.
- Information on progeny is of primary value in culling the breeding herd.

DEVELOPMENT OF AN IMPROVEMENT PROGRAM

Technical information on the inheritance of performance traits that are important in beef production and procedures used to evaluate these traits for purposes of selection have been described in the preceding sections. To develop a sound herd-improvement program, selection must be combined with a specific breeding procedure or mating system.

Mating Systems

The average degree of relationship between animals mated together defines the mating system.

Mating related animals — Inbreeding is the intermating of related animals. The closer the relationship, the higher the inbreeding. All individuals of a breed trace their ancestry to a rather small proportion of the cattle in existence at the time of breed formation. Therefore animals of a breed are, to a certain extent, related and matings among them may be considered inbreeding. However, the term inbreeding is commonly used only to describe close matings (for example, animals with one or more grandparents in common).

Linebreeding occurs when animals are mated because they share a specific ancestor; their offspring are linebred to that ancestor. Linebreeding is therefore a form of inbreeding, which is high if the favorable ancestor is close and low if the ancestor is distant, designed to concentrate the desirable qualities of the chosen ancestor. For most traits important in beef production, however, such pedigree selection is much less effective than selection based on performance of the animal itself or on the average performance of its progeny.

Inbreeding is detrimental to the vigor and reproductive capacity of all animal species. Close inbreeding is likely to result in reduced fertility, thrift, milk production, and growth rate. For this reason, deliberate close inbreeding should generally be avoided except in the testing for genetic defects of sires for A. I. (page 21).

Herds of domestic cattle may tolerate levels of inbreeding up to 25 perecent, particularly if the level is increased slowly, and individual animals may retain their productivity at levels higher than this; but, on the average, the output of beef from a herd is likely to decline by 5 to 10 percent for every 10 percent increase in the inbreeding coefficient. (The method for calculating inbreeding is given on pages 32 and 34).

There are circumstances in which the advantage of more than minimum inbreeding may outweigh the detrimental effects. For example, closing the herd may improve the accuracy of selection enough to compensate for the associated increase in inbreeding.

A herd that is to be closed for an appreciable period of time should be large enough to keep the rate of inbreeding increase down to 2½ percent per generation. This would require at least five bulls in more or less equal use annually with a minimum of 10 cows per bull. Smaller herds could be closed for periods of two or three generations.

All closed-herd breeding operations should be flexible enough to permit introductions, either to correct weaknesses in the herd or to forestall the adverse effects of inbreeding.

In a selection program, the selection differential is at a maximum when the smallest possible number of sires is used. This may be as few as two or even one, particularly if A. I. is used. If the sires are chosen from within the herd, however, the problem of inbreeding as outlined above dictates that no fewer than five sires should be used, despite the fact that this considerably reduces the selection differential. To get a fairly high intensity of selection (about 1/10) and still use five sires each generation, 50 bulls should be tested each year, and the cow herd should be more than 100 head. To preserve genetic variation in a closed herd so that future selection will be effective, it is wise to minimize the relationship between selected animals that are mated. Maximum selection pressure combined with a minimum inbreeding rate will be in the best interests of herd improvement.

INBREEDING

Inbreeding results from intermating related animals. Genetically, inbreeding results in gene pairs that are "identical by descent," that is, gene pairs with paternal and maternal members that are identical because they are derived from the same common ancestor. The intensity of inbreeding is expressed in terms of the inbreeding coefficient, which is the proportion of gene pairs expected to be identical by descent.

Two different approaches to the estimation of inbreeding follow.

1. The inbreeding of an animal may be estimated from his pedigree by use of the formula:

$$F_X = \tfrac{1}{2}[\tfrac{1}{2}^n (1 + F_A)]$$

where F_X is the inbreeding coefficient of animal X,
F_A is the inbreeding coefficient of an ancestor A that is common to both parents, and
n is the number of generation intervals in a line of descent that traces from one parent to the common ancestor A and back to the other parent.

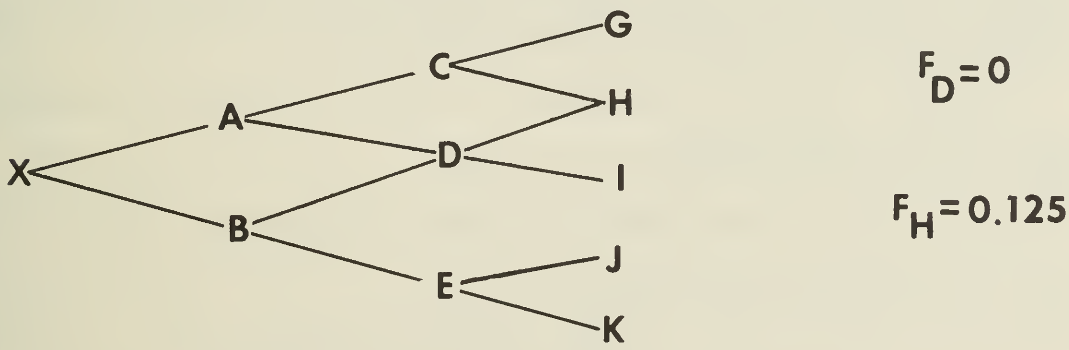
The ½ outside the bracket represents the probability that a gene present as one member of the gene pair in each parent will be transmitted to the same offspring by both parents (making the offspring's gene pair identical, or homozygous). The $\tfrac{1}{2}^n$ inside the bracket represents the probability that a specific gene present in the common ancestor will be transmitted through n different generation intervals. The $(1 + F_A)$ adjusts for the fact that inbreeding in the common ancestor increases the likelihood that the same genes will be transmitted to both parents of animal X.

If the parents of animal X are related through more than one common ancestor, the inbreeding from each must be summed to give the appropriate total inbreeding of animal X. The formula then becomes:

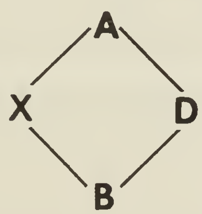
$$F_X = \Sigma\ \tfrac{1}{2}[\tfrac{1}{2}^n(1 + F_A)]$$

where Σ is a sign denoting summation of all appropriate values of $\tfrac{1}{2}[\tfrac{1}{2}^n(1 + F_A)]$.

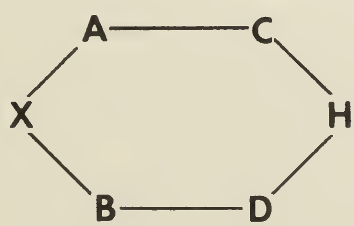
As an example, consider the following pedigree:



The parents of animal X have two common ancestors: D, who was not inbred, and H, who was 0.125 (12.5 percent) inbred. The common ancestors contribute as follows to the inbreeding of animal X.



$$F_X \text{ from D} = \tfrac{1}{2}[\tfrac{1}{2}^2(1 + 0)] = 0.125 \text{ (12.5 percent)}$$



$$F_X \text{ from H} = \tfrac{1}{2}[\tfrac{1}{2}^4(1 + 0.125)] = 0.0351 \text{ (3.5 percent)}$$

$$F_X \text{ total} = \begin{array}{l} 0.125 \\ \underline{0.035} \\ 0.160 \text{ (16.0 percent)} \end{array}$$

2. The average increase per generation of inbreeding in a closed herd of fixed size may be estimated from the formula:

$$\Delta F = \frac{1}{8M} + \frac{1}{8F}$$

where ΔF is the increase in inbreeding per generation,

M is the number of males, and

F is the number of females in the herd.

It is assumed that all animals are given equal chance to produce offspring and that there is no special effort to intermate animals that are either more or less closely related than the average for the herd.

The rate of inbreeding per generation can be estimated from the number of breeding animals in the herd because this determines the probability that genes originating in the same ancestor will reach an offspring through both sides of his pedigree. The larger the population of animals contributing genes, the smaller the chance that any one of them reaches an individual through both maternal and paternal parents, and the lower the per generation increase in inbreeding.

As examples, consider four closed herds of equal size (100 cows) using different number of bulls in each generation.

Herd 1: One bull used on 100 cows.

$$\Delta F = \frac{1}{8} + \frac{1}{800} = 0.125 + 0.00125 = 0.12625 \doteq 12.6 \text{ percent}$$

Herd 2: Two bulls used equally on 100 cows.

$$\Delta F = \frac{1}{16} + \frac{1}{800} = 0.0625 + 0.00125 = 0.06375 = 6.4 \text{ percent}$$

Herd 3: Four bulls used equally on 100 cows.

$$\Delta F = \frac{1}{32} + \frac{1}{800} = 0.03125 + 0.00125 = 0.0325 = 3.2 \text{ percent}$$

Herd 4: Eight bulls used equally on 100 cows.

$$\Delta F = \frac{1}{64} + \frac{1}{800} = 0.01562 + 0.00125 = 0.01687 = 1.7 \text{ percent}$$

Note that the 100 cows contribute only slightly more than 0.1 percent per generation to the inbreeding level of the herd, but the sires contribute large increases because they are fewer in number.

Four generations in a two-sire closed herd and only two generations in a one-sire closed herd are needed to raise the average level of inbreeding within the herd to 25 percent, the equivalent of one generation of brother–sister mating.

Examples of expected inbreeding increments (ΔF) when various types of relatives are intermated:

Mating system	ΔF (Inbreeding increments)
Brother × sister	25.00 percent
Sire × daughter	25.00 percent
Half-brother × sister	12.50 percent
Uncle × niece	12.50 percent
Half-uncle × niece	6.25 percent
First cousins	6.25 percent
One common great-grandparent	3.13 percent

Mating unrelated animals — Outbreeding is the mating of animals less closely related than the breed or population average. This procedure avoids the adverse effects of inbreeding but lacks the advantages of closed-herd breeding. Owners of outstanding herds may find that unrelated bulls with performance as high as their own animals are virtually impossible to obtain. But outbreeding is the only method for introducing superior genetic material into a closed herd.

Crossbreeding is the intermating of animals from different breeds. Also termed hybridization, it is a form of outbreeding and is the direct opposite of inbreeding. As inbreeding leads to deterioration in prolificacy and vigor, so crossbreeding leads to improvement in these traits (pages 14 and 19). Hybrid vigor is particularly evident in the maternal qualities of fertility and milk production. For this reason, hybrid cows are particularly suited to breeding use in commercial herds.

Seed stock production — The main purpose of seed stock breeding operations is to provide commercial breeders with stock of truly superior performance. Breeders who fail to keep full and accurate performance records, or who fail to use this information to ensure that the animals kept for breeding are superior to those sold out of the herd, cannot be considered as seed stock producers. Unless a breeder continually improves the productivity of his stock the commercial cattleman cannot afford to patronize his herd.

Foundation stock — The first requirement of foundation stock for a new herd is that it must include the best-performing stock obtainable. The second is that the stock must come from at least three unrelated sources to increase the likelihood of developing superior combinations of desired traits. The foundation animals may be drawn from one breed or from two or more breeds.

Because of the large number and wide diversity of cattle breeds in the world, it is difficult to argue that more breeds are needed. It is clear, however, that even the most popular breeds have deficiencies that can be corrected most easily by an infusion of genetic material from stocks that are strong in these traits. Thus the relatively low milking ability of the British beef breeds, especially the Hereford, could be improved much more readily by genetic introduction from high milking breeds than by selection. The tendency of these breeds, particularly the Shorthorn, to fatten too readily could be corrected in the same way. In fact, a careful selection of new parental stocks could correct both these deficiencies by a single introduction.

The development of new breeds is not an end in itself. It is simply one effective method for increasing the productive merit of livestock. The technique is to form "gene pools" by crossing two or more existing breeds, intermating the crossbreds, and selecting those individuals that best meet the goals established. By this process, the combination of traits in the parental breeds can be reorganized into a pattern more appropriate to current production requirements. After a period of selection, a new breed can be tested in comparison with other breeds to determine its future value for economical beef production.

Through the formation of hybrid foundations, the breeder, to a meaningful degree, can introduce the genes of his choice into his population. Hybridization is not only a quick way to increase desired genetic variability but can also be controlled and directed by man in such a way as to enhance the likelihood of effective recombinations. This process has been an integral part of livestock improvement since the time of domestication.

Breeding plan — Seed stock production should feature a "closed herd" operation. Thus, the breeding herd should be perpetuated mainly from performance-selected offspring from the breeders own herd. There should be no hesitation of testing outside stock that appear capable of making a genuine contribution to the performance level of the herd and one of every five or ten bulls might well come from outside the herd. These "imports" should be made to earn their way into the herd. They should be chosen initially for outstanding individual performance, and introduced into a small proportion of the herd. Selection based on performance among the resulting calves will ensure that the "imports" contribute in proportion to their genetic value. Another cycle of selection can be made by using the best-performing sons of the superior "import" sires.

A breeding program must be kept simple and, in beef cattle breeding, a simple program yields almost the maximum possible rate of progress. A simple program involves the performance testing of all male and female calves and the selection of the best performers as replacement breeding animals (see pages 40 and 41).

Most gain results from testing males, and as many as possible should be performance tested each year under uniform, practical test conditions.

Size of herd — The number of cows mated to each bull will determine the intensity of selection that can be applied in replacing the bulls. If a sire leaves ten calves, five may be expected to be bulls, and the selection intensity for bulls will be one in five. The selection intensity should be between this and one in ten, which means that each sire should be mated to at least 12 but not more than 24 cows.

However, a useful size of breeding unit should comprise from five to ten bulls, each mated to 20 to 30 cows, or a total cow herd of 100 to 300. The greater the number of bulls, the more scope there will be for closing the herd without serious inbreeding depression. The greater the number of cows per bull, the greater will be the intensity of selection and, therefore, the rate of improvement. To overcome small herd size, several breeders could work together by pooling their herds for purposes of selection.

Turnover rate — An important decision is how long to keep breeding animals in the herd.

Cows should be left in the herd as long as they are producing good calves. On the average, approximately 20 percent of the cow herd must be replaced annually because of infertility, unsoundness of various types, and poor calf performance. This means that at least 40 percent of the heifers produced each year must be selected as replacements. A more rapid replacement rate would simply reduce the intensity of selection practiced and, by reducing the average age of the cow herd, it would tend to reduce the average weaning weight of the calves.

Bull selection is another matter. Progress in a selection program depends a great deal upon how rapidly one generation moves to the next. In the kind of selection program proposed, a bull of superior genetic merit should sire better-performing sons. Thus, to use a bull more than 1 year, no matter how good he seems to be, is likely to reduce the rate of improvement in the long run.

Another factor affecting the generation interval is the age at which animals are first used for breeding. The use of yearling bulls (which should not have difficulty handling the small breeding groups suggested in this type of program) as compared with 2-year-old bulls reduces the generation interval (the time required to make one generation's progress) by 6 months. Breeding yearling heifers, a recommended practice, will have a smaller effect on the generation interval because females remain in the herd an average of 5 or 6 years.

Expected rate and duration of improvement — Selection does not make spectacular changes in a herd of cattle. Because their reproductive rate is low, genetic change takes place very slowly, and a breeder may easily become discouraged. However, experience has shown that the type of selection program recommended here will yield results if carried out persistently. In a closed-herd breeding program with main emphasis on yearling weight, the rate of improvement will likely be between 5 and 10 pounds per year. A program of this type actually yielded 40 pounds improvement in average yearling weight between 1960 and 1965 at the Research Station, Lacombe. Introduction of outside stock may, of course, result in faster improvement if outside stock superior to stock found within the herd can be obtained.

It is impossible to predict how long a selection program will continue to be effective. In experiments with laboratory mice, improvements due to selection often become irregular or cease altogether after 20 or more generations of selection. However, this is equal to 80 to 100 years for the average cattle operation.

SAMPLE BREEDING PLAN

A typical breeding plan might be carried out as follows:

- Use 200 individually identified breeding cows and 10 yearling bulls (20 cows mated to each yearling bull).
- Begin breeding as early as it is practical for the district concerned and have as many as possible of the cows settled in the first six weeks of breeding. Late calves cannot be accurately compared with spring calves, and they are less likely to be ready for breeding in time the following year. Each bull should be used in a separate, well-fenced pasture or artificially so that the sire will be known for all the offspring if maintenance of pedigree registration is required. In some breeding operations, the identity of the sire may not be important. Under such circumstances more than one bull could be run with a group of females. This offers some insurance against low conception due to nonbreeding or infertile bulls.
- Calve out and rear calves under uniform conditions and management. Individually identify all calves at birth, and record date of birth and dam identification. Do not castrate male calves.
- Weigh calves at weaning and record calf identification, weight, and date. Calculate weight per day of age. To a large extent this is a measure of the dam's milk production — particularly if creep feeding is not practiced.
- Cull cows after weaning on the following priorities: open cows, based on pregnancy diagnosis, major physical unsoundness, age, and calf performance.

- Place the calves on a feeding test using a plane of nutrition adequate to stimulate expression of genetic differences in growth rate, although not necessarily full feeding. Heifers should be fed to gain approximately 1 pound per day to be ready for breeding as yearlings.
- Weigh the calves off test at about 1 year of age (breeding will begin again when the oldest calves are 15 months of age) and record calf number, weight, and date. Compute the weight per day of age to the end of the test, adjusted for age of dam.
- Select the 10 bulls with the highest yearling weight per day of age as herd sires for the coming season.
- Keep the heaviest 60 percent of the yearling heifers for breeding. Select for yearling weight among *pregnant* heifers after the breeding season, keeping approximately 40 pregnant heifers to replace the cows culled each year.
- If possible, avoid all matings among animals with more than one grandparent in common.

Commercial Production

The first concern of a commercial beef producer is the fertility, survival, and milk production of his cow herd. Since these are traits that are improved by hybrid vigor, the use of crossbred cows is highly recommended. Before a breeder embarks on a crossing program, he should know exactly how he is going to replace his crossbred females. Two systems of crossbreeding that are recommended follow.

Rotational crossbreeding

- Select two or three breeds having the combination of maternal, growth, and carcass traits desired in the crossbred brood cows and the feeder calves (for example, breeds A, B, and C).
- Mate the existing cow herd continually to bulls of breed A.
- Select crossbred heifers for growth rate and mate them continually to bulls of breed B.
- If two breeds are used, mate selected B × A heifers to breed A and repeat the cycle.
- If three breeds are used, mate selected B × A heifers to breed C bulls; then select C × (BA) heifers to mate to breed A bulls and repeat the cycle.
- Continue the same system indefinitely, always selecting the best-performing replacement heifers and mating them to the breed of sire to which they are *least related.*

Specific three-breed crossing

- Select three breeds for crossbreeding — two (breeds A and B) that will produce crossbred cows with high fertility and milking ability, and a third (breed C) with superior postweaning growth rate and carcass merit.
- Locate and encourage development of reliable sources of A × B heifers

sired by performance-selected bulls. Gradually replace the cow herd with purchased crossbred females, to be used as long as they are productive.

- Mate A × B females continually to breed C bulls.
- Market all calves and continue to purchase A × B replacement females.

Rotational crossbreeding lets you select your own replacements but requires the continual presence of all breeds of bulls to keep the program systematic. The performance of crossbred calves may vary more than straightbreds because of the variability among the calves sired by different breeds and raised by cows of differing backgrounds.

Specific crossing permits a breeder to use each breed according to its most favorable performance traits. Only one breed of bull is required at all times, simplifying bull maintenance and contributing greater uniformity to the calves marketed. Reliable sources of crossbred heifers are necessary.

Once crossbred cows are in production, genetic improvement will depend upon how intensively breeders select to improve the genetic merit of seedstock herds supplying bulls for crossbreeding.

Culling the cow herd — Most of the culling in commercial cow herds is automatic, that is, due to death, aging, or any factor that renders the cow unfit for further breeding. If the cows and calves can be individually identified, a record should be kept of birth dates and weaning weights, with adjusted (for age of dam) weaning weight per day of age computed for each calf. All open cows should be culled as soon after the close of the breeding season as is possible. An open cow will not contribute a calf that will be available for selection the following year and she should be replaced by a pregnant heifer. Cows whose calves have had a low weaning weight per day of age should also be culled if promising heifers are available to replace them. As with purebred herds, there will be little opportunity to cull on lifetime cow production because unsoundness and infertility alone may require culling 20 percent of the cow herd, and there will not likely be suitable heifers available to replace more than 25 to 30 percent. Further, since 2- and 3-year-olds wean lighter calves than mature cows, a commercial operator may wish to avoid having too many of them in his herd at one time.

Choosing replacement heifers — If heifers are to be bred as yearlings, a practice generally recommended on economic grounds, the operator must choose the heaviest ones at breeding time. Yearling heifers should average about 600 pounds at the time of breeding. If the necessary records are available, the replacements should be picked on adjusted weight per day of age in order to single out those calves with good growth potential from good milking dams. However, practical considerations must come first, and a particularly late calf with a good weight per day of age may still be too light for breeding.

Buying bulls — Bulls should be obtained from a reputable breeder engaged in performance selection. The main measure of the bull is his weight per day of age at the end of the test. The considerations involved in selecting a replacement sire from another herd have been given on page 29. The prospective buyer should see the records on *all* the bulls in the test, and should try to get one that tested above the average. He must not settle for a bull that tested in the lower third because it is unlikely to perform better than a bull calf picked at random from his own herd.

Artificial insemination gives the commercial producer a chance to pick highly selected replacement bulls for his herd. To choose a bull from an A. I. stud, he should consider both the individual performance record and the progeny record of the animals available. However, he should remember that A. I. studs must replace their sires and therefore to prove the breeding worth of potential replacements he must use progeny tests. Owners of commercial herds, particularly those who have large herds and keep good records, may assist in this progeny testing work by making some use of unproven bulls from A. I. studs. This does not involve any real risk because bulls must show considerable individual merit before they are accepted at an A. I. unit.

PERFORMANCE SELECTION WITH MINIMUM RECORDS

Performance selection is often criticized for requiring too much time and expense and too many records. This criticism is justified if a breeder collects records that are never useful for either selection or sale of stock. Although full particulars are always given for *detailed* records of performance (page 26), *simplicity* within any breeder's program is also emphasized. It is the prerogative of the breeder to use those parts of a records program that best satisfy his objectives and those of the commercial beef industry. A sample performance selection program with minimum records is described here.

Objectives

To select cattle that will grow more rapidly to 1 year of age.

To maintain a herd with high reproductive performance and physical soundness.

Mating plan

Closed herd: selection of all male and female replacements under one-herd environment.

If registration is required, use single-sire breeding pastures; otherwise, multiple-sire breeding can be practiced to place some natural selection pressure on mating efficiency of bulls.

Herd size

A minimum of 125 cows and 6 bulls.

Breeding season

Restricted to no more than 60 days for accuracy of performance comparison of calves born, and to maintain sound management and nutrition for high herd fertility.

Calving season

Use double ear tags to identify all calves; record birth date and number brand of dam. Record any observed calf defects.

Nursing period

Record unsound or extremely small calves and the number of their dam, for potential culling of both calf and dam. Aim to have notes on more cow–calf pairs than can be culled for production.

Weaning time

Weigh all calves, recording weight, calf number, and date.

Cull the lightest 25 percent of the bull and heifer calves based on their *actual weaning weight* and start them on feed for slaughter.

Feed the selected bull calves sufficient to stimulate expression of genetic differences in growth rate. This feeding can be done in a feedlot or with grain and hay on pasture.

Feed the selected heifer calves to gain 1 pound per day to prepare for breeding as yearlings; the weight at breeding time should be 625 pounds.

Number brand selected heifers for quick identification, using the year number and their individual herd number.

Cull cows that are open (as shown by pregnancy testing), physically unsound, or unproductive (as shown by calf performance).

Yearling (12 months)

Weigh all calves selected at weaning, and record their weight and calf number, and the date.

Compute weight per day of age on all bulls. Select on yearling weight, keeping more than the desired number of bulls to permit some culling for physical unsoundness. Replace no less than 50 percent of the bull battery each year.

Cull only the physically unsound yearling heifers and those that may weigh less than 625 pounds at breeding time, therefore leaving most of them for breeding.

Long yearling (18 months)

Cull all open heifers.

Select among *pregnant* heifers for high absolute weight and physical soundness to reduce the total number of replacement females to that desired for the herd.

GENERAL COMMENTS

This selection and breeding program is more a timetable for management than a detailed record-keeping program. Decisions are made one at a time, leaving adequate opportunity for selection at yearling age, which is the main objective for improvement. This permits the breeder to remove the more obvious culls from the breeding herd and to feed them up for early slaughter.

To many cattlemen, ear tagging calves at birth is a detailed practice that is most disturbing. However, the easiest time to handle the calf and to record the number of its dam is at birth. Then, if a nursing calf is marked for probable culling, the breeder has to record only the dam's brand number. Her calf can be sorted off for culling when weighed at weaning. Bulls can be selected accurately for yearling weight per day of age only if the birth date is known.

Culling for weight at weaning will discriminate against lower-milking and late-calving dams. Also, heifers that weigh less than average at weaning are unlikely to be heavy enough to conceive early as yearlings or to calve successfully as 2-year-olds.

Under this proposed system no records are accumulated for the cows. When each cow is charged with weaning a heavy calf each year to remain in the herd, no printed lifetime records for cows are required.

Most attention is focused on selection of bulls, which accounts for over 80 percent of the potential genetic progress in a herd. The only calculations needed are those for weight per day of age for bulls. No adjustment is made for age of dam effects. This biases selection against bulls produced by younger dams, except that the younger cows have been performance selected and are genetically superior to older dams and they show part of this in the weight of their progeny. However, there is little discrimination against selection of heifer calves produced by 2-year-old dams because a large percentage of the heifers born are used for replacements.

Final selection of heifers is delayed until after breeding so that the breeder can cull for reproductive efficiency before first calving. By this method the breeder is assured of retaining the heaviest heifers among those that conceive, and thereby of increasing percentage calf crop. Heifer selection for *actual* yearling weight is emphasized because of its importance for ease of calving at 2 years.

The advantage of this program is its simplicity. It makes use of the large differences that are easily recognized by the breeder and does not require him to take a large number of written records. It is a radical approach, but it has proved to be practical and effective if followed consistently.

BREEDS AND CROSSES

Domestication of wild cattle began 10,000 years ago in the Middle East. From there, domestic cattle accompanied man east to India and China, south to Africa and west to Europe, thence to Britain, the Americas, and Australia. As parts of the world cattle populations were split and became isolated geographically, distinctive types and breeds developed which differed genetically from other isolated stocks. Local environmental conditions imposed natural selection for adaptation which further separated the stocks genetically. Man selected certain preferred or unusual traits, which resulted in recognizable breed characteristics. It is less clear whether cattle were genetically adapted through selection to man's specialized purposes or whether man adapted his purposes to the particular capabilities of his cattle, such as butter production, cheese production, beef, and draft. Man improved the traits that were easily seen but new techniques now evolving, which provide more accurate appraisal of economic merit, should result in more rapid improvement of productive characteristics.

Breeds

Several breeds have been tested as straightbreds and in crosses for beef production. These breeds have been grouped by genetic and (or) geographic origin into the following categories:

British breeds — Hereford, Aberdeen Angus, Shorthorn, Galloway, and West Highland were developed in England and Scotland. These breeds are shorter legged and blockier in conformation than other breeds. The first three fatten earlier than other breeds.

European breeds — Charolais, Holstein-Friesian, and Brown Swiss originated in France, the Netherlands, and Switzerland respectively. These breeds are large in size, fatten less readily, and milk more heavily than the British breeds. Other European breeds that appear to have potential for Canadian use include the Simmental (Switzerland), Limousine (France), Romagnala (Italy), and South Devon (England). These breeds have not yet been evaluated under Canadian conditions.

Zebu — The American Brahman consists of several Indian Zebu breeds. These humped cattle are strikingly different in conformation from other cattle and may be considered to be a separate subspecies. The Brahman is noted for superior heat tolerance and relatively slow growth as straightbreds. Conception rates are reduced in lactating females and sexual maturity is late. Mortality in Brahman calves is higher, though milk production is superior, to that of the British breeds. Despite the apparent deficiencies of the Brahman, heterosis in crossbreeding is dramatic and the breed deserves further evaluation for Canadian use.

New breeds — The Santa Gertrudis, the first new breed of cattle to originate in North America, was developed by the King Ranch in Texas from a Brahman × Shorthorn foundation. Selection has been largely for performance. The Beefmaster was developed by the Lasaters of Texas and Colorado from a Hereford, Shorthorn, and Brahman foundation with selection based solely on performance traits. The Santa Gertrudis and Beefmaster were intensely selected on a closed-herd basis following the initial crossing of the parental breeds. Other new breeds such as the Brangus (Brahman–Angus) and Charbray (Charolais–Brahman) have not been subjected to such a period of selection before release to the general public. Crossbreds with the appropriate percentage breeding of each parent breed are accepted for registry. Generally, these breeds derived from the Brahman are superior to the parent breeds in growth rate and milking ability and carcasses are intermediate to the parent breeds in fatness, tenderness, and palatability.

Other breeds — In Britain, Ayrshire cows mated to various breeds of bulls are an important source of beef. The Lincoln Red, Red Polled, Welsh Black, Devon, South Devon, and Sussex have been tested in crosses, but only limited performance data are available.

The Jersey and Guernsey are classed as inferior for beef production, but Jersey beef has been shown to be more tender and palatable than a wide range of breeds including the Hereford, Angus, Holstein, Charolais, and Brahman. Jersey carcasses are inferior by conformation standards and have excessive internal fat, but they have little external fat and large rib eye muscle areas compared to their carcass weight. Their desirable eating qualities and high milk solids could be valuable contributions to breed development.

Little is known of the beef qualities of the Canadian breed, which is found chiefly in Quebec.

Specific Breeds

A general assessment of the various breeds based on experimental results follows.

Herefords are predominant in Canadian beef production and their reputation for winter hardiness under range conditions has given the breed a strong hold throughout western North America. They fatten more readily than non-British breeds (though generally they are leaner than the Angus and Shorthorn) and their growth rate and carcass quality are good. Herefords have a higher incidence of cancer eye, sunburned udders, and genital prolapse than other breeds. The first two are a direct result of selection for white face and underline

— and therefore absence of protective pigment in these areas. A more serious deficiency of the breed is inferior milking ability. In many comparisons, Hereford cows have been consistently surpassed in milk production by other breeds and crosses. This may have improved the breed reputation for winter range hardiness, as low milkers start the winter in better condition. However, as more intensive production and better management practices are adopted by the industry, milk production will become important.

Aberdeen Angus have a high reputation in carcass competitions. Whether this reputation will be maintained when newer carcass evaluation techniques are used is yet to be determined. Angus calves are generally smaller at birth than calves of other breeds. This, coupled with the fact that the breed is polled, has led to the practice of mating Angus bulls to yearling heifers in cases where difficult calving is expected. However, experiments have not shown that yearling Hereford heifers bred to Angus have any less difficulty during calving than those bred to Herefords. This breed generally surpasses the Hereford in milking ability.

Shorthorns, once the leading beef breed in North America, are considered to be the best of the British beef breed in milk production. Growth rate is good but reproductive performance is lower than in other breeds tested under comparable conditions. The most serious criticism is that carcasses are fatter and the yield of lean beef is consistently lower than in other breeds.

Galloway and West Highland, though not widely tested in Canada, have a good reputation for hardiness. Feedlot gains are lower than for other British breeds, but, in tests conducted in Alberta, Hereford–Highland calves and crossbred cows performed better than straightbred Herefords.

Charolais, either pure or in crosses, grow more rapidly and have better milking ability than the British breeds. As straightbreds, they may be difficult to fatten sufficiently to satisfy present grading standards. However, crosses with British breeds generally produce a high-grading, lean carcass. The crosses are superior in yield of lean beef mainly because they have less fat at acceptable market weights.

Holstein and Brown Swiss are high-milking breeds. Their rate of gain in the feedlot is high. Their carcasses lack the fat cover and conformation required by the present "choice" grade standards but their lean content is high and research has shown that the quality of the beef is competitive with British beef breeds. Carcass grading results are improved by crossing with the more readily fattened British breeds. The general suitability of these breeds and their crosses as range cows is now being evaluated. Tests have not shown any udder damage due to high milk production. In fact, Brown Swiss cows tested under American range conditions have weaned exceptionally heavy calves. Both these breeds may prove useful for improving udder structure and milking ability in beef herds.

Brahman have potential for crossbreeding. In extensive tests conducted at Manyberries, Alberta, crossbred progeny from Herefords, Angus, and Shorthorn dams grew more rapidly than straightbred Herefords and the crossbred females were superior to Herefords in milking ability and longevity.

Selection of a Breed

Breed selection should be based upon the productive merit of the breed and its value as a source of seed stock for commercial production. Performance in crosses with breeds that predominate in the industry is of primary importance.

The value of a breed for crossbreeding is largely determined by the amount of heterosis generated in the crossbred progeny and the actual productive merit of those offspring. The amount of heterosis is related to the genetic divergence or "unrelatedness" of the breeds being crossed. Therefore, more heterosis would be expected from crossing the Brahman and Hereford than from crossing the Shorthorn and Hereford. However, since heterosis is measured against the average of the parent breeds, two breeds that cross well may still produce crossbred progeny that fall short of the better parent or of other more productive straightbreds. For example, some Holstein crosses milk well above the average of the parent breeds but still do not exceed the Holstein.

Crossbreeding Results and Expectations

Average results that may be expected in crossbreeding among some of the breeds available on this continent are summarized in Tables 5, 6, and 7. One general observation from Table 5 is that crosses that provide a large heterotic advantage in weaning weight may not be the best in terms of rate of feedlot gain. Also, in some trials, crossbreds have done less well than straightbreds. Such negative results are infrequent, but they show that as much care must be taken in selecting sires for crossbreeding as for straightbreeding. A broad comparison of crossbred calf performance from six breeds of sires is given in Table 6. Table 7 illustrates the additional heterotic advantage that may be obtained by using the crossbred female as a brood cow.

Crosses among British breeds — The advantages of crosses among British breeds are modest. Crossbred calves out of Hereford dams and sired by Angus, Shorthorn, and Highland bulls have given increases over the straightbred Herefords of approximately 5 percent in weaning weight, survival, and rate of feedlot gain. They have shown little heterosis in carcass merit. Crossbred females have had earlier puberty, more efficient reproduction, 5 to 10 percent greater milk production, and heavier calves at weaning than straightbred Herefords.

European–British crosses — Charolais, Holstein, and Brown Swiss sires used on Hereford dams produce calves that generally wean 15 to 25 percent heavier than straightbred Herefords. In some experiments, the advantage has exceeded 100 pounds per calf. Advantages from 5 to 15 percent in rate of feedlot gain have also been consistently reported. Carcasses are leaner, and have averaged one-third to two-thirds of a grade lower, but the yield of trimmed carcass is higher because of less fat waste. Crossbred females are substantially superior to straightbred Herefords in milking ability and weight of calves at weaning.

Brahman and Brahman derivatives crossed with Hereford — Brahman

Table 5. Experimental comparisons of crossbreds out of Hereford dams with straightbred Herefords

Station	Years	Breed of sire	Breed of dam	Calves weaned	Age at weaning	Crossbred advantage		Postweaning A.D.G. crossbred advantage	
						Pounds	Percent	Pounds	Percent
Louisiana	1952–56	B	H	21	180	+ 5	+ 1.2	+ 0.20	+ 10.9
Sonora, Texas	1921–29	B	H	205	180	+ 10	+ 2.7	—	+ 68.0
Lufkin, Texas	1944–57	B	H	101	205	+ 27	+ 6.5		
McGregor, Texas	1952–58	B	H	1737 in 15 breed groups	180	+ 38	+ 9.8		
Alberta	1952–58	B	H	63	173	+ 22	+ 6.5	—	+ 17.9
Alabama	1948–53	B	H	100	270	+ 27	+ 5.2		
Alabama	1949–52	B	H	28	220	+ 31	+ 6.1		
Louisiana	1952–56	BA	H	21	180	— 3	— 0.7	+ 0.08	+ 4.4
McGregor, Texas	1952–58	SG	H	1737 in 15 breed groups	180	+ 40	+ 10.4		
Quebec	1959	CB	H	25	?	+ 70	+ 18.9	+ 0.27	+ 14.2
McGregor, Texas	1952–58	C	H	—	180	+ 83	+ 21.5		
Louisiana	1952–56	C	H	23	180	+ 3	+ 0.7	+ 0.18	+ 9.8
Miles City	1958–59	C	H	14 steers	180	+ 71	+ 17.9	+ 0.33	+ 14.1
Alberta	1957–59	Hi	H	64	?	+ 26	+ 6.7	+ 0.01	+ 0.5
Louisiana	1952–56	A	H	26	180	— 47	— 11.3	— 0.04	— 2.2
Ohio	1940–47	A	H	46 steers	220	+ 38	+ 9.6	+ 0.03	+ 1.7
Ohio	1940–47	A	H	49 heifers	220	+ 8	+ 2.1	+ 0.01	+ 0.6
Louisiana	1952–56	S	H	21	180	— 23	— 5.5	+ 0.16	+ 8.7
Alabama	1951–53	S	H	58	270	+ 6	+ 1.2		
Miles City	1940–41	S	H	57 steers	180	+ 19	+ 4.7	+ 0.20	+ 11.4
Miles City	1940–41	S	H	55 heifers	180	+ 8	+ 2.1		
Nebraska	1960–63	A	H	37 heifers	200	+ 33	+ 8.1	+ 0.07	+ 16.5
Nebraska	1960–63	S	H	31 heifers	200	+ 43	+ 10.6	+ 0.10	+ 17.8
Nebraska	1960–63	A	H	29 steers	200	+ 38	+ 9.0	— 0.10	— 5.5
Nebraska	1960–63	S	H	33 steers	200	+ 37	+ 8.7	— 0.06	— 3.4

A — Angus; B — Brahman; C — Charolais; H — Hereford; Hi — Highland; S — Shorthorn; SG — Santa Gertrudis.

Table 6. Influence of breed of sire on weaning weight and feedlot performance of crossbred calves

	Both sexes (1961–64)				Steers on feed (1961–63)			
			Feeder grade				Carcass grade	
Sire	Number of calves	205-day weaning weight adjusted for age of dam and sex of calf (pounds)	Grade	Score	Number of steers	Average daily gain on feed (pounds)	Grade	Score
Angus	141	405	H-Good	10.7	50	1.94	L-Choice	12.0
Brahman	134	442	Good	9.7	52	1.84	Good	10.0
Brangus	147	429	Good	10.4	70	2.02	H-Good	10.8
Charolais	172	475	H-Good	10.6	40	2.03	H-Good	10.7
Hereford	122	426	H-Good	11.3	46	2.02	H-Good	10.9
Shorthorn	146	426	H-Good	11.0	55	2.00	L-Choice	12.1

Table 7. Calf performance in relation to system of mating (straightbred versus first crosses versus calves from hybrid dams)

	Both sexes (1961–64)				Steers on feed (1961–63)			
			Feeder grade				Carcass grade	
Group	Number of calves	205-day weaning weight adjusted for age of dam and sex of calf (pounds)	Grade	Score	Number of steers	Average daily gain on feed (pounds)	Grade	Score
Straightbreds	124	386	Good	9.9	42	1.85	H-Good	10.8
Single crosses	217	415	Good	10.4	72	2.08	H-Good	11.1
Backcrosses	258	455	H-Good	10.7	99	1.96	H-Good	11.1
3-Breed crosses	276	456	H-Good	10.8	105	2.01	L-Choice	11.6

crossbreds out of Hereford dams give increases of from 5 to 20 percent in weaning weight but their rate of feedlot gain shows little heterosis and may be less than for straightbred calves. Carcasses carry less fat but are less tender than the British breeds.

Brahman crossbred cows have considerably greater milking ability than the British breeds and wean calves 15 to 25 percent heavier than straightbred Herefords. Some reports show that Brahman-cross females may have unsatisfactory conception rates if bred while nursing a calf. In nearly all tests, however, net production per cow has tended to favor the crossbred.

Calves sired by Brahman derivatives, for example, Santa Gertrudis, Charbray, and Brangus have shown heterosis in weaning weight approximately equal to that shown by Brahman crosses.

Summary

The typical commercial producer with cows of British breeding has several breed choices for crossing. He may forgo heterosis and breed within an existing breed of cattle, or he may achieve slight (almost negligible) heterosis by crossing inbred lines with that breed. However, straightbreeding is the least productive route open to the commercial industry.

Modest crossbred advantages may be achieved by crossing the British breeds. Presently, however, the European breeds and the Charolais, in particular, offer the most consistent crossbred advantages, with the least penalty on carcass grading.

Crossbred females must be returned to the herd if the full advantages of crossbreeding are to be realized. The selection of a breed of sire for crossbred females is complicated by grading standards that penalize the leanest carcasses. If the cow herd is predominately British, sires of non-British breeds should be used and if the cow herd is predominately non-British, sires of the British breeds can be used. Non-British sires may reduce carcass grades (though not cutout value) and British sires will reduce milking ability and increase fatness.

When the seed stock producers make their initial choice of breeds, they must be guided by the demands of the commercial industry. Therefore their choice should be based on the potential crossing performance of the breed as well as on the productive merits of the straightbreds.

ARTIFICIAL BREEDING IN BEEF CATTLE

A description of beef breeding procedures is not complete without mention of artificial insemination. This breeding technique, widely adopted by the dairy industry, is receiving increased attention from the beef industry.

Advantages

- Sires with known ability for producing fast-growing calves can be brought within the reach of all breeders. (Refer to page 21 for information on bull testing for A. I.)
- Increased uniformity within a calf crop, a decided advantage to the large beef producer, can be achieved by using fewer sires to service the herd.
- Venereal diseases are virtually eliminated by using disease-free bulls and sterile instruments.
- Crossbreeding is made easier in both large and small herds. Commercial breeders can take advantage of heterosis from the crossing of breeds without having to maintain bulls of several breeds and without having to provide separate breeding pastures.
- The close herd observation needed to locate the cows in heat results in improved herd management. Individual identification and keeping of herd records will permit more accurate selection of replacements.
- Breeding costs are generally lower for artificial than for natural breeding.

Limitations

- Deleterious recessive genes may be spread widely if carriers are not detected (see page 22).
- Dairy breed associations allow the registration of purebred calves sired artificially but some of the beef breed associations are more restrictive. The breed society should be contacted for up-to-date information on the use of A. I. for production of purebreds.
- Summer range may be somewhat remote, of low carrying capacity, or of rough topography, any of which would make it difficult to observe all the cows at least twice a day during the breeding season. This limita-

tion may be overcome by calving in the winter and breeding the cows before the pasture season. If winter shelter and feed quality are adequate, this system more fully utilizes the labor on small farms. Further, early calves can utilize pasture during their first summer and weigh heavier by fall, thereby increasing beef production per acre. Another approach is to use a small breeding pasture and supplemental feed during the A. I. period.

- The availability of a trained and competent technician and riders will affect the extent to which artificial mating can be applied to beef cattle operations.
- The number of cows to be bred artificially in an area may have a bearing on the feasibility of applying A. I. In most farming areas an artificial breeding service is available. Ranchers and community pastures have to acquire the services of a technician and riders for the A. I. breeding period. Most artificial breeding units have relief technicians who are available for summer work in range areas. Groups of cattlemen may arrange to send one of their men to take a short training course in artificial breeding, thus ensuring service for the group.

Facilities Required

The breeding pasture should be a small, open area of high carrying capacity reserved specifically for use during the breeding period. To reduce cost and to increase efficiency, several small herds might be combined in one breeding pasture. The herd should be put into the breeding pasture at least one week before the start of breeding. The riders should circulate among the cattle during this prebreeding period to accustom them to the presence of man and horse.

A simple and inexpensive corral and chute arrangement is illustrated in Figure 3. These may be constructed of planks or poles. The chute may be built to hold one to five head, depending upon the size of the herd. Both backout and walk-through chutes have been used successfully. The latter requires a space behind the lead cow where the technician can step to perform the insemination. In the backout chute the technician inseminates each cow beginning with the last cow in the chute and allowing her to back out before proceeding with the next cow in line. Near the chute there should be a shelter to store semen and equipment and for the use of the technician in preparing his instruments. The corral should be situated so that the cows do not have to be driven more than one-half mile. It should be near a watering place, since cattle tend to congregate there, and it should be near the downwind fence line, as cows tend to drift with the prevailing wind. In a large field, several smaller corral systems located throughout the field instead of one centrally located large corral eliminate driving the cattle any great distance. Do not use a squeeze chute because nervousness caused by restraint and noise will result in lowered conception rates.

Semen is purchased in individual breeding doses that are frozen in sealed glass ampoules and it is usually stored in a liquid-nitrogen refrigerator. This

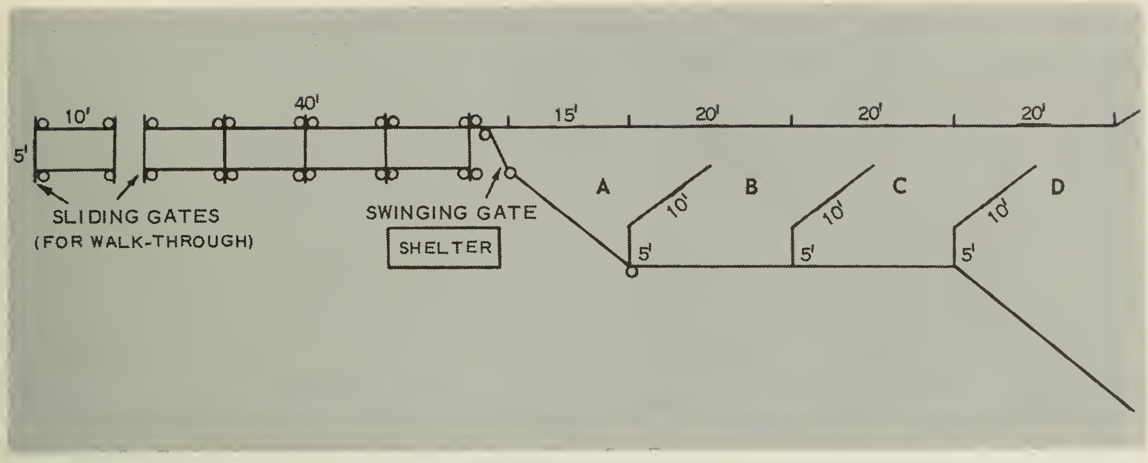


Figure 3. Corral and chute arrangement for artificial insemination. *A* is the crowding pen. *B* is the holding pen for the morning group and *C* is the holding pen for the afternoon group. *D* is a wing-fence area for easy corralling.

consists of a hollow-walled, vacuum-insulated drum with a narrow neck, which requires refilling with liquid nitrogen only once in three or four weeks.

Upon request to semen-producing organizations, a breeder can obtain complete information on services and equipment available and photos, pedigrees, and performance records of the bulls in stud.

Management

Management of the breeding herd is vital to the success of an artificial breeding program. Each cow must be bred at the proper time in her breeding cycle and cows in heat must be accurately identified. Cows should receive a sound, nutritious diet, not only to show heat symptoms but also to conceive readily. Deficiencies of energy, phosphorus, and vitamin A are the most common nutritional causes of poor conception. Supplemental feeding before and during the breeding season helps to overcome this problem and helps to gather the herd twice a day for close observation for signs of heat. Heat symptoms are most pronounced early in the morning and early in the evening, and cows should be watched closely during these periods.

Cows exhibiting heat in the morning should be bred that afternoon and those observed in heat during the afternoon and evening should be bred the following morning. Typical symptoms of cows coming into heat are not unlike those of cows going off heat. Therefore, it is necessary to watch the cows at two periods in the day. The usual symptoms of cows coming into heat are the following: cows standing head to head, ruffled hair on the back and reddened areas on the pelvis from riding, clear stringy mucus sticking to the tail and hips, swollen vulva, restless pacing and bawling, and frequent attempts to ride other cows. A cow that will stand to be ridden by others is in standing heat and should be bred 12 hours later for best results. Refer to the accompanying illustration for the best time to breed for highest conception results.

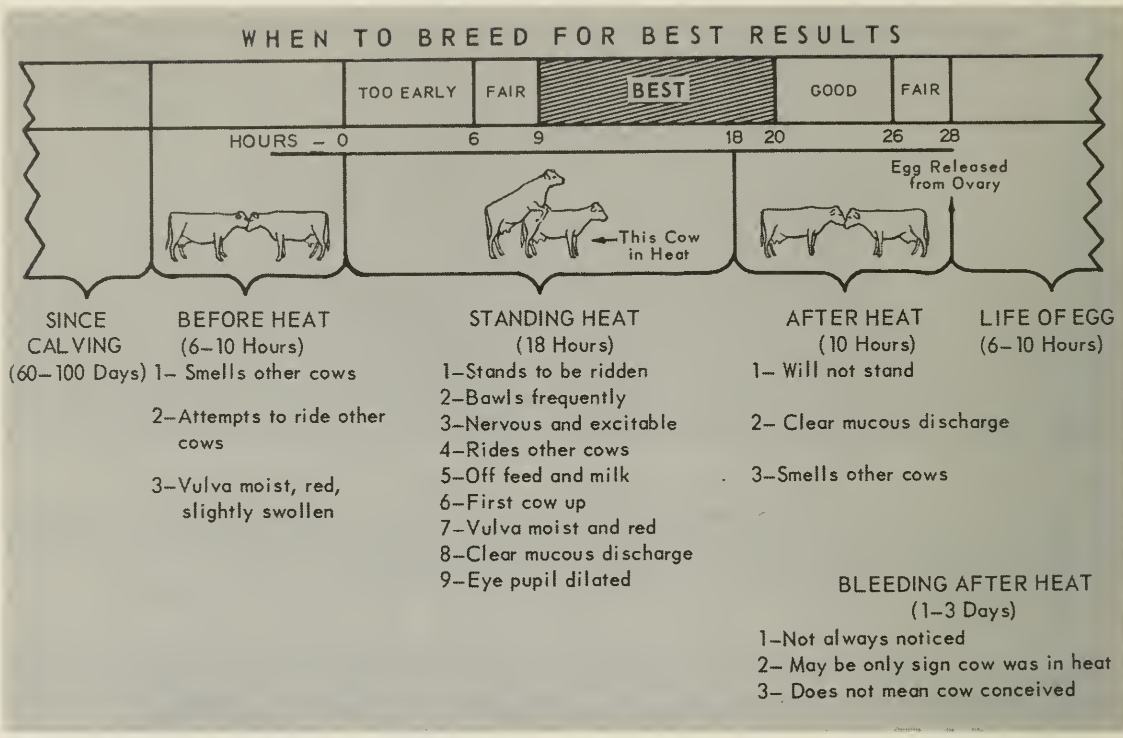


Figure 4. Conception results are best when the female is bred no earlier than 60 days after calving and during the latter part of standing heat.

Aproned bulls or vasectomized bulls or treated steers as detectors of cows in heat do not increase the efficiency of heat detection. Heat-detection pads may find some use in small beef herds where constant observation cannot be given to the cows. These pads are glued to the back on the mid-line above the pelvis and when subjected to the weight of a mounting animal for 5 to 10 seconds, the pad turns from white to red, and identifies the cow in heat.

To aid in sorting the cow herd and to facilitate the keeping of records, which must ultimately be used in making selections of replacement stock, each animal should be individually identified with some permanent marking. While the best system is undoubtedly the use of a scar brand, this may in some areas violate the Brand and Brand Inspection Act. Many cattlemen have successfully used large easily read plastic ear tags, or neck chains with large plastic tags, but these can be lost, particularly in bushy pastures. Each calf should be ear-tagged and tattooed at birth to permit accurate records of parentage. Temporary marks such as dye, paint, marking crayon, or powder are useful for short-term identification.

For best conception results a cow should not be bred sooner than 50 to 60 days after calving to allow the reproductive tract and organs to return to normal. Cows that have had difficulty calving or that have retained placenta should be culled.

While some beef breeders are using A. I. throughout the breeding season of eight to nine weeks, others are breeding artificially for only four weeks and then turning in clean-up bulls at a ratio of one bull to 70 or 80 cows. An efficient A. I. program results in about three-quarters of the cow herd settling to top-performing bulls at the first breeding. Herd replacements should be taken from these. The late calvers, shy breeders, and repeats to first service are then mated by the clean-up bull, usually of a different breed so that calves will be color-marked. The cost of retaining a technician and riders during the later part of the breeding period to catch the unmated cows becomes higher than the cost of providing a few bulls.

The control of the breeding cycle of cows so that they all come into a fertile heat together has not been perfected yet. The most common problems still to be solved are the differences in reaction of individual cows to the treatment, the variable levels of intake of the drug because of group feeding, absence of visible symptoms of heat, and the low conception to the first breeding after treatment. Further research will no doubt overcome these problems, but at present no method of heat control can be recommended.

Breeders of purebred beef cattle who wish to register the artificially sired offspring must become familiar with the regulations set out by their individual breed associations.

ABNORMALITIES

There are a number of abnormal or defective conditions, known in all breeds of cattle, that impair performance, reduce longevity, modify structure and function, or otherwise reduce efficiency of production. Some of these conditions are controlled by inheritance, some are known to result from non-genetic causes, while others are incompletely understood and may or may not be of genetic origin.

In certain cases, notably scrotal rupture and cryptorchidism, corrective surgery can make the affected animals appear and perform as though completely normal. In cases where the defect impairs feedlot performance, appropriate corrective surgery should be considered, but the defective animals, whether or not the condition has been corrected by surgery, should not be used for breeding purposes.

Some of the conditions that are due in some degree to inheritance are listed in Table 8.

Table 8. Abnormalities

Name	Description	Treatment
DWARFISM	SNORTER — Heavy, thick, labored, audible breathing sounds like respiratory trouble, bulging foreheads, jaw projected, enlarged abdomens, short legs. COMPREST — Small, early maturing, short-legged, bow-legged.	An inherited defect. Cull defectives and then parents. Do not use for breeding any bulls or cows whose immediate relatives are dwarfs. Selection for rapid growth rate tends to discriminate against carriers of dwarfism.
HYDROCEPHALUS	Fluid accumulation on brain of calves, calves stillborn or die within week after birth. Internal hydrocephalus may account for many unexplained losses during first few days *post partum*. Calves are weak, incoordinated, and cannot nurse.	Inherited as a simple recessive with variable degree of expression. Vitamin A deficiency may cause a somewhat similar condition.
EYE CANCER	Occurs primarily in cattle with unpigmented (white) hair and skin around eyes. Develops on membrane lining eyelids.	Select breeding animals with pigmented (colored) hair around eyes and face or cross with pigmented breed.
UMBILICAL HERNIA	Intestines pass through abdominal wall near navel.	May be inherited. Affected animals may be made to appear normal by corrective surgery but they should be culled even if made to appear normal.
SCROTAL HERNIA	Descent of intestines through inguinal canal into the scrotum.	May be inherited. Affected animals may be made to appear normal by corrective surgery but they should be culled even if made to appear normal.
CRYPTORCHIDISM	Present either in unilateral (one testis descended) or bilateral (both testes fully within abdominal cavity) form. Unilateral cases may have normal fertility, bilateral completely sterile.	May be inherited. Either type should be castrated and not used for breeding.
FREEMARTIN	Appears in 90 percent of females born twin to a bull calf. Freemartins appear normal; however, genital organs are small and fail to develop. Caused by hormonal imbalance in female due to secretion of male hormone by testes of twin male fetus.	Should be culled from herd if examination verifies infantile genital trait.
VAGINAL AND UTERINE PROLAPSE	Appears in females late in pregnancy. Age of cow is not important. Cases must be treated immediately; otherwise, animal will die from complications such as septicemia, necrosis, uremia or intestinal strangulation.	Some breeds are more highly affected than others. This suggests that the condition may be inherited. Nutritional deficiencies may be contributing factors. Cull affected animals.

(Table 8 continued)

Table 8. Abnormalities (Concluded)

Name	Description	Treatment
SUNBURN	Sunburn of teats and udders of cattle with unpigmented (white) skin on the udder presents a troublesome problem to range cattle operators. Teats become sore and red, skin peels, and cows are reluctant to let calves nurse.	Practical solution is to select animals with pigmented skin (colored) on the teats and udder or cross with pigmented breed.
BLOAT	An excessive accumulation of gas in the rumen. Mild distension is of little consequence but severe bloat causes great discomfort and is often fatal. Seriously interferes with normal performance.	CHRONIC bloaters should be eliminated from the breeding herd.
FOOT AND HOOF DEFECTS OR LEG WEAKNESS	Toes grown together or missing. As animal gets older, feet become tender and the animals become lame. Bone defects also cause lameness.	Prospective breeding stock with leg, foot or hoof defects should be eliminated.
ATRESIA ANI	Closure of the anal canal.	Corrective surgery must be performed immediately. Probably inherited, cull from herd.
SIZE AND SHAPE OF TEATS	Abnormally large teats may interfere with calves' nursing ability.	Should be culled from herd. Selection effective in correcting udder defects.

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