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CROSSBREEDING SYSTEMS AND THE THEORY
BEHIND COMPOSITE BREEDS

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INTRODUCTION

Crossbreeding serves the beef cattle industry as a tool to improve productivity through heterosis (hybrid vigor) and through complementarity (combining different breed strengths) to match genetic resources to various feed resources, climates, management levels and markets. Commercial cattlemen need to understand the principles of crossbreeding so they can adapt crossbreeding to their specific environment and needs. Seedstock breeders must be able to intelligently advise their commercial customers and know where their seedstock best fits into crossbreeding programs. Cattlemen today can be much more sophisticated in their approach to using crossbreeding. They realize many of the crossbreeding mistakes of the past were made because many breeds used were not well characterized and crossbreeding programs were not tailored to individual ranch needs. The knowledge level regarding crossbreeding has increased dramatically in recent years; now is an ideal time to plan or replan a crossbreeding program.

CROSSBREEDING

Crossbreeding (the mating of animals of different breeds) is similar to outcrossing (the mating of unrelated and, thus, genetically unlike animals within the same breed). Breeders have long used outcrossing to incorporate specific traits and increase performance levels within a breed by mating animals from different families or bloodlines. Results from crossbreeding are more pronounced than outcrossing because breeds are more genetically unlike than families within the same breed.

ADVANTAGES OF CROSSBREEDING

1. **INDIVIDUAL HETEROSIS.** Heterosis (hybrid vigor) is the degree to which crossbred calves deviate from the average of calves of the parental breeds. The amount and percentage of heterosis can be calculated as follows where straightbred Angus (A), straightbred Hereford (H), and crosses between Angus and Hereford (AH and HA) were raised as contemporaries:

$$\text{Amount of Heterosis} = \frac{AH + HA}{2} - \frac{A + H}{2}$$

$$\text{Percent of Heterosis} = \frac{\text{amount of heterosis}}{\frac{A + H}{2}} \times 100$$

As an example for weaning weight, if A = 400 lb, H = 450 lb, AH = 440 lb and HA = 450 lb, then:

Amount of Heterosis = 445 lb - 425 lb = 20 lb

Percent of Heterosis = $\frac{20}{425} \times 100 = 5\%$

Note that heterosis may be positive or negative and that there may be positive heterosis even when one of the parental breeds performs better than the average of crossbreds.

2. MATERNAL HETEROSIS. Maternal heterosis arises from using crossbred cows. A maternal heterosis value of 6 percent for calf weaning weight means that crossbred cows wean calves that weigh 6 percent more than if those same calves had been raised on straightbred cows. Maternal heterosis is usually greater than individual heterosis for maternally influenced traits and, as a result, crossbreeding programs should include use of a crossbred cow.

3. COMPLEMENTARITY OF MALE AND FEMALE TRAITS. Certain crossbreeding systems allow the breeder to match traits of the bull breed to traits of the crossbred cow. Normally this means that the breeder chooses a bull breed that will transmit rapid growth and desirable carcass traits to progeny while the crossbred cow provides ample milk for the rapidly growing calf and produces a live, healthy calf every year. Complementarity can work in a negative way in poorly designed crossbreeding programs where large, terminal sire breeds are bred to small, young, hard-calving cows. This can result in an excessive frequency of dystocia.

4. "BUILDING" THE BEST MATCH OF CROSSBRED COW TO ENVIRONMENT. This advantage has been overlooked by some breeders. But, in many different range environments, this may be the most important consideration. There are many beef breeds available to the producer and some combination of these breeds should result in a desirable match of crossbred cow genotype to the particular range environment.

5. EFFECTS OF CROSSBREEDING ACCUMULATE. Crossbreeding may result in relatively small levels of heterosis (4 percent for each trait, but these heterosis effects accumulate so that there can be large increases (25 percent) in overall productivity!

6. RAPID ADAPTATION TO CHANGING MARKET OR RESOURCES. Terminal sire systems give the breeder an opportunity to change sires rapidly so that calves can be changed according to market demands or resources.

HETEROSIS

Heterosis is measured as the difference in performance of crossbred animals from the average contemporary performance of straightbred animals of the breeds contributing to the cross. Heterosis obtained through systematic beef cattle crossbreeding can increase calf weight weaned per cow exposed by 18-20 percent. Cattlemen should know the level of heterosis to

expect from beef cattle crossbreeding. Table 1 lists the percentages of individual heterosis (from crossbred calf) and maternal heterosis (from crossbred cow) averaged over many research trials. Study of Table 1 shows that the percent heterosis varies from low to high. Generally the greatest benefit from heterosis is realized for traits with low heritability, like reproductive performance of the cow and liveability of the calf. Highly heritable traits like carcass traits exhibit little heterosis.

GENETICS OF CROSSBREEDING

Genetic effects of crossbreeding are the opposite of genetic effects of inbreeding. Whereas inbreeding tends to increase the number of gene pairs that are homozygous (both members of a gene pair are alike: AA or aa) in the population, crossbreeding tends to increase the number of gene pairs that are heterozygous (members of a gene pair are different; Aa). Livestock producers have long known that when animal populations are subjected to inbreeding, the performance level of certain traits tends to be reduced below that of the non-inbred population (inbreeding depression). It is inevitable that existing breeds of beef cattle become mildly inbred lines, and to the extent that heterosis is due to the dominance effects of genes, heterosis is the recovery of accumulated inbreeding depression. There are two basic genetic requirements for a trait to exhibit heterosis:

1. There must be genetic diversity between the breeds crossed and
2. There must be some non-additive gene effects present for the particular trait involved.

The failure to either one of these conditions being fulfilled for a particular cross for some trait would result in that trait exhibiting no heterosis. In such a case, expected performance of the crossbred offspring would simply be the average of the performance levels of the particular straightbred parents involved in the cross. For those traits that express heterosis, the magnitude of heterosis will be dependent upon how much genetic diversity exists between the two breeds crossed and the relative importance of non-additive gene effects that are involved in the genetic determination of that trait.

GENETIC DIVERSITY

Genetic diversity refers to the degree of genetic similarity or dissimilarity that exists between the two breeds. Two breeds will be quite similar genetically for a trait if the gene frequencies are about the same at most of the loci (gene pairs) that control a particular performance trait. On the other hand, if two breeds have quite different gene frequencies at the majority of the loci controlling a trait, they will be quite dissimilar genetically. Breeds having similar origins and that have been subjected to similar types of selection pressure during their development will be expected to be much more alike genetically (small amount of genetic diversity) than would breeds that have quite different origins and have been selected for different purposes during their development.

Table 1. Average percent of individual and maternal heterosis for traits of beef cattle.

Trait	Individual heterosis, %	Maternal heterosis, %	Total heterosis, %
Gestation length	0	0	0
Calving rate	0	6	6
Weaning rate	0	8	8
Female age at puberty	-3		-3
% reaching puberty by 15 mo.	15		15
Survival birth	2	-1	1
Survival weaning	3	1	4
Calving difficulty	2	0	2
Birth weight	4	2	6
Weaning weight	5	6	11
Yearling weight	4		4
Cow mature weight	1		1
Cow mature height	1		1
Cow condition	-4		-4
Carcass weight	3		3
Dressing %	0		0
USDA carcass grade	2		2
Loin eye area	2		2
Fat thickness	6		6
% fat trim	6		6
Kidney fat	5		5
Carcass yield grade	5		5
% cutability	0		0
Feed conversion (TDN/gain)	-2		-2
Days on feed	-4		-4
Tenderness	0		0
Palatability	0		0
Trimmed retail cuts	3		3
Cow milk production			9
Calf wean weight/cow exposed			18
Cow efficiency			2
Cow-calf TDN consumed			3
Calf wean weight/cow weight			8
Cow longevity			38
Cow lifetime productivity			25

Kress, D.D. and T.C. Nelsen, 1988.

NON-ADDITIVE GENE EFFECTS

Non-additive gene effects refer to the kinds of gene actions that exist with regard to the many gene pairs that are involved in determining a particular performance trait. Non-additive gene effects that are expressed by individual gene pairs (due to level of dominance that exists between different genes present at that particular locus). The non-additive gene effects at individual loci (gene pairs) can be caused by complete dominance, partial dominance or overdominance. If gene effects are strictly additive, the effect of the heterozygote (Aa) is exactly intermediate between the effects of the two homozygous genotypes (AA and aa). Loci (gene pairs) with this kind of gene action will not make any contribution to heterosis. Complete dominance is very common genetic property that exists when the effect of the heterozygote is closer to that of one of the homozygotes without being exactly the same. Overdominance describes the situation whereby the heterozygote has a more extreme effect than with homozygote. To whatever extent they occur, gene pairs that exhibit overdominance would have a relatively large effect on the amount of heterosis exhibited by a trait. It is not really known, however, how prevalent gene pairs exhibiting overdominance are among the many loci that control livestock performance traits. Although some examples of overdominant gene pairs are known, this phenomenon is not nearly as frequently encountered as is partial and complete dominance.

Epistatic gene action involves gene combinations at one locus (gene pair) interacting with the effects of gene combinations at other loci (gene pairs). There are many different kinds of epistatic effects but their relative influence has been very difficult to measure because of their complexity. It seems doubtful that these epistatic effects would be the primary cause of heterosis in the case of most traits.

COMPLEMENTARITY AND BREED DIFFERENCES

In addition to heterosis, crossbreeding allows cattlemen to combine the strengths of two or more breeds, thus achieving a higher frequency of desirable traits among crossbreds than that found in a single breed. Breed complementarity simply means that strengths of one breed can complement or cover up weaknesses of another breed.

This effect of breed differences is very powerful. Poor choices of breeds and bulls within a breed will have a lasting impact on the success of any crossbreeding plan. A brief review of these substantial breed differences that cattlemen have to work with is presented in Table 2.

Table 2 lists various beef breeds and groups them according to biological type based on: 1) level of milk production; 2) growth rate and mature size; 3) percentage retail product; and 4) age at puberty. This is not an exhaustive list, but from a practical standpoint it does a good job of classifying breeds into biological types.

Table 2. Breeds grouped by biological type^a

Breed	Milk production	Growth Rate and Mature Size	Percentage Retail Product	Age at Puberty
Red Poll	***	*	*	**
Jersey	*****	*	*	*
Devon	*	*	**	***
Hereford	**	**	*	***
Angus	***	**	*	**
Santa Gertrudis	***	****	*	**
Brangus	**	**	*	*****
Brahman	***	***	***	*****
Tarentaise	****	***	****	**
Pinzgauer	****	***	***	*
Brown Swiss	****	***	**	*
Simmental	****	*****	*****	**
Gelbvieh	****	****	****	*
Holstein	*****	****	****	**
MaineAnjou	**	*****	****	**
South Devon	**	****	**	**
Limousin	*	***	*****	*****
Charolais	**	*****	*****	*****
Chianina	**	*****	*****	*****

^aIncreasing number of *'s indicate greater values for the traits. For example, ***** = greatest milk production or oldest age at puberty and ** = below average percent retail product and relatively early age at puberty. Based in part on a cluster analysis of breed group means presented by Dr. L.V. Cundiff at the Third World Congress on Genetics Applied to Livestock Production.

It is important to match the biological type of the cow to the environment of the beef operation. Table 2 can be very helpful during this process. For example, if the environment is characterized by good quantity and quality summer forage, and plentiful winter feed, then the proper biological type of cow to match that environment would be a high milking, fast growing rate type of cow with early age at puberty. However, if the environment is more limiting, as in most low rainfall areas, then the proper biological type of cow would be one with lower milk production, a slower growth rate and early age at puberty. Intermediate types of environments would dictate intermediate biological types of cows. Low quality and quantity summer range

would dictate biological types of cows with lower milk production. Low quality and quantity winter feed would dictate smaller mature size. All biological types considered for the maternal side of the herd should have average or earlier age at puberty. Therefore, the proper biological type of cow may be an Angus x Hereford cross in one environment and a Simmental x Tarentaise cross in another environment.

The primary characteristics to be desired, in regards to terminal sire breeds, are rapid growth rate and a high percentage of retail product.

PLANNING THE CROSSBREEDING SYSTEM

It is impossible to plan a crossbreeding system to fit all commercial situations. Whether a conventional or simplified crossbreeding system is chosen, it is important to plan ahead several generations, not just several years. The hard questions concerning: 1) number of breeding pastures needed, 2) how replacement heifers will be generated, 3) optimum herd size, 4) source of breeds, 5) source of bulls, 6) feed resources required, 7) availability of labor, and 8) potential use of artificial insemination, must be resolved or at least thoroughly considered in the planning phase of your crossbreeding program.

CONVENTIONAL CROSSBREEDING SYSTEMS

Two-Breed Rotation

The two-breed rotation is initiated by mating cows of breed A to bulls of Breed H, with the resulting heifers mated to bulls of breed A for their entire lifetime. In each succeeding generation, replacement heifers are bred to bulls of the opposite breed than their sire as shown in figure 1.

A minimum of two breeding pastures are required for this system and replacement heifers must be identified by breed of their sire. Two breeds of bulls are required after the first two years of mating and the breeds chosen should be comparable in birth weight, mature size and milk production in order to minimize calving difficulty in first-calf heifers and stabilize nutrition and management requirements in the cow herd. The two-breed rotation does generate replacement heifers within the herd and restores a substantial level of heterosis from one generation to the next. The level of heterosis in a two-breed rotation is, on the average, expected to stabilize after a few generations at 67 percent of maximum for both the individual and material components of heterosis.

Figure 1. 2-BREED ROTATION

1. Requires two breeding pastures or AI.
2. Utilizes individual and maternal heterosis (67% of maximum).
3. Allows limited use of complementarity.
4. Replacement females produced within the system and need to be identified by breed of sire.
5. Genetic improvement determined primarily by genetic potential of A and H sires.
6. Breeds should be similar for size and milk production.
7. Expected to increase calf production per cow exposed by 16%.

Beginning with a foundation herd of Hereford cows, breed all cows to Angus bulls. The Angus x Hereford daughters are saved for replacement and mated to Hereford bulls. The H x (AH) replacements are moved to the herd mated with Angus bulls. This continues such that daughters born in the A sire herd are bred in the H sire herd and vice versa. In any one year there are two breeding pastures with Angus bulls in one and Hereford bulls in the other.

A = Angus

H = Hereford

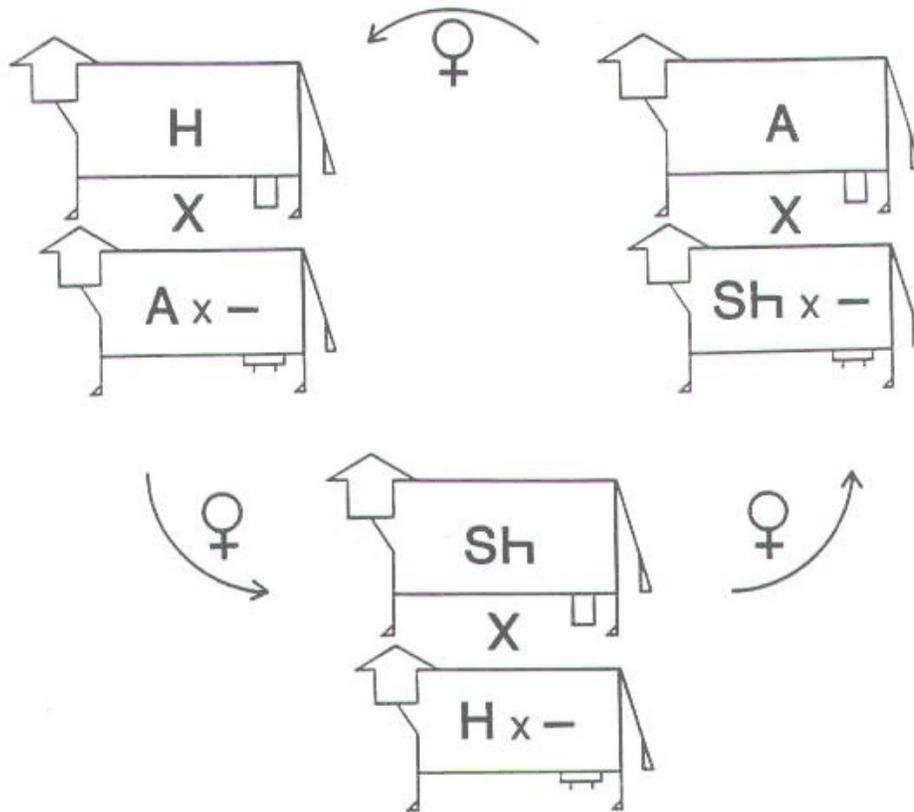
Three-Breed Rotation

The three-breed rotation follows the same pattern as is followed with the two-breed rotation, but a third breed is added to the rotation as indicated in figure 2.

The management requirements for the three-breed rotation are similar to those for the two-breed, with the obvious exceptions being an increase from 2 to 3 in number of breeding

pastures needed and breeds of bulls needed. Identifying three sources of bulls from breeds which are comparable has proven to be difficult for some producers who don't wish to use artificial insemination. The three-breed rotation does sustain a higher level (86 percent of maximum individual and maternal heterosis) of heterosis than the two-breed rotation because the relationship of bulls and cows mated is more remote, thus less backcrossing is involved.

Figure 2. 3-BREED ROTATION



1. Requires three breeding pastures or AI.
2. Utilizes individual and maternal heterosis (86% of maximum).
3. Allows limited use of complementarity.
4. Replacement females produced within the system and need to be identified by breed of sire.
5. Genetic improvement determined primarily by genetic potential of H, A and Sh sires.
6. Breeds should be similar for size and milk production.
7. Each crossbred cow should be mated to the breed of sire to which she is most distantly related.
8. Expected to increase calf productivity per cow exposed by 20%.

H = Hereford

A = Angus

Sh = Shorthorn

The level of heterosis in rotational systems fluctuates in the early generations, but once crossbred cows enter the system, this fluctuation is negligible in terms of performance, because a relatively lower level of heterosis in calves in one generation is offset by a higher level of heterosis in cows and vice versa for succeeding generations.

Rotational systems appeal to many people because replacement heifers are produced within the system. This is an important point, but genetic improvement within the herd is still largely determined by the bulls selected. Several research experiments have demonstrated that 80 to 90 percent of genetic improvement within a herd is attributable to sire selection.

ROTATIONAL-TERMINAL SIRE SYSTEM

This system (figure 3) involves the use of rotational matings of maternal or all-purpose breeds in a portion of the herd to provide cross-bred replacement females to the entire herd; the older (4 years old and older) crossbred cows are then mated to a terminal sire breed for the remainder of their productive life. The rotational portion of the herd would require about 45 percent of the cows, leaving about 55 percent of the cows to be mated to the terminal sire breed.

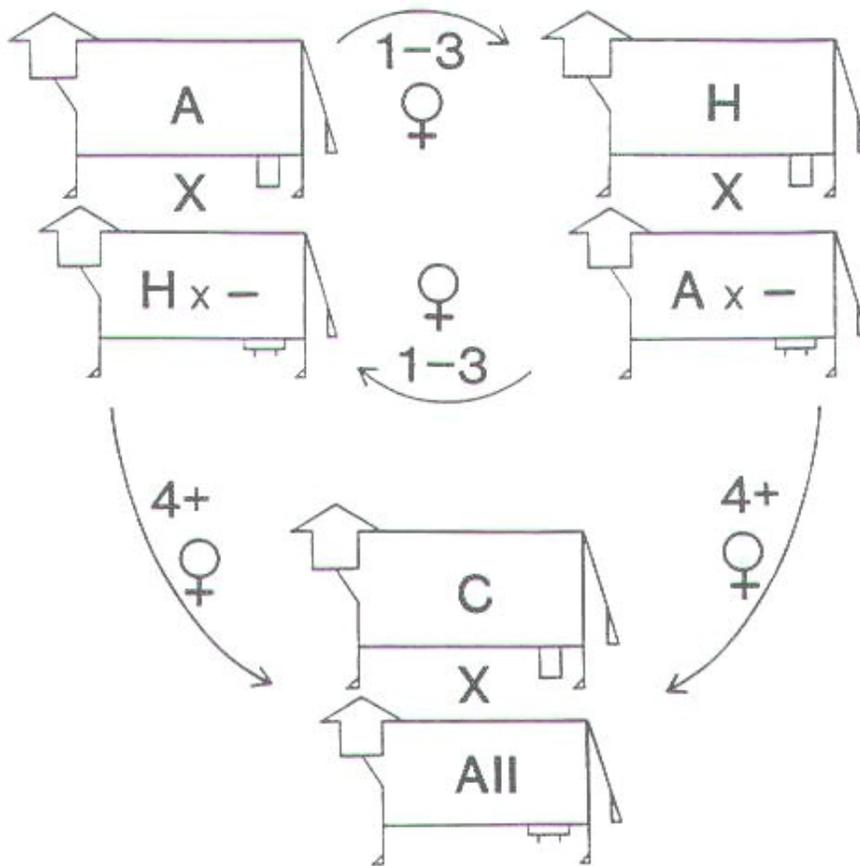
The maternal rotation portion of this system can be run with either two or three breeds. Two or three breeds in the maternal rotation would require 3 or 4 breeds of bulls and 3 or 4 breeding pastures, respectively. Cows must be identified by breed of sire and year of birth.

The three-breed rotational terminal system can be run with two breeding pastures if the bulls of breeds in the maternal rotational portion of the herd are restricted to only two years of use. This is possible since all cows would be 4 years old or older before bulls of the same breed of their sire were scheduled for use and all 4 year old and older cows will be mated to the terminal sire breed. This modification is not as beneficial in a two-breed rotational-terminal system because many of the cows would be less than 4 years old and still be in the maternal rotation when their sire breed was scheduled for use, thus considerable backcrossing would result.

The rotational-terminal system is a very productive system because about 70 percent of the calves marketed are by the terminal sire breed, the remaining 30 percent being steers from the rotational maternal breed matings. This system would sustain a higher level of production than either the two- or three-breed rotation, however both the two- and three-breed rotational-terminal sire systems require a high level of management.

The measure of cow productivity is the pounds of calf weight weaned per cow exposed to breeding and refers to the crossbred advantage relative to straightbreds.

Figure 3. ROTATIONAL-TERMINAL SIRE



1. Requires three breeding pastures or AI.
2. Approximately 45% of females in rotation and 55% of females in terminal portion of system.
3. Utilizes individual and maternal heterosis.
4. Maximizes complementarity in 55% of herd.
5. Roughly 70% of progeny marketed are from terminal sire breed.
6. AI and sexed semen would make this system more efficient.
7. Genetic improvement determined primarily by genetic potential of A, H and C sires.
8. 1- to 3-year-old females are bred in the rotational part of the system and 4-year-old and older cows are bred in the terminal part of the system.
9. Expected to increase calf production per cow exposed by 21% for 2-breed rotation and 24% for 3-breed rotation.

A = Angus
H = Hereford
C = Charolais

SIMPLIFIED CROSSBREEDING SYSTEMS

In many herds the level of management required to use some of the conventional crossbreeding systems which maximize heterosis, utilize complementarity through terminal sire breeds and reduce costs of production most efficiently are simply not feasible. Many cow herds are small, or are the second enterprise to cropping, feeding, or other livestock within the operation, thus, relatively simple systems of mating would be more practical. Also, the relatively large herds may find conventional crossbreeding systems equally difficult to manage. It is possible, with some modification, to use the basic principles from the crossbreeding systems previously discussed to design some simplified crossbreeding systems which produce some of the benefits of crossbreeding, yet avoid many of the limitations of the conventional systems.

For some cattlemen, artificial insemination (A.I.) could be used to simplify a conventional crossbreeding system. An example would be, all cows and heifers bred A.I. to two maternal breed bulls for 21 days, then the cows bred naturally to a terminal breed for the remainder of the breeding season.

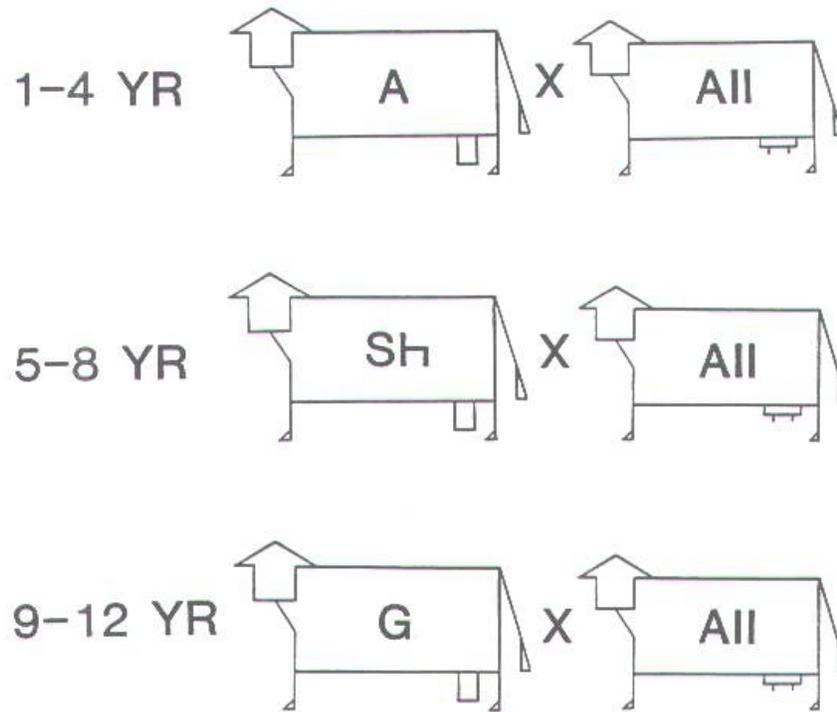
PURCHASED CROSSBRED FEMALES

This "system" is more of a management decision than a crossbreeding system, yet it is the simplest and fastest method of utilizing crossbreeding. Purchased two- or three-breed crossbred females would be mated to a different terminal sire breed, thus maximizing both individual and maternal heterosis. Only one breed of bulls is needed (the terminal sire breed) and only one breeding pasture is required. Since all progeny are marketed, no identification by sire breed and year of birth would be required. While this system is simple and easy to manage, it does have the disadvantage of not generating replacement females, thus making the operator dependent on the market in order to replenish the system with crossbred females. However, replacements need not be purchased every year, depending on the age composition of the original cows, replacements may only be needed every 3, 4 or 5 years. The operator could then buy replacements in years when the supply was relatively greater and prices were relatively lower. This system would also work well for producers who had facilities for backgrounding calves and feeding cattle. Weaned, crossbred heifer calves could be purchased, fed through the winter, sorting off the better performing heifers for replacements for the cow herd and feeding the remainder for slaughter. Obviously, the available supply of crossbred females in the area is very important and some producers would be reluctant to risk the introduction of disease which would always be possible with purchased females.

SIRE BREED ROTATION

Another simple alternative to conventional crossbreeding options is a sire breed rotation as illustrated in figure 4. This one-pasture system involves one sire breed being used on all females for one to four years. Small herds with only one or two bulls should consider rotating sire breeds every two years to avoid inbreeding. A sire-breed rotation using three breeds would yield a 16 percent advantage compared to a 20 percent advantage for a conventional three-breed rotation and 15 percent for a three-breed composite. This sacrifice in heterosis may be very acceptable to many cattlemen in order to simplify management of the breeding program.

Figure 4. ROTATE SIRE BREED



1. Requires one breeding pasture.
2. Start with available and adapted female breed (H for example).
3. Utilizes individual and maternal heterosis.
4. Allows limited use of complementarity.
5. Replacement females from within the system and do not need to identify cows by breed of sire.
6. Genetic improvement determined primarily by genetic potential of A, Sh and G sires.
7. Each sire breed could be used two to four years.
8. This system can be considered an approximation to a 3-breed rotation.
9. Expected to increase calf production per cow exposed by 16%.

A = Angus
Sh = Shorthorn
G = Gelbvieh

Bennett (1987) explored several variations of sire-breed rotations with interesting results. Table 3 presents the expected heterosis from a variety of sire-breed sequences.

Table 3. Heterosis maintained by using sire breeds one to four consecutive mating periods in sire-breed rotations^a

Sire-breed Sequence	Maximum age ^b of females before culling							
	3	4	5	6	7	8	9	10
AB	.47	.40	.47	.44	.47	.45	.47	.46
AABB	.62	.54	.53	.55	.55	.53	.53	.54
AAABBB	.61	.59	.57	.54	.54	.54	.55	.55
AAAABBBB	.59	.61	.59	.58	.57	.55	.54	.54
ABA	.44	.45	.47	.44	.45	.46	.45	.45
AABBAA	.54	.53	.51	.49	.48	.48	.49	.49
AAABBBAAA	.53	.53	.52	.52	.51	.50	.49	.48
AAAABBBBAAAA	.50	.51	.51	.51	.51	.51	.50	.50
ABC	.65	.67	.71	.66	.67	.68	.67	.67
AABBCC	.81	.80	.77	.73	.72	.72	.73	.73
AAABBCC	.80	.79	.78	.77	.76	.75	.73	.72
AAAABBBBCCCC	.74	.77	.77	.76	.76	.75	.75	.74
ABAC	.66	.57	.62	.60	.63	.61	.62	.61
AABBAACC	.76	.71	.69	.70	.69	.67	.67	.67
AAABBBAAACCC	.74	.73	.72	.70	.69	.69	.69	.69
AAAABBBBAAAACCCC	.69	.71	.71	.71	.70	.69	.69	.68

^aMaximum age of reproducing females before culling is varied from 3 to 10 mating periods.

^bAge is shown in terms of mating periods (1yr for cattle).

Bennett, G.L. 1987

Heterozygosity of sire-breed rotations that used a sire breed one mating period (AB, ABC, ABAC, etc.) tended to be less than those that repeated a sire breed two or more consecutive mating periods (AAAABBBB, AABBCC, AABBAACC, etc.), especially when females are culled at younger ages.

Differences between sire-breed rotations that used a sire breed for two consecutive mating periods (AABB, AABBCC, etc.) and those using a sire breed for a single mating period (AB, ABC, etc.) were as much as .16 when dams were culled at younger ages. This difference decreased to .08 or less when surviving dams were culled at an age equal to 10 mating seasons. These differences can be explained by the sire breed of the youngest reproducing females. This age class of reproducing females is the largest age class. In an AB rotation, the current sire breed and the sire breed of the youngest reproducing females are always the same.

Proper selection of maximum culling age for females and appropriate selection of sire-breed sequence resulted in more heterosis for a sire-breed rotation than an equivalent composite for all rotations studied by Bennett (1987). This comparison of sire-breed rotations with composites does not include the lack of heterosis in purebred populations which provide purebred bulls for the sire-breed rotation.

COMPOSITE BREEDS

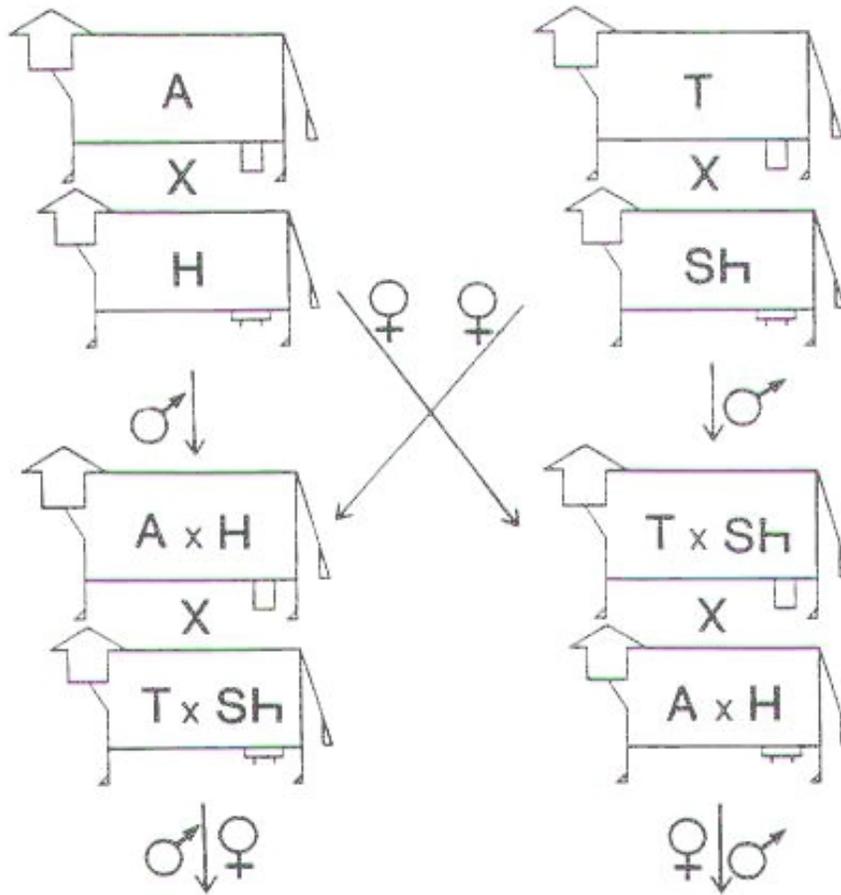
Another alternative to the more complex crossbreeding systems is the development of composite breeds based on matings among crossbred animals resulting from crosses of two or more breeds (figure 5). The management of a composite breed system is simple, especially for producers who have limitations on herd size and number of breeding pastures. Only one breeding pasture would be required and no identification of females by sire or year of birth would be required. Replacement females would be generated within the system.

Composite breeds do not sustain as high a level of heterosis as do rotational systems, however composite breeds do allow for more complementarity between breeds to be utilized. For example, breeds which vary considerably in mature size, milk production and carcass merit could be utilized in forming a composite breed fitted to specific feed resources, environmental and climatic conditions.

Also to be considered is the importance of paternal heterosis, since bulls in a composite system are crossbreds too. Utilizing composite breed bulls may serve as an extra bonus, since some studies have indicated evidence for paternal heterosis in some semen traits, libido and mating vigor of crossbred bulls.

With 55 percent of the U.S. beef breeding herd and 93 percent of the operations that have beef cows represented by units of 100 cows or fewer, there are obvious limitations on feasible options for optimum crossbreeding systems. The limitations are most significant if female replacements are produced within the herd and natural service breeding is used. Further fluctuation between generations in additive genetic (breed) composition in breed-rotation crossbreeding systems restricts the extent to which breed differences in average additive genetic merit can be used to match climatic adaptability and performance traits to the climatic and feed environment. Thus, the formation of composite breeds based on a multi-breed foundation is an attractive alternative to conventional crossbreeding systems. Once a new composite breed is formed, it can be managed as a straightbred population, and the management problems that are associated with small herd size and with fluctuations between generations in additive genetic composition in rotational crossing systems are avoided.

Figure 5. COMPOSITE



Composite Population
1/4 A, 1/4 H, 1/4 T, 1/4 Sh

1. Requires one breeding pasture after composite development.
2. Utilizes individual and maternal heterosis.
3. Allows limited use of complementarity.
4. Replacement females and bulls from within the system and do not need to be identified by breed of sire.
5. Genetic improvement determined primarily by genetic potential of selected sires in composite.
6. Expected to increase calf production per cow exposed by 17%.

A = Angus
H = Hereford
T = Tarentaise
Sh = Shorthorn

GENETIC BASIS OF COMPOSITE BREEDS

Retention of initial heterozygosity after crossing and subsequent random (inter se) mating within the crosses is proportional to $(n-1)/n$, where n is the number of breeds involved in the cross. This loss in heterozygosity occurs between the F_1 and F_2 generations. If inbreeding is avoided, further loss of heterozygosity in an inter se mated population does not occur. This expression, $(n-1)/n$ assumes equal contribution of each breed used in the foundation of a composite breed. Table 4 produces information on level of heterozygosity relative to the F_1 that is retained after equilibrium is reached for two-, three- and four-breed rotation crossbreeding systems and is presented for two-, three-, four-, five-, six-, seven- and eight-breed composites, with breeds contributing in different proportions in several of the composites. Obviously, the maximum number of breeds that can contribute to an optimum additive genetic (breed) composition is preferred because retention of heterozygosity is a function of the number of breeds included in the foundation. Estimates of increase in weight produced per cow exposed to breeding, based on the assumption that retention of heterosis is approximately proportional to retention of heterozygosity, are presented in Table 4 for each mating type.

Existing breeds of cattle are mildly inbred lines, and to the extent that heterosis is due to the dominance effects of genes, heterosis is the recovery of accumulated inbreeding depression. Deviation of heterosis from linear association with heterozygosity results from epistatic effects of genes. For loss of favorable epistatic combinations that may either have become fixed or are maintained by selection in parental breeds, the deviation from linearity of loss in heterosis with loss in heterozygosity is negative (greater); however, for loss of unfavorable epistatic combinations that may have become fixed through chance, the deviation from linearity of loss in heterosis with loss in heterozygosity obviously is likely to be positive (less). Both genetic situations may exist, and the likelihood is greater for favorable than for unfavorable epistasis combinations in parental breeds. Also, heterosis may deviate from heterozygosity in a positive direction if a threshold effect of heterozygosity should exist.

Other than for characters affected by natural or automatic selection (fitness), the likelihood is small that fixed favorable epistatic combinations are important because of changing selection goals that have characterized beef cattle breeding.

If retention of heterosis is linearly associated with retention of heterozygosity, composite breed formation offers much of the same opportunity as rotational crossbreeding for retaining individual and maternal heterosis, in addition to heterosis in male reproductive performance (Table 4). Further, composite breeds offer the opportunity to use genetic differences among breeds to achieve and maintain the performance level for such traits as climatic adaptability, growth rate and size, carcass composition, milk production and age at puberty that is most optimum for a wide range of production environments and to meet different market requirements. Further, composite breeds may provide herds of any size with an opportunity to use heterosis and breed differences simultaneously.

Table 4. Heterozygosity of different mating types and estimated increase in performance as a result of heterosis.

Mating type	Heterozygosity percent relative to F ₁	Est. increase in calf weight weaned per cow exposed ^a (%)
Pure breeds:	0	0
Two-breed rotation at equilibrium	66.7	15.5
Three-breed rotation at equilibrium	85.7	20.0
Four-breed rotation at equilibrium	93.3	21.7
Two-breed composite:		
F ₃ - 1/2A, 1/2B	50.0	11.6
F ₃ - 5/8A, 3/8B	46.9	10.9
F ₃ - 3/4A, 1/4B	37.5	8.7
Three-breed composite:		
F ₃ - 1/2A, 1/4B, 1/4C	62.5	14.6
F ₃ - 3/8A, 3/8B, 1/4C	65.6	15.3
Four-breed composite:		
F ₃ - 1/4A, 1/4B, 1/4C, 1/4D	75.0	17.5
F ₃ - 3/8A, 3/8B, 1/8C, 1/8D	68.8	16.0
F ₃ - 1/2A, 1/4B, 1/8C, 1/8D	65.6	15.3
Five-breed composite:		
F ₃ - 1/4A, 1/4B, 1/4C, 1/8D, 1/8E	78.1	18.2
F ₃ - 1/2A, 1/8B, 1/8C, 1/8D, 1/8E	68.8	16.0
Six-breed composite:		
F ₃ - 1/4A, 1/4B, 1/8C, 1/8D, 1/8E, 1/8F	81.3	18.9
Seven-breed composite:		
F ₃ - 3/16A, 3/16B, 1/8C, 1/8D, 1/8E, 1/8F, 1/8G	85.2	19.8
Eight-breed composite:		
F ₃ - 1/8A, 1/8B, 1/8C, 1/8D, 1/8E, 1/8F, 1/8G, 1/8H	87.5	20.4

^aBased on heterosis effects of 8.5% for individual traits and 14.8% for maternal traits and assumes that retention of heterosis is proportional to retention of heterozygosity.

COMPLEMENTARITY IN COMPOSITES

Composite breeds do not permit the use of different genotypes (complementarity) for male and female parents. However, specialized paternal and maternal composite breeds may be developed for use in production systems in which the production resource base and market requirements favor the exploitation of complementarity. Between-breed selection is highly effective for achieving and maintaining an optimum additive genetic composition for such specialized populations by using several breeds to contribute to the foundation population for each specialized composite breed. There is the potential to develop general purpose composite breeds through careful selection of fully characterized candidate breeds to achieve an additive genetic composition that is better adapted to the production situation than is feasible through continuous crossbreeding or through intra-breed selection.

MINIMUM HERD SIZE FOR COMPOSITE BREEDERS

The maintenance of effective herd size sufficiently large that the initial advantage of increased heterozygosity is not dissipated by early re-inbreeding is essential for retention of heterozygosity (heterosis) in composite breed seedstock herds. Thus, the resource requirement for development and use of composite breeds as seedstock herds is high, and from an industry standpoint requires a highly viable and creative seedstock segment. Early re-inbreeding and a small number of inadequately characterized parental breeds contributing to the foundation of composite breeds have likely been major causes for failure of some previous efforts at composite breed development.

For the breeders of composite breeds, it is suggested that the number of females be sufficient for the use of not less than 25 sires per generation. Use of 25 sires per generation would result in a rate of increase in inbreeding of about .5 percent per generation. With an average generation interval of five years, the accumulated inbreeding in a composite breed after 50 years (e.g., 10 generations) would be 5 percent. Further, a large number of sires of each purebreed contributing to a composite breed should be sampled in order to minimize the rate of inbreeding in subsequent generation of inter se mating. Inbreeding may be viewed as the "other side of the coin" to heterosis and must be avoided in order to retain high levels of heterozygosity (heterosis) in composite breeds. It should be pointed out that this constraint on minimum herd size only applies to seedstock breeders of composite breeds and no such constraint is applied to users of composite bulls which could be large or small herds.

COMPOSITE BREED RESEARCH

A major study of three composite breed populations was initiated at the USMARC in 1978. Each composite was composed of four or five breeds. Breed composition of these composites is as follows:

MARC I = 1/4 Braunvieh, 1/4 Charolais, 1/4 Limousin, 1/8 Hereford, 1/8 Angus

MARC II = 1/4 each Angus, Hereford, Gelbvieh, Simmental

MARC III = 1/4 each Angus, Hereford, Red Poll, Pinzgauer

Subsequent numbers of cows were committed to each of the three composite populations (approximately 250-300 cows per year) and to each of the nine parental breeds (approximately 100 cows per year). The objective of this study was to determine the percentage of initial heterosis (F_1) that is retained in composite populations. The F_1 here is defined as the first generation where all four or five breeds are represented.

Gregory, et al., 1991 reported the results of this study. Heterosis effects for birth weight, ADG from birth to weaning, 200-d weight, ADG from weaning to 368-d, 368-d weight, 368-d height, 368-d condition score, and 368-d muscling score (males only) were evaluated separately for each sex in F_1 , F_2 , and combined F_3 and F_4 generations in three composite beef cattle populations. Breed effects were evaluated for the nine parental breeds that contributed to the three composite populations. Breed effects were significant for all traits evaluated. The large differences among breeds for growth and size traits in combined additive direct and additive maternal genetic effects provide an opportunity to use genetic differences among breeds to maintain optimum additive genetic (breed) composition to match cattle genetic resources to a wide range of production and marketing situations. Combined individual and maternal heterosis was significant in the F_1 , F_2 , and combined F_3 and F_4 generations for each composite population and for the mean of the three composite populations in both sexes for most of the traits evaluated. In both sexes, heterosis retained in combined F_3 and F_4 generations was greater ($P < .05$) than expected based on retained heterozygosity for birth weight, ADG from weaning to 368-d, and for 368-d weight and did not differ ($P < .05$) from expectation for other traits.

The results of this study are encouraging because they demonstrate that composites can retain heterosis consistent with expected heterozygosity after four generations of inter se matings. These results also support the hypothesis that heterosis is due to dominance effects of genes for growth and size traits in cattle.

Another advantage of composites over rotations is the elimination of inter-generation variation. Advantages of rotations over composites are theoretically lower intra-generation variation, greater genetic diversity among parent populations and the ability to rapidly respond to industry/market changes.

PUREBRED, CROSSBRED AND COMPOSITE BULLS

A related but separate question is where do purebred, crossbred and composite bulls fit into crossbreeding systems? Purebred bulls are the basis of many of the crossbreeding systems and will remain so. Thus, it is extremely important that sound and accurate within breed evaluation programs continue. This will allow the breeder that is designing a crossbreeding system to choose sires within breeds as well as choose breeds. Composites can be used as a separate crossbreeding system. In other respects, crossbred and composite bulls can be used to add a small percentage (25% or smaller) of a given breed to the cow herd and take advantage of any paternal heterosis for reproductive traits such as percentage of cows settled.

SUMMARY

Systematic crossbreeding can be used to increase weight of calf weaned per cow exposed by 20 percent. Comprehensive breed evaluation programs have revealed large breed differences for most productivity traits in beef cattle. Most rotational crossbreeding systems prevent substantial use of complementarity. Conventional crossbreeding systems are difficult for many breeders to use due to requirements for herd size, breeding pastures, breeds and sire breed identification of females. Artificial insemination can simplify most conventional crossbreeding systems for those breeders willing to manage it properly. Simplified crossbreeding systems present an attractive trade-off between small sacrifices in heterosis vs. savings in time, labor and management of a one-pasture system. Examples of one-pasture systems are sire-breed rotations and composite breeds. Sire-breed rotations maintain slightly higher heterosis than comparable composites. Breeders of composites must maintain large populations to avoid inbreeding but users of composite bulls have no such constraint. Heterosis can be retained in advanced generational crosses of a composite breed. Heterosis retained is proportional to heterozygosity and heterosis is most likely explained by the dominance effects of genes.

Crossbreeding will be successful so long as the breeder carefully plans the breeds, sires and crossbreeding system to match the level of management and environment.

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