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Crossbreeding Programs for Beef Cattle in Florida[1]

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Introduction

The purpose of this bulletin is to assist Florida ranchers in the design of crossbreeding systems that will be most appropriate and profitable for their particular ranches. Recommendations for use of various breeds and crossbreeding systems are based on many years of crossbreeding studies in Florida and throughout the United States.

Planned crossbreeding programs, such as two- and three- breed rotations, have probably been used longer and more effectively in Florida than in any other part of the United States. But, many cattle in Florida are more "mongrelized" than crossbred: they are the result of no particular mating design, nor any particular goal. The economic benefits obtained from a crossbreeding system can be great, but efficacy of the system depends upon the proper mating of cows to superior, unrelated bulls.

Although rotational crossbreeding systems involving the Brahman (a *Bos indicus* breed) and one or two *Bos taurus* breeds - usually Hereford and(or) Angus - have been extensively researched in Florida, and although these systems generate highly productive animals, the declining value of feeder calves with distinctive Brahman characteristics (hump, large ears, and excess skin) has led many cattle producers to investigate alternative crossbreeding systems that result in calves that appear to have no more than 1/4 to 3/8 Brahman breeding. Such a goal can be accomplished through the use of rotational systems that utilize Brahman x *Bos taurus* crossbred bulls, bulls of Brahman-derivative breeds such as Brangus, Braford, Beefmaster, etc., or bulls of tropically adapted *Bos taurus* breeds such as the Senepol - and with or without utilizing bulls of *Bos taurus* breeds of Bristish or European origin. Objectives of this bulletin are (1) to discuss the genetic aspects of crossbreeding beef cattle in Florida, (2) to explain how various crossbreeding systems are conducted, together with their respective advantages and disadvantages, and (3) to examine the use of specific breeds that are most appropriate for particular crossbreeding systems and environmental conditions.

Why Use a Crossbreeding System: What Are the Advantages?

A properly designed crossbreeding system allows the cattle producer to take advantage of appropriate combinations of the superior traits of several different breeds *(complementarity)* and it also yields *heterosis.* Heterosis, often referred to as "hybrid vigor," measures the difference between average performance of crossbred animals and average performance of the breeds that were crossed to

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produce them. For example, purebred calves of Breed A have an average weaning weight of 480 lb, and Breed B calves have an average weaning weight of 520 lb; calves resulting from the mating of Breed A sires to Breed B dams have an average weaning weight of 560 lb, and calves resulting from the reciprocal cross (Breed B sires mated to Breed A dams) have an average weaning weight of 540 lb. The amount of heterosis produced by the cross is calculated by subtracting the average of the weaning weights for purebred calves ([480 lb + 520 lb] ÷2=500 lb) from the average of the weaning weights for crossbred calves ([560 lb + 540 lb]÷2=550 lb). The amount of heterosis produced by this cross is 50 lb. Often, heterosis is expressed in terms of the percentage of improvement that crossbreds exhibit above the purebred average. To determine ***percentage*** of heterosis, divide 50 lb (the amount of heterosis) by 500 lb (the purebred average); then multiply by 100%; this yields a heterosis value of 10% for the Breed A - Breed B crossbred combination.

Table 1 compares average levels of heterosis for F_1 crosses of *Bos taurus* x *Bos taurus* (Angus x Hereford, for example) to average levels for *Bos indicus* x *Bos taurus* (Brahman x Angus, for example) F_1 crosses, by trait. The F_1 cross requires that purebred bulls be mated to purebred cows. Traits are classified according to the two types of heterosis, individual and maternal.

Individual heterosis is heterosis that results because an animal is crossbred (regardless of whether its dam is purebred or crossbred); it is expressed by heavier birth weight and faster growth compared to average performance of the breeds that were crossed to produce the crossbred animal. Individual heterosis levels for *Bos taurus* x *Bos taurus* crosses are low relative to levels shown for *Bos indicus* x *Bos taurus* crosses. Individual heterosis levels for weaning weight average 3.9% for *Bos taurus* x *Bos taurus* crosses, compared to 12.6% for *Bos indicus* x *Bos taurus* crosses. The difference is heterotic effect of *Bos indicus* x *Bos taurus* crosses compared to *Bos taurus* x *Bos taurus* crosses can be even greater for postweaning gain. Although the increased postnatal growth rate of *Bos indicus* x *Bos taurus* crosses is certainly desirable, the concurrent effect of heterosis on birth weight (11.1%) can result in substantial increase in calving difficulty when *Bos taurus* heifers are bred to *Bos indicus* bulls. With the reciprocal cross (*Bos indicus* heifers bred to *Bos taurus* bulls), however, calving difficulty is generally not a concern due to the inherent ability of *Bos indicus* females to restrict fetal growth.

Maternal heterosis is expressed for traits measured on crossbred cows (such as calving rate) and for traits measured on their progeny (including calf survival, birth weight, and weaning weight). Crossbred cows have higher calving rates than purebred cows, For *Box taurus* x *Bos taurus* F_1 crosses, calving rates are 3.7% higher than the purebred average, whereas they are 13.4% higher for *Bosindicus* x *Bos taurus* F_1 crosses. Because fertility is such an economically important trait, even the smaller 3.7% increase due to heterosis from *Bos taurus* x *Bos taurus* crosses can have a decisive effect on profitability. Crossbred cows also have calves with higher survival rates and birth weights than calves of purebred cows. The level of maternal heterosis for calf weaning weight is particularly high, averaging 16% for *Bos indicus* x *Bos taurus* and 3.9% for *Bos taurus* x *Bos taurus* crosses. Assuming a modest average weaning weight of 475 lb for calves of purebred cows, the calves of *Bos indicus* x *Bos taurus* F_1 crossbred cows would be expected to weigh 16% more (or 551 lb) at weaning due to the effects of maternal heterosis alone. Individual heterosis effects would further increase expected weaning weight.

The trait, "pounds of calf weaned per cow exposed" (within a defined breeding season), measures total productivity of the cow herd. Both individual and maternal heterosis improve this measure of productivity. If we assume a calving rate of 85%, a calf survival rate of 93%, and a weaning weight of 500 lb for purebred average performance, then pounds of calf weaned per cow exposed would be 395 lb (.85 x .93 x 500 lb) for purebred cows. Use of *Bos indicus* x *Bos taurus* F_1 crossbred cows increases potential calving rate by 13.4%, calf survival rate by 5.1%, and calf weaning weight by 16%. The increase in productivity due to heterosis from using these F_1 cows results in a potential 544 pounds of calf weaned per cow exposed, a 38% increase over purebred average performance! Although such a large increase would not likely be achieved in all cases, this example illustrates the advantages of maximizing heterosis through properly designed crossbreeding systems.

It should be emphasized that heterosis will not improve ***all*** traits. Carcass traits such as rib-eye area, marbling, meat tenderness, etc. are not affected by crossbreeding. These can be improved only be selection of breeds - and bulls within those breeds - that excel in carcass traits. Similarly, heterosis has little effect on the mature size of crossbred cows.

Crossbreeding offers and advantage besides heterosis: producers can select breeds whose superior traits will *complement* each other in a particular crossbreeding system, producing crossbred animals with a more desirable combination of traits than can be found in existing breeds. The effect of combining desirable traits from two or more different breeds to produce superior crossbred animals is referred to as ***complementarity.***

Breed complementarity can be illustrated in terms of adaptation of the Florida's climate. Angus cattle are at a disadvantage in Florida during summer months due to their inability to control body temperature during periods of heat stress. Brahman cattle, on the other hand, are comfortable during the summer because they are well adapted to high temperatures, but they often suffer in the winter during wet, cold, and windy periods. The F_1 animal that results from crossing Angus with Brahman is comfortable during both summer and winter months in Florida; its level of adaptation to cold, and to heat, is intermediate to the corresponding levels of adaptation exhibited by each parental breed.

Complementarity can be explained as the effect of an appropriate combination of traits controlled by additive genetic genes contributed by the parental breeds. Additively controlled traits are those by which the superiority - or inferiority - of the parents is passed consistently to the progeny. Traits that are highly heritable, such as adaptive traits, mature size, and carcass traits are strongly controlled by additive genes. (If traits were *entirely* controlled by additive genes, performance of F_1 progeny would always equal the exact average of the parental breeds' performances.) Through proper selection of breeds for use in a crossbreeding system, producers can "genetically engineer" the desired level of performance for specific traits in the crossbred progeny.

The Genetic Basis of Heterosis

Increase in the performance of animals due to crossbreeding (heterosis) occurs because the purebred breeds that are crossed are inferior in performance due to the effects of inbreeding. When purebred breeds are crossed, the effects of inbreeding are removed and performance increases. Inbreeding is the mating of related animals, such as half-brother x half-sister, and was used during breed development to achieve uniformity with regard to coloration, spotting, and other physical traits. For example, all Herefords are red with some form of the spotting pattern that is characteristic of the Hereford breed, but the foundation animals of the Hereford breed were not as uniform. The inbreeding process resulted in animals that were more *homozygous* than the "outbred" animals that were used to found the breed.

Homozygosity describes a condition where the pair of genes at a given locus (location on a chromosome) is identical. The more homozygous animal has a higher percentage of loci at which gene pairs are identical, and with increasing homozygosity comes increasing uniformity. While inbreeding accomplished the goal of within-breed uniformity, the same increase in homozygosity that afforded such uniformity also extracted a price: lowered productivity due to the expression of recessive genes - each with small effects - at many loci. But each breed tended to become homozygous for *different* recessive genes. So, when two breeds are crossed, the recessive (frequently deleterious) genes from one breed are often "covered up" by dominant, desirable genes from the second breed. The effect of this covering up is increased performance, measured as heterosis.

This process can be most easily explained by hypothetical example, illustrated in Table 2. A particular trait found in Breeds A and B is controlled by genes at five loci, A through E. Recessive genes, indicated by lowercase letters, are expressed as lowered productivity. (Individually, pairs of recessive genes have only a minor effect on productivity, but their cumulative effect can be quite pronounced). The F_1 animal that results from crossing breeds A and B is

Table 1. Average heterosis levels for economically important traits of beef cattle.

Trait	Type of Cross: ***Bos taurus*** x ***Bos taurus***	Type of Cross: ***Bos indicus*** x ***Bos taurus***
Individual Heterosis		
Birth weight	2.4%	11.1%
Weaning weight	3.9%	12.6%
Postweaning gain	2.6%	16.2%
Maternal Heterosis		
Calving rate	3.7%	13.4%
Calf survival	1.5%	5.1%
Birth weight	1.8%	5.8%
Weaning weight	3.9%	16.0%

Adapted from: L.V. Cundiff, L.D. Van Vleck, L.D. Young, K.A. Leymaster and G.E. Dickerson. 1994. Animal Breeding and Genetics. In: Encyclopedia of Agricultural Science, Vol. I. pp 49-63. Academic Press Inc.

Table 2. Explanation for the cause of heterosis.

Genotype	Locus A	Locus B	Locus C	Locus D	Locus E
Breed A	A/A	b/b	C/C	d/d	e/e
Breed B	a/a	B/B	c/c	D/D	E/E
Ax**B** (F_1 crossbred)	A/a	B/b	C/c	D/d	E/e

not homozygous - recessive at any of the five loci. A dominant, desirable gene (indicated by a capital letter) at each locus masks the effect of the recessive, undesirable gene. While the effect of masking any single recessive gene may be minor, the total combined effect across the many loci that affect traits such as calving percentage, growth, and milk production can be substantial.

More heterosis results from *Bos indicus* x *Bos taurus* crosses than from *Bos taurus* x *Bos taurus* crosses because there is ***less*** similarity of genetic composition between any given *Bos indicus* breed and any *Bos taurus* breed than there is between any two *Bos taurus* breeds. When two *Bos taurus* breeds are crossed, less heterosis results because more loci remain homozygous for undesirable recessive genes.

Another explanation for part of the greater heterosis effects in *Bos indicus* x *Bos taurus* crosses may be the complementarity for adaptation to subtropical environments that was previously discussed.

Importance of Bos indicus Breeding for Crossbreeding Systems in Florida

Beef cows must be adapted to environmental conditions to achieve maximum productivity (measured by high reproductive rates and heavy calf weaning weights). In Florida, the use of Brahman breeding produces animals that are able to maintain normal body temperature throughout the extreme heat of summer months. Although it may be possible, through many generations of selection under Florida conditions, to produce *Bos taurus* cattle that are adapted and productive in the Southeast, adapted and productive animals can be immediately produced through the use of Brahman x *Bos taurus* crosses. The high level of maternal heterosis expressed by the Brahman x *Bos taurus* F_1 female in the southeastern United States results in much higher productivity than crossbred females without Brahman influence can achieve (Table 1). Brahman and Sahiwal (another *Bos indicus* breed) x *B. taurus* F_1 crossbred cows have surpassed the performance of *Bos taurus* x *Bos taurus* F_1 crossbred cows even in Nebraska and Canada, where subtropical adaptation would be useless at least 11 months of the year.

The productive advantage of *Bos indicus* x *Bos taurus* crossbred cows is partially due to higher levels of milk production later in lactation than *Bos taurus* x *Bos taurus* crossbred cows are able to achieve under subtropical conditions. Additionally, the *Bos indicus* (and *Bos indicus* crossbred) female has the ability to restrict the birth weight of her calf by 10 lb or more, resulting in less calving difficulty. There is also evidence that the greater pelvic area and unique pelvic structure of *Bos indicus* females may help explain their greater ease of calving compared to *Bos taurus* females.

The *Bos-indicus* - sired dam's ability to restrict her calf's birth weight and to calve easily permits a producer to breed Brahman-crossbred cows to bulls of large breeds such as Simmental, Gelbvieh, or Charolais with little concern for calving difficulty. The calves from such a mating (three-breed terminal cross), while relatively small at birth, have the genetic potential for very rapid growth due to a combination of effects: 50% of their genes are from the large sire breed, plus both individual and maternal heterosis positively affect growth. This genetic potential for growth, along with the high and sustained milk yield of the *Bos indicus* x *Bos taurus* crossbred cow, can result in exceptional calves at weaning. (Unfortunately, however, such exceptional growth-to-weaning could also be related to lowered growth postweaning).

For many years in Florida, Brahman cattle have been used in two- and three-breed rotational crossbreeding systems with Angus and Hereford breeds. In a two-breed rotational crossbreeding system, the daughters of one breed (e.g., Angus) are bred to bulls of another breed (e.g., Brahman) and vice versa (daughters of Brahman bulls bred to Angus bulls). The two-breed rotational system has sometimes been called a *crisscross* breeding system. The three-breed rotational system is similar but more complex, using three breeds in rotation instead of two. In a three-breed rotation that utilizes Brahman, Angus, and Hereford breeds, daughters of Brahman bulls are bred to Hereford bulls, daughters of Hereford bulls are bred to Angus, and daughters of Angus bulls are bred back to Brahman.

Over the past 15 years, cattle producers in Florida have increasingly used rotations that include the Brahman-derivative breeds (Brangus, Braford, Beefmaster, Simbrah, etc.) - in exclusively Brahman-derivative rotations and in rotations that utilize *Bos taurus* breeds as well - to capitalize on desirable traits of the Brahman without the penalty of price discounts which accompany production of animals with more than 50% Brahman breeding. The two-breed rotation of Brangus with Braford (daughters of the Brangus x Braford cross are bred to Brangus bulls, and their progeny, in turn, are bred to Braford bulls) produces calves that are 3/8 Brahman in breed composition - a quantity likely to provide sufficient adaptation to the central and south Florida environment and yet produce calves that are generally acceptable to feeder-calf buyers.

Use of Non-Bos indicus Sources of Tropical Adaptation

Offsetting the many advantages of using *Bos indicus* breeds (generally Brahman) in crossbreeding systems are some distinct disadvantages. The greatest is the price discount often received for calves that exhibit distinctive *Bos indicus* characteristics; that is, the hump, large ears, and extra skin usually associated with calves that have over 50% Brahman breeding. This discount is due, in part, to the lower quality grades (less marbling) of the carcasses from such cattle. Meat from carcasses with more than 25% Brahman breeding is less tender than meat from carcasses without Brahman breeding. Other problems with Brahman and Brahman crossbred cattle are excitable temperaments (nervous cattle tend to grow more slowly in feedlots) and late puberty. It can be difficult to achieve a high pregnancy rate (>90%) in yearling heifers (13 to 15 months of age) that have 50% or more Brahman influence, and it is even more difficult to get purebred Brahman heifers pregnant at this age. Purebred Brahman cows and cows with high levels of Brahman breeding are also susceptible to lactational anestrus (failure to come back into heat following calving while nursing a calf) unless they are maintained under a favorable nutritional environment.

One alternative to the use of Brahman, Brahman-crossbred, or Brahman-derivative breed bulls (Brangus, Braford, etc.) in a rotational crossbreeding system is the use of Senepol bulls, or bulls of other tropically adapted *Bos taurus* breeds such as the Tuli or Romosinuano. The Senepol is a *Bos taurus* breed developed on the island of St. Croix (one of the U.S. Virgin Islands) from a cross of the Red Poll and the N'Dama, an African breed noted for its resistance to trypanosomiasis (a blood-parasitic disease transmitted by the tsetse fly). The Senepol breed has an extremely short hair coat, and data from Florida have shown it to be as heat tolerant as the Brahman. This short-haired trait and corresponding heat tolerance is usually exhibited by Senepol x Hereford as well as Senepol x Angus crossbred progeny.

Senepol cattle generally have the short ears and tight sheaths and dewlaps characteristic of most *Bos taurus* cattle. Another advantage of the Senepol breed is that its meat is similar in tenderness to the meat of other *Bos taurus* breeds. Senepol heifers also reach puberty earlier than purebred *Bos indicus* heifers (though not as early as Simmental or Angus heifers). A disadvantage is that Senepol cows lack the ability of *Bos indicus* cows to control fetal growth (and thus reduce calving difficulty), and young purebred Senepol cows seem to share the *Bos indicus* females' susceptibility to lactational anestrus. In the case of both young Senepol and young Brahman females, however, lactational anestrus appears to be largely associated with low body condition scores (<=4); therefore, increased nutrition should alleviate the problem.

Another tropically adapted *Bos taurus* breed of potential utility for crossbreeding systems in Florida is the Romosinuano, a breed from Columbia. The Romosinuano is similar in appearance to the Senepol (red, polled, and short haired) and is descended from the Spanish cattle that constituted the original cattle population of the Americas. Interest in the Romosinuano breed by United States cattle researchers is based on the reputed high fertility of the Romosinuano cow (i.e., short calving intervals) under tropical conditions. The breed was developed in the Sinu region of northwestern Columbia - which has fertile soils and good pastures but is extremely hot and humid. Reports from Venezuela of high fertility in Romosinuano x *Bos indicus* crossbred females have corroborated the results of earlier studies done in Colombia.

A third breed of potential utility as a tropically adapted *Bos taurus* breed is the Tuli from southern Africa. The Tuli is a Sanga-type animal noted for its tropical adaptation combined with good fertility. The Sanga breeds (Africander is another example) were developed centuries ago from crosses of *Bos indicus* and *Bos taurus* cattle. So, Sanga cattle can be thought of as similar to the American Brahman-derivative breeds, except they have been bred as purebreds for a much longer period of time. Tuli cattle that have been imported into the United States appear to have about 20% to 25% *Bos indicus* inheritance. The Tuli was one of two breeds selected by Australian cattle producers for importation to Australia. The Tuli was selected for importation over other African breeds because of its superior muscling (beef-type conformation) and fertility. The Tuli breed is also reputed to have a calm disposition and resistance to heat and ticks. Research with the Tuli is currently under way at the Subtropical Agricultural Research Station in Brooksville, Florida; at the U.S. Meat Animal Research Center in Nebraska; and at other Southern locations from New Mexico to Georgia.

More recently, the Bonsmara breed has been imported from southern Africa. The Bonsmara is a composite developed by the legendary south African animal scientist, Jon Bonsma. The breed is composed of Africander, Shorthorn and Hereford and is reported to have tropical adaptation, good meat quality traits and early puberty.

Selection of Breeds for Use in Crossbreeding Systems

The choice of breeds to include in a crossbreeding system is of critical importance because, for many traits, there are large differences in the average performance of different breeds. The specific breeds and breed crosses that are most appropriate for one particular ranch, with its own set of management and nutritional conditions, may not - and likely *will* not - be the most appropriate combination for another ranch, operating under different conditions.

Breeds differ in growth rate, milk production, carcass traits, age at puberty, fertility, and - as previously discussed - adaptation to Florida's climate. These differences between breeds, as well as variability in the level of heterosis expected from various crosses, need to be considered when planning a crossbreeding program. To make informed decisions regarding choice of breeds to use in a crossbreeding program, it is important to understand what level of performance can be expected of the different breeds - in terms of growth rate, milking ability, carcass traits, and other economically important traits - when they are used in a crossbreeding system.

Data from crossbreeding studies in Florida and throughout the Southeast were used to estimate average values for the additive genetic effects (or *breed effects* - basically, the genetic differences between breeds) on growth traits and maternal traits (primarily, milking ability) for various breeds, measured *relative to Angus* (Table 3); data were also used to estimate values for the individual and maternal components of heterosis for various breed crosses (Table 4). Breed effects were designated *relative to Angus* because Angus cattle have been included in most breed-comparison studies over the years and were widely represented in crossbreeding systems. The g^I (individual performance) values in Table 3 indicate the portion of expected growth-to-weaning (by breed, compared to Angus) that is due to individual growth potential of the calves of that breed, independent of milking ability of their dams. For example, purebred Brahman and Hereford calves are expected to have slightly greater growth potential (6 and 7 lb respectively) than Angus calves, apart from any difference in milk yield of their dams. Similarly, purebred Simmental and Charolais calves are expected to be 80 lb heavier at weaning than Angus calves. Note that these values are for calves sired by breed-average bulls; if bulls with very high additive genetic potential for growth-to -weaning (as indicated by their EPD values for weaning weight being among the highest in the ***Sire Summary*** for that breed) are available, then the relative differences between the g^I values of the breeds would change.

The g^M (maternal performance) values in Table 3 allow comparison of the effect of milk production on weaning weight among cows of the different breeds. (Again, all breeds are compared to Angus). So, Brahman cows are expected to wean calves 8 lb heavier than calves of Angus cows, due to greater milking ability and apart from any differences in growth potential of the calves. And Hereford cows - known to produce less milk than Angus cows - are expected to wean calves 21 lb lighter than those of Angus cows. Simmental and Charolais cows are also expected to wean heavier calves (20 and 9 respectively) than Angus cows, due to increased milk yields.

The Hereford's lower milking ability makes it an appropriate breed to use in crossbreeding systems where the cows must produce under limited nutritional conditions; cows with higher milking abilities would be less likely to rebreed while lactating under such conditions. The Limousin is another breed with lower-than-average milking ability, which could be utilized under lower-nutrition regimes.

As discussed previously, one expression of heterosis is increased calf growth rate. The h^I (individual heterosis) values in Table 4 indicate the effect of heterosis on growth-to-weaning of F_1 calves, for each breed combination shown. Individual heterosis values are very high for F_1 crosses of Angus or Hereford with Brahman, and only slightly lower for crosses of Simmental or Charolais with Brahman. Crosses between the different *Bos taurus* breeds, however, yield much less heterosis. In the Southeast, crossing two large *Bos taurus* breeds (such as Simmental and Charolais) generally yields ***no*** heterosis for calf growth-to-weaning. Likewise, increase in calf growth attributable to the crossbred dam, h^M (maternal heterosis), is very high for *Bos indicus* x *Bos taurus* F_1 crossbred cows and much lower for the F_1 crosses between *Bos taurus* breeds (Table 4).

To fully utilize the effects of heterosis, both individual and maternal, a *Bos indicus* x *Bos taurus* F_1 cow (Brahman x Angus, for example) would have to nurse an F_1 calf of the same cross. In such a calf the total effect of heterosis on weaning weight would be 97 lb (52 lb [h^I] + 45 lb [h^M]). The F_1 cow, however, cannot give birth to an F_1 calf without transferring an embryo into her.

The closest we can come to taking full advantage of the effects of heterosis is through the three-breed terminal cross in which the F_1 cow is bred to an unrelated third breed. In the case of the Brahman x Angus F_1 cow bred to a Charolais bull, the individual heterosis of the resulting calf is .50 h^I (Charolais x Brahman cross) + .50 h^I (Charolais x Angus cross). This is because half of the gene combinations in the calf are Charolais with Brahman and half Charolais with Angus. Thus the total individual heterosis for this cross is .50 (42) + .50 (8) which is 25, considerable below that of the F_1 *Bos indicus* x *Bos taurus* levels. The total heterosis, h^I + h^M, for this type of terminal cross is 70 lb, 25 + 45.

When choosing breeds for a crossbreeding system, the environment - both nutritional and climatic - must also be considered. For example, the growth potential of the Simmental breed is much higher than that of the Angus and Hereford breeds, but cows sired by Simmental bulls may not maintain sufficient body condition to rebreed while lactating unless the level of nutrition provided is adequate to support their higher requirements. This problem is especially acute for lactating first-calf heifers. So, under low-input production systems (native range, for example), use of the larger, heavier-milking breeds - likely to produce cows weighing over 1100 lb - would not be feasible. Traditional crosses involving the Angus, Hereford, and Brahman breeds and (or) Brangus and Braford are likely to be more profitable because reproductive rate is the trait with the greatest impact on profitability. The higher nutritional requirements of the Simmental and other heavy-milking breeds and their crosses must be considered in order to avoid lowered fertility. With improved, fertilized pastures and adequate supplementation during the winter months, the use of larger, heavier-milking breeds can produce highly productive cows (as long as excessively large-framed bulls that will produce extremely large daughters are not used). An additional advantage to using breeds and breed crosses characterized by high milk production is their early puberty compared to breeds with lower average milk yields.

Another factor that must be considered in breed selection is *market demand*. Breeds selected must be utilized in a system that will produce calves that are in demand by stockers and feeders. It is for this reason that the Brahman can no longer play as large a role in crossbreeding programs as it has in the past, or the breed must be utilized differently to avoid production of calves with distinctive Brahman characteristics. Feeder calves must also have moderate frame sizes - an indicator of the weight of the carcass that they will produce - in the range from 5 to perhaps as high as 7 and possess adequate muscling. Therefore, the breeds selected must also have bulls available with appropriate frame scores and muscling to produce medium-framed, muscle-score - #1 feeder calves.

Crossbred bulls can be used as profitably as purebred bulls in crossbreeding systems. These bulls can have been bred as purebreds for many generations, like the Santa Gertrudis and some Brangus or Braford (which could arguably be considered as purebred bulls); or they can be new, first-generation crosses (produced, for example, by the cross of 3/4 Brahman: 1/4 Angus bulls and Angus cows). It is commonly assumed that crossbred bulls will sire less-uniform progeny than purebred sires. While some additional variability can occur for traits such as color and presence or absence of horns, there should be *no* increase in variability for traits controlled by large numbers of genes; these traits include weights at all ages and most other traits of interest (except for color and horns). This statement is in contrast to the opinions of many but has been proven in a number of studies with beef cattle, as well as in studies with swine and sheep. We would also not expect to see *less* variation in the progeny of multigeneration Brangus bulls (those bred Brangus to Brangus for many generations) than in progeny of first-generation crossbred bulls (except for coloration and presence or absence of the polled gene). Weaning and yearling weights for first-cross bulls would probably be superior to those for multigeneration bulls because first-cross bulls express more heterosis than multigeneration bulls. Therefore, when deciding which bulls to select, the performance of first-cross bulls should be compared only to the performance of other first-cross bulls and not multigeneration bulls.

To produce a consistent set of calves year after year, it is essential that an appropriate crossbreeding system with a particular set of breeds be established and consistently maintained. Thus, continuous availability of superior bulls for each breed included in the system is, necessarily, an important criterion for breed selection. Availability of bulls of some breeds that may be useful for crossbreeding programs in Florida is a major concern. While adequate numbers of Brahman and Brahman-derivative breed bulls are produced here, only a relatively small number of bulls of the *Bos taurus* breeds are produced in Florida. It is also important that the bulls that are purchased be able to maintain their body condition and breed cows under your ranch's conditions and continue to do so for at least 4 years. Bulls born and raised in the Southeast are more likely to accomplish this goal.

Crossbreeding Systems

This section discusses the crossbreeding systems that may be used by Florida cattle producers, beginning with the simplest (or traditional) systems and continuing on to newer systems that may be more appropriate for the future. There are three basic types of crossbreeding systems: terminal, rotational, and composite. All have been used in various parts of the world; each has its own inherent set of advantages and disadvantages.

Terminal Crosses

Two-Breed Terminal Crossbreeding

In a two-breed terminal crossbreeding system the cows, which are all of one breed, are bred to a purebred sire of a different breed, and all the resulting F_1 progeny are sold. Figure 1 shows an example of a two-breed terminal cross in which Angus cows are bred to Charolais bulls and all the calves - steers and heifers - are sold at weaning. It is not a practical system for use in Florida because all dams are purebred, which precludes the effects of maternal heterosis, and all must be purchased or produced in a separate herd. The F_1 calves, however, exhibit the full effects of individual heterosis (primarily faster growth, pre- and postweaning). Another advantage is that two-breed terminal crossbreeding can produce very uniform, productive calves that are highly desirable to feedlot operators and packers, depending on proper choices of breeds and bulls within those breeds. The Charolais x Angus cross (given appropriate choices of Charolais sires and postweaning management) should result in calves that grow well in the feedlot and "hang up" excellent carcasses with adequate finish (fatness) and acceptable marbling.

Table 3. Additive genetic effects for individual and maternal components of calf growth-to-weaning, by breed.

Breed	g^{I} [a]	g^{M} [b]
Angus	0	0
Brahman	6	8
Hereford	7	-21
Simmental	80	20
Charolais	80	9

[a] The g^{I} values represent the difference (lb) in weaning weight between Angus calves and specific-breed calves that is attributed to additive genetic effects.
[b] The g^{M} values represent the difference (lb) in effect of maternal ability on calf weaning weight between Angus cows and specific-breed cows that is attributed to additive genetic effects.

Table 4. Heterotic effects for individual and maternal components of calf growth-to-weaning, by breed combination.

Crossbred Combination	h^{I} [a]	h^{M} [b]
Angus-Brahman	52	45
Angus-Hereford	11	10
Angus-Simmental	8	15
Angus-Charolais	8	15
Brahman-Hereford	52	45
Brahman-Simmental	42	35
Brahman-Charolais	42	35
Hereford-Simmental	5	15
Hereford-Charolais	5	15
Simmental-Charolais	0	8

[a] The h^{I} values represent the effect on calf weaning weight (lb) attributed to F_1 crossbreeding for each breed combination.
[b] The h^{M} values represent the effect on calf weaning weight (lb) attributed to F_1 crossbreeding of the dam for each breed combination.

Although the two-breed terminal cross allows for careful designing of the crossbred feeder calf (per choice of sire and dam breeds), the system has not been used successfully on a large scale anywhere in the United States because it does not allow for the utilization of maternal heterosis. Furthermore, unless there is a local supply of Angus heifers available for purchase, this system requires that much of the herd (about 50%) be bred to Angus bulls in order to produce purebred Angus replacement heifers. So, 50% of all matings would also preclude *individual* heterosis in the production of purebred Angus calves.

British cattle producers once used the two-breed terminal cross when they crossed Angus or Galloway cows with white Shorthorn bulls to produce blue-roan feeders. The single cross might be used to a minimal extent by dairy producers in Florida who could breed their poorer Holstein cows to Belgian Blue or Piedmontese bulls to produce F_1 calves. Both steer and heifer calves of the cross could be used as feeders to produce lean, tender beef. Because of the drawbacks of availability of replacements and lack of utilization of maternal heterosis, the two-breed terminal cross is not likely to be used extensively by the cattle industry.

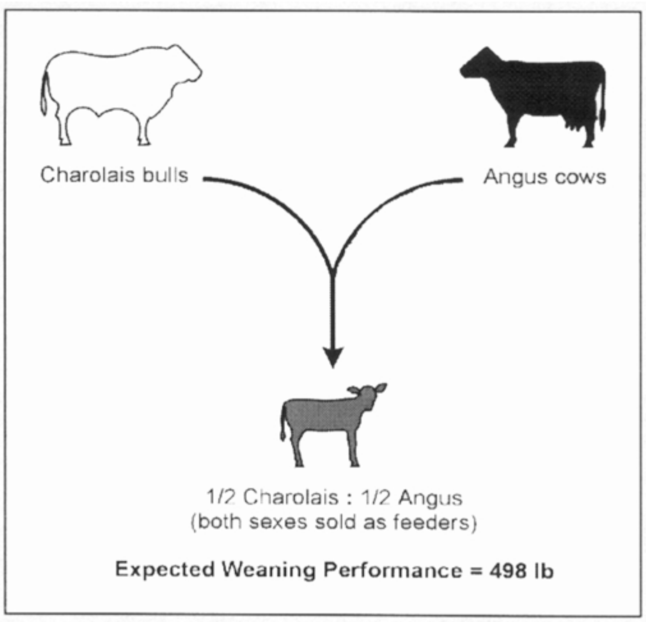

Figure 1. Two-breed terminal cross (single cross).

Three-Breed Terminal Crossbreeding

The three-breed terminal cross is diagramed in Figure 2. In the first phase, Brahman bulls are mated to Angus cows to produce Brahman x Angus F_1 calves. The males can be castrated and sold as feeders or grown out as bulls and the selected animals sold for breeding. The heifer calves are retained, grown out, and bred to Angus or Hereford bulls for their first calves (to minimize calving difficulty) and to Charolais bulls for all subsequent calves. All Charolais-sired calves, steers, and heifers, are sold as feeders.

The three-breed terminal cross has certain very desirable attributes. Both individual and maternal heterosis are fully utilized in the terminal-cross progeny because the dams are F_1 crosses and the terminal-sire breeds used do not have any breed composition in common with the F_1 dams (i.e., there is no Charolais in the 1/2 Brahman: 1/2 Angus dams). The terminal cross allows a producer to design the optimal type of F_1 cow to suit a ranch's environment. The choice of a terminal-sire breed is made to complement the F_1 dam to produce fast-growing calves that will produce appropriate-sized carcasses with adequate muscling and meat quality. Perhaps the most effective method of using this system in Florida would be to (1) breed moderate-framed Brahman bulls to small Angus cows to produce 950 to 1100 lb Brahman x Angus F_1 cows, (2) breed these F_1 cows to frame score 6 or 7 bulls of a muscular sire breed with high growth potential (Charolais, Limousin, Simmental, Belgian Blue, etc.) in order to (3) produce rapidly growing, muscular terminal-cross calves that will have .4 in fat before they reach 1250 lb.

Because both the heifer and steer progeny of the three-breed terminal cross are slaughtered, the major problem with the three-breed terminal cross is the lack of an efficient method to produce replacement heifers. Unless the replacement heifers can be purchased (which is not generally possible), about 50% of the cow herd must be straightbred Angus (in this example) to allow the production of replacement heifers. About half of the purebred cows (25% of the total herd) must be bred to Angus bulls to provide Angus replacement heifers for the system. The other half of the Angus cows would be bred to

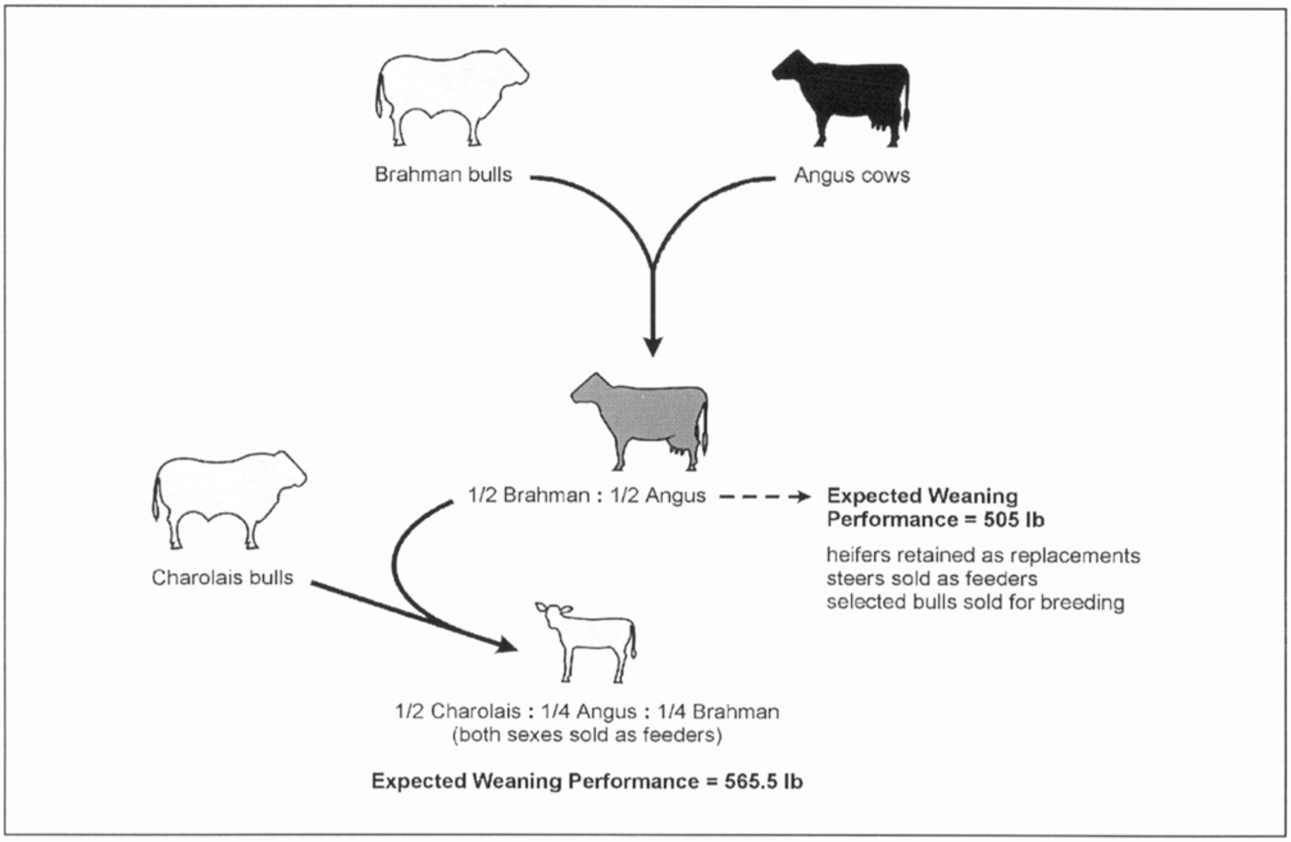

Figure 2. Three-breed terminal cross.

Brahman bulls to produce the F_1 cows. Since half the cows in the system are purebreds, this half does not utilize any of the positive effects of maternal heterosis. If sexed semen were to become available, the production of the F_1 brood cows would be made easier as only half as many Angus cows would be needed to produce the F_1 replacement heifers (since no bull calves would be produced). With the increased interest in F_1 bulls for crossbreeding, however, the sale of the Brahman x Angus F_1 bulls that would be produced along with the F_1 cows could improve the profitability of the system.

It is possible for owners of small herds (<50 cows) and a few larger producers to use this system, or an approximation of it, by utilizing purchased crossbred heifers or young cows which are then bred to terminal sires (Charolais, Simmental, Gelbvieh, etc.). Quality F_1 heifers or cows are seldom available at commercial prices, and while crossbred heifers and young cows that have a Brahman influence may be available through auction markets, the exact breed composition and, therefore, expected heterosis, is not known. In any case, the likelihood of obtaining an F_1 cross is remote, The purchase of auction-market females as replacements also brings with it a considerable risk of introduction of diseases. If quality crossbred heifers from well-managed rotational crossbreeding programs can be obtained, then a terminal crossbreeding system may be a good alternative to rotational systems for producers with smaller herds.

It would be wise to breed all types of crossbred heifers for the first time (especially when bred to calve at 2 years of age) to calving-ease bulls, avoiding the use of bulls of any terminal-sire breeds. Moderate-sized Hereford or Angus bulls with low birth weights and low birth-weight EPDs would be a good choice on Brahman x Angus crossbred heifers. A bull's EPD values for birth weight indicate the expected birth weights of his calves relative to those of other bulls of the same breed. Obviously, we would like the birth weights of calves from first-calving heifers to be quite small, and use of bulls with the lowest EPD values for birth weight will help ensure that this occurs. It needs to be emphasized, however, that EPD values cannot be compared directly across breeds. A Hereford bull with a +3 EPD for birth weight will likely sire lower-birth-weight calves than a Gelbvieh or Simmental bull with an EPD for birth weight of -1. The necessity to use bulls with lower growth potential for the first calf crop from F_1 females reduces the advantage gained from the terminal cross system but is unavoidable in order to minimize calving difficulty.

Rotational Crossbreeding Systems

Two-Breed and Three-Breed Rotational Crossbreeding

The traditional crossbreeding programs in Florida have been two- and three-breed rotational crosses of the Brahman and *Bos taurus* breeds such as the Angus and Hereford. Such crossbreeding systems have worked well and produced productive cows which are well adapted to Florida. The nutrient requirements of cows produced by these systems are moderate and generally not difficult to meet under typical Florida pasture and winter supplementation programs. In a two-breed rotational crossbreeding system (diagramed in Figure 3), two breeds of bulls are used. The daughters of Angus bulls are bred to Brahman bulls and the daughters of Brahman bulls are bred to Angus bulls. Such a two-breed rotation involving the Brahman has fallen out of favor in recent years as half the calves from the cross are about 2/3 Brahman (after the proportions have stabilized when the system has been in place for several generations) and would be subject to large price docks as feeder calves. As can be seen in Figure 3, the predicted weaning weights for calves from the Brahman and Angus bulls are very similar. It is here that their similarity ends as the Angus-sired heifers reach puberty much earlier than the Brahman-sired heifers. Angus- and Brahman-sired calves are also very different in appearance and for this reason could not be sold as a uniform group. This illustrates the need for the bulls of the breeds involved in two- as well as three-breed rotations to be similar in frame size and level of potential milk production so that replacement heifers and cows can be managed as groups - except during the breeding season - and uniform sets of calves are produced.

The three-breed rotation involving the Brahman and two *Bos taurus* breeds, such as Brahman x Hereford x Angus continues to be used in Florida. Such a program is shown in Figure 4 along with the percentage of each breed in the calves produced each generation. The calves sired by Brahman bulls are about 4/7 Brahman (after the proportions have stabilized when the system has been in place for several generations), slightly over half, and would likely be discriminated against by some feeder calf buyers. The Brahman-sired heifer calves, on the other hand, should perform nearly as well as the highly productive Brahman x Hereford or Brahman x Angus F_1 cow. This is particularly true if only those cows showing little or no Brahman influence are bred to Brahman bulls. Those Angus-sired females that by chance retain a greater Brahman influence could be bred instead to Hereford bulls. Their heifer progeny could either be sold as feeders or retained and bred to Brahman bulls. As with the two-breed rotation, however, the Brahman-sired females are distinctly different from the Angus- and Hereford-sired females, in both appearance and in expected age at puberty. An analysis of the expected weaning weights from rotational crosses is shown in the Appendix.

Rotational Crossbreeding Systems Using Brahman-Derivative Breeds or Crossbred Bulls

A criticism of two- and three-breed rotations is the variability that they can produce. It is possible to maintain a constant level of Brahman influence (e.g., 3/8) in all calves produced through use of a rotation of Brahman-derivative breeds (each with 3/8 Brahman), such as the rotation of Brangus x Braford x Simbrah (Figure 5). One advantage of this type of rotation is that the appearance of the calves from each of the sire breeds is similar in terms of Brahman characteristics and other traits. This is especially true when bulls of each sire breed are approximately the same frame size. While some variation in amount of ear and skin occurs in the calves from this type of crossbreeding program, the majority of the calves appear to have roughly the same degree of Brahman influence as the 3/8-Brahman parental breeds. One of the disadvantages of this system is that the growth and reproductive rates of the calves produced are likely to be somewhat less than those from the three-breed

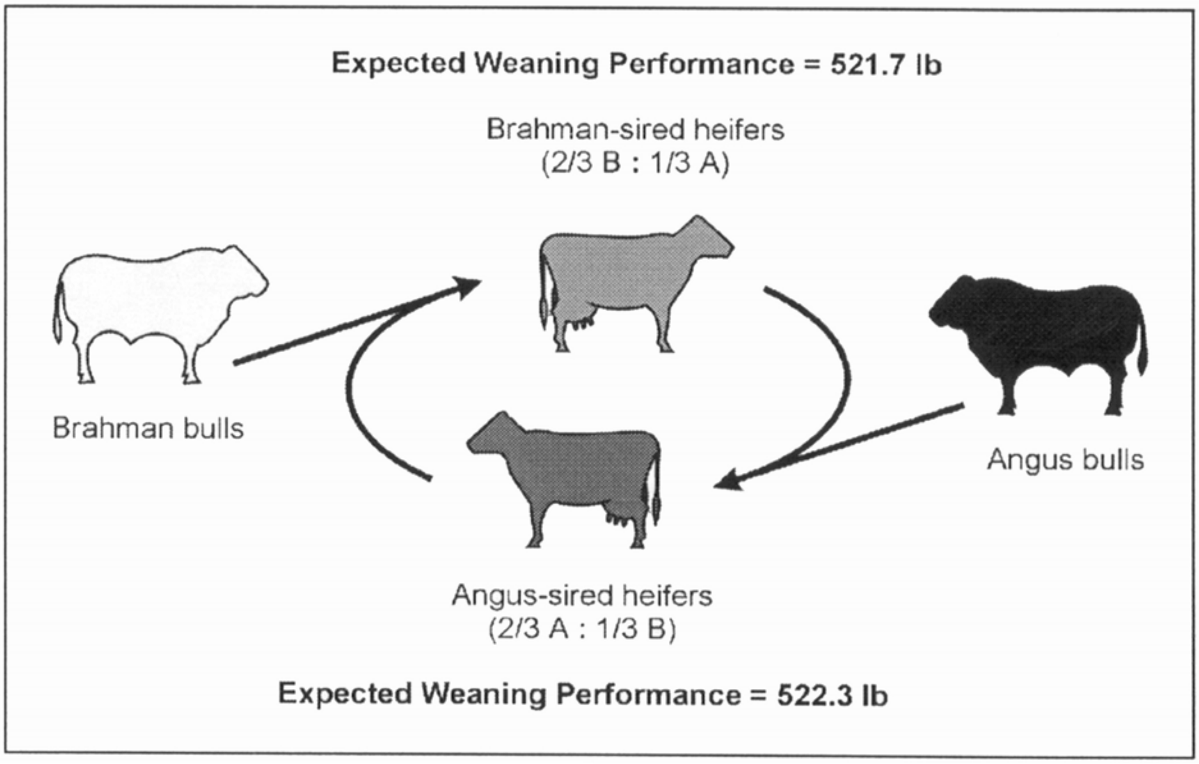

Figure 3. Two-breed rotational cross using Brahman and Angus breeds.

rotation involving the "purebred" sire breeds (Brahman, Angus, Hereford) due to a lower level of maintained heterosis using this system. The weaning weights of the calves from such a system may not be less than that of the traditional three-breed rotation of Angus, Hereford, and Brahman, however, if a larger breed such as the Simbrah is included in the rotation.

In this rotation, Simbrah-sired calves are expected to be heaviest (531 lb) and Brangus-sired calves lightest (511 lb), with Braford-sired calves intermediate at 526 lb. The average weight of all calves weaned from this rotation of Brahman-derivative sires is nearly 523 lb (Figure 5). This is about 10 lb more than the average expected weaning weight for the three-breed rotation using purebred Angus, Hereford, and Brahman bulls as the Simmental adds growth potential which more than compensates for the loss in heterosis. While the system using purebred bulls offers the opportunity for somewhat greater use of both individual and maternal heterosis (86.5% of maximal heterosis as opposed to 80.5%), the greater growth potential of the Simmental breed and the reduced impact of low milk production of the Hereford results in a higher average predicted weaning weight for the Brahman-derivative breed system.

Rota-Terminal Crossbreeding

A variation on the terminal-cross type of crossbreeding which at least partially overcomes the problem of the procurement of replacement heifers for a terminal crossbreeding system has been called a rota-terminal crossbreeding program. With a rota-terminal system (diagramed in Figure 6), replacement heifers are produced in a two-breed rotational crossing scheme (such as Brangus x Simbrah), and then all cows that are not needed to produce replacements are bred to an unrelated, rapidly growing breed with good carcass characteristics, such as the Charolais. All the Charolais-sired calves and the Brangus x Simbrah crossbred steers are sold as feeders. A simple and practical way of handling this type of system would be to maintain Brangus and Simbrah breeding herds during the first part of the breeding season, say 4 to 6 weeks, and then pull all Brangus and Simbrah bulls and turn out Charolais bulls for the remainder of the breeding season. The

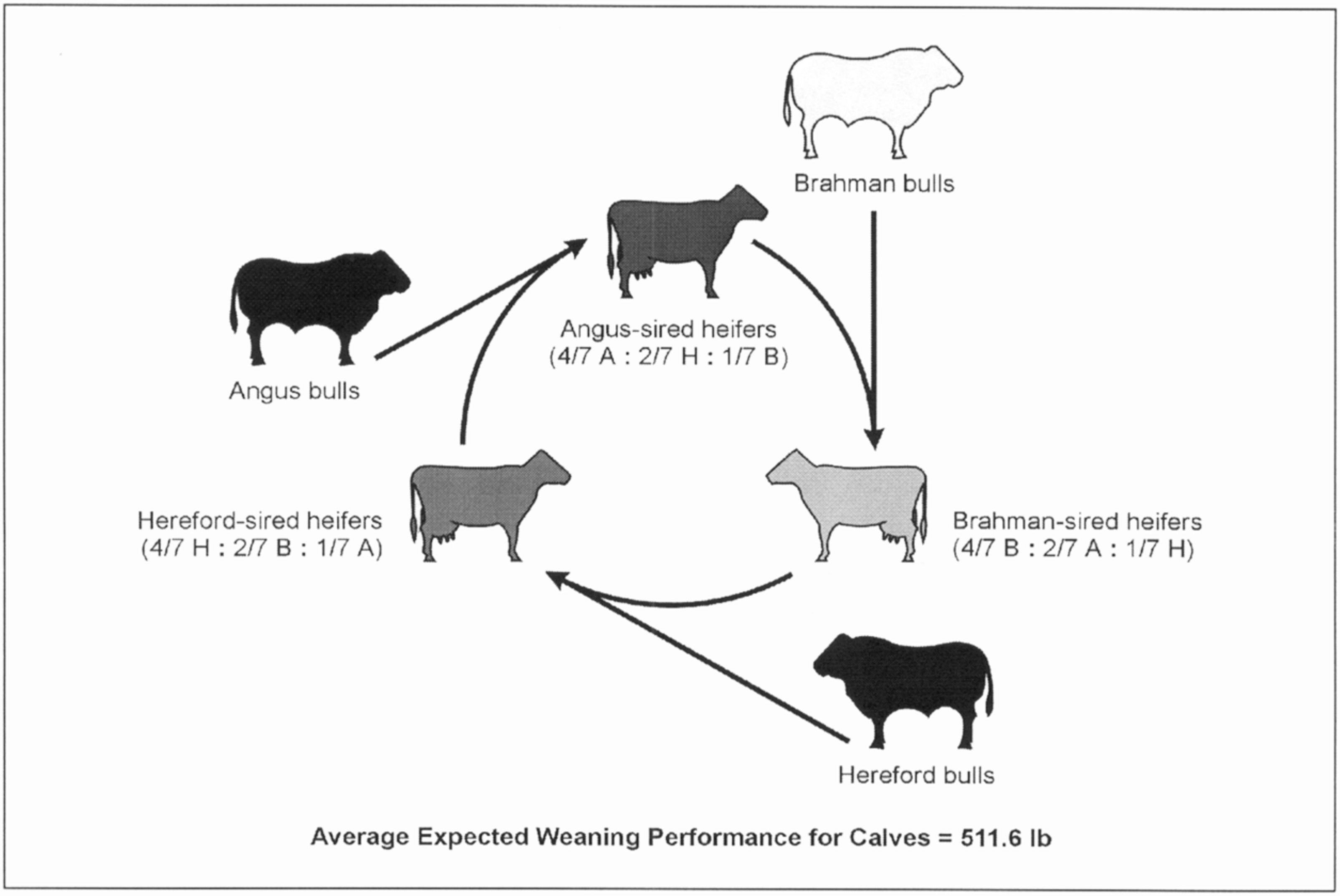

Figure 4. Three-breed rotational cross using Brahman, Hereford, and Angus breeds.

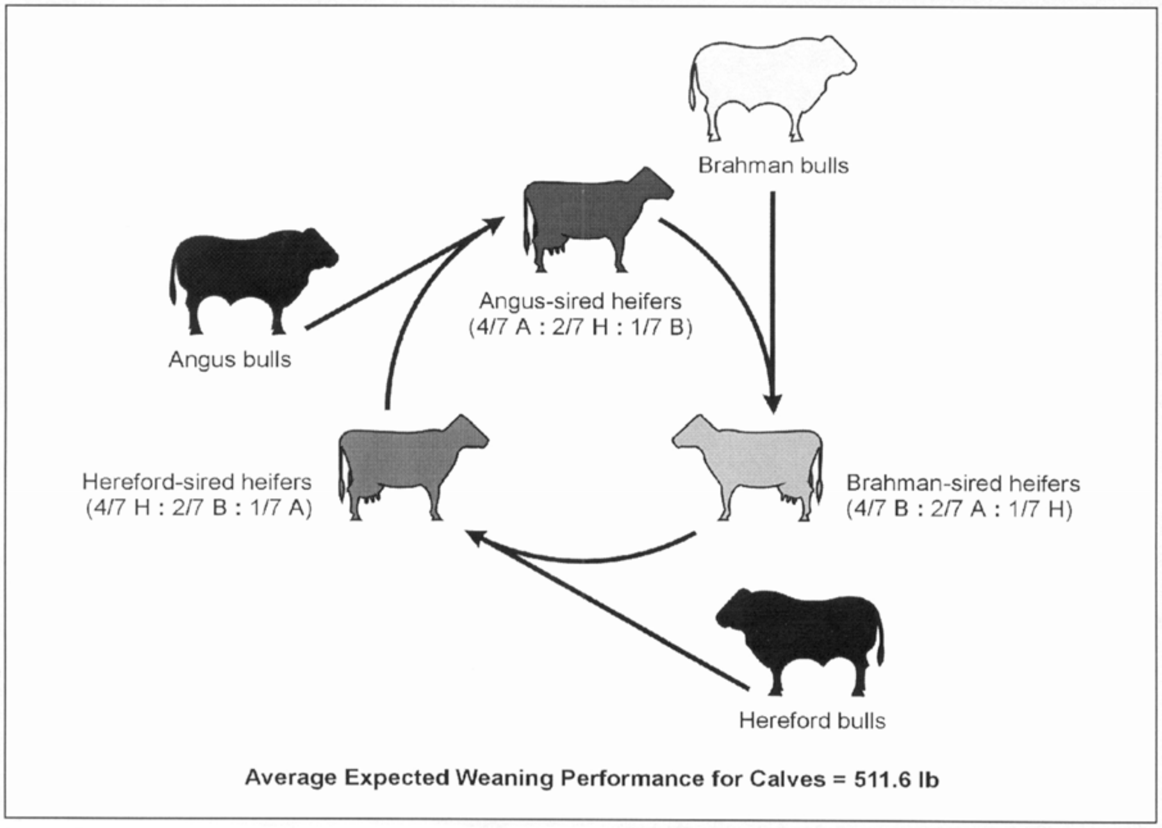

Figure 5. Three-breed rotational cross using Brahman-derivative breeds.

replacement heifers are thus kept from the earlier-calving, more fertile cows. This system had the added advantage that the early-born heifer calves, which tend to conceive earlier as yearlings, are the ones from which the replacements are kept. Also, the later-born heifers, which otherwise would be lighter at weaning simply due to being younger, may be comparable in weight to the earlier-born heifers as they are sired by the growthier, terminal-cross bulls. An alternative system for more intensively managed operations would be to use artificial insemination to proven Brangus and Simbrah sires during the first part of the breeding season to produce the replacement heifers and then turn out terminal-cross (Charolais) bulls as cleanup sires for the remainder of the breeding season. Calculation of the predicted weaning weights for this system is shown in the Appendix.

Use of Rotational Crossbreeding Systems in Small Herds

Many herds in Florida, particularly those in north Florida, have fewer than 50 cows - below the number required for optimal use of any of the crossbreeding systems previously discussed except the two- or three-breed terminal cross. A question that arises, then is "How can rotational crossbreeding systems be altered to make them practical for small herds where the use of only one bull can be justified?" This problem was examined through the use of simulation studies at North Carolina State University (Lamb and Tess, 1989a). These researchers examined 30-cow herds initially composed of purebred cows of a single breed, designated as Breed A. In order to adapt a two-breed rotation to a 30-cow herd, each bull was replaced every 2 years, and the bull breed was changed every 4 years. The sequence of bulls over the first 8 years was $B_1B_1B_2B_2A_1A_1A_2A_2$, where bulls of Breed B were used the first 4 years, followed by Breed A bulls for 4 years. Different bulls of the same breed are indicated by use of different subscripts. Beginning

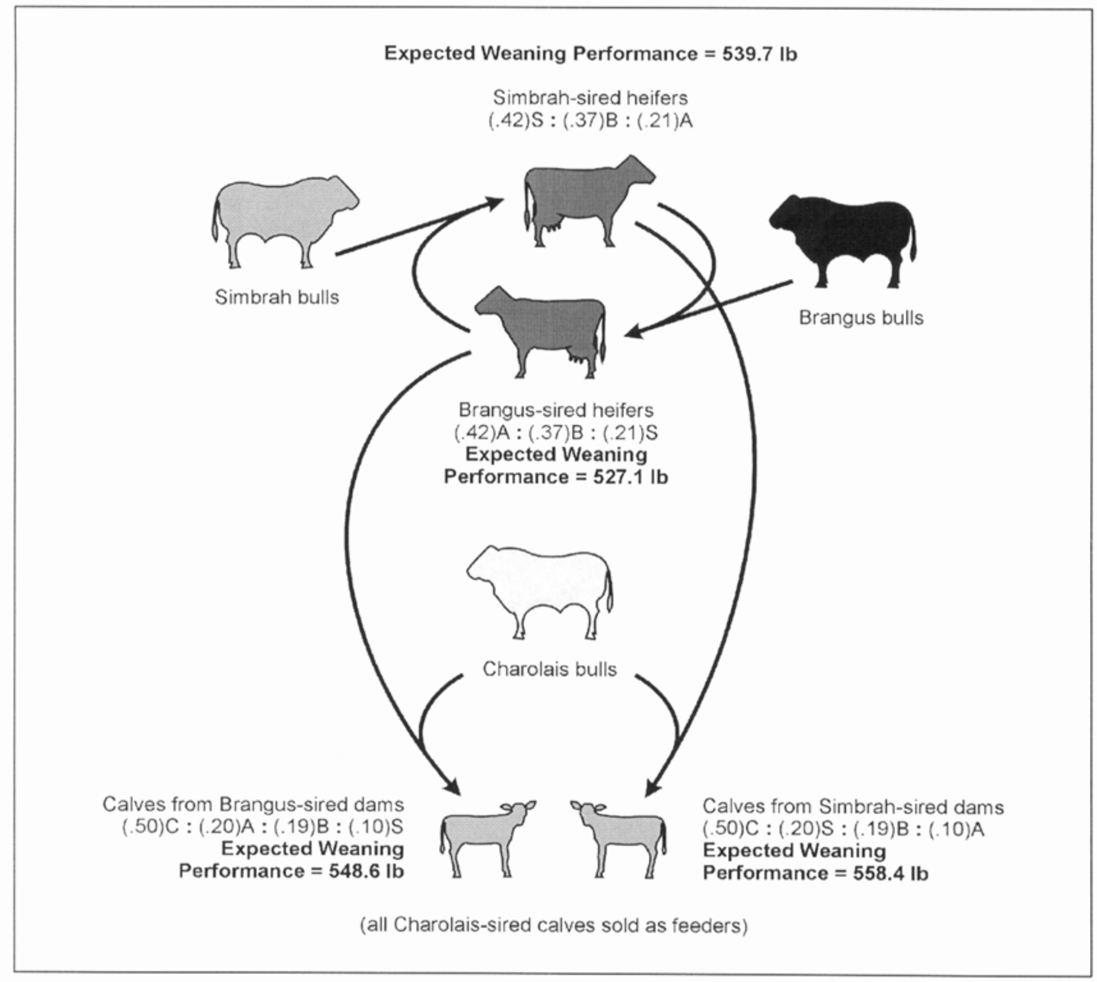

Figure 6. Rota-terminal cross using Simbrah, Brangus and Charolais breeds.

in the 9th year, a Breed B bull would be used again. This system yielded a substantial increase in profitability over a purebred system, and Lamb and Tess found that the productivity and profitablity of such a system were not significantly less than in a system where all matings each year were to the proper breed of bull to give the most heterosis (as would be possible if the herd size were larger and the concurrent use of bulls of several breeds could be justified). The use of three sire breeds in succession, each breed for 4 years, with individual bulls being used for 2 years ($B_1B_1B_2B_2C_1C_1C_2C_2A_1A_1A_2A_2$) in the same-sized herd (30 cows), increased the level of heterosis utilized but did not significantly increase profitability. Such results are encouraging in that they show that even small herds can practically and profitably utilize a rotational crossbreeding system.

A subsequent study by the same authors (Lamb and Tess 1989b) examined two-sire systems for 50-cow herds and looked at methods of adapting two- and three-breed rotations as well as a two-breed rota-terminal system to herds of this same size. The sire usage for the two-breed system, assuming an initial herd of cows of Breed A, was to begin with two bulls of Breed B (B_1 and B_2). These two bulls were used for 2 years and then replaced by two different bulls, A_1 and B_3, which were used for 2 years. Then sets of one bull of Breed A and one of Breed B were changed every 4 years. For the three-breed rotation, again an initial herd of Breed A cows was assumed, and initially two bulls of Breed B were purchased. After 2 years, one of the Breed B bulls was replaced with a Breed C bull that was used for 4 years. The other original Breed B bull would be replaced after having been used a total of 4 years. Thereafter, each bull would be used 4 years. The order of use, beginning with year 1, would be B_1B_2, B_1B_2, B_1C_1, B_1C_1, A_1C_1, A_1C_1, A_1B_3, A_1B_3, B_3C_2, B_3C_2, etc. Use of a two-breed rota-terminal system was simulated assuming that cows over 6 years of age were bred to terminal-cross sires and that all rotational-cross heifer calves were kept as replacements. Lack of a sufficient number of replacement heifers each year limits the usefulness of the rota-terminal system in small herds. Random fluctuations in the sex ratios born each year can have major impacts on annual availability of a sufficient number of replacement heifers. As a result, only about 35% to 40% of the cows can be bred to terminal sires each year to ensure that there are sufficient replacement heifers born. The simplest system, the two-breed rotation, was again shown to yield substantial improvements in productivity and profitability over the purebred systems. As in the previous study, however, the authors found that modifications to the most appropriate (highest heterosis level for each mating) mating design, made necessary because of the small herd size, did not significantly lower profitability of the system. The three-breed rotation and the two-breed rota-terminal were somewhat more profitable than the two-breed rotation, but the advantages were not great enough to justify the increased complexity of the system.

Composite Crossbreeding

Another crossbreeding system that allows the utilization of heterosis in small herds is the use of composite populations of beef cattle. The definition of a composite population is a group of cattle (it could be considered a breed under some circumstances) that all have the same original combination of two or more breeds. An example of a composite population would be a group of cattle that is 25% Simmental, 25% Hereford, 25% Brahman, and 25% Angus in breed composition. Once the foundation matings have been made (for example, the mating of Simmental x Hereford F_1 bulls to Brahman x Angus F_1 cows), each year the mating system is the same; bulls of this breed composition are bred to cows of the same breed (Figure 7). Only one breeding pasture is needed as only one type of bull is used. In this sense the system is not different from a purebred system and works equally well regardless of the size of the herd, even the one-bull herd of less than 30 cows). The amount of heterosis expected to be retained in composite populations is directly related to the number of breeds that were involved in its production and the percentage of each breed in the composite. The more breeds involved in its formation, the greater the heterosis that is expected to be retained in the case of composites involving only *Bos taurus* breeds. More heterosis is expected to be retained in a composite with four breeds (75% of that seen in the F_1 generation) than one made up of only two breeds (50%). The heterosis loss occurs the first generation that four-breed crossbred bulls are mated to similar cows, but after this cross, the remaining retained heterosis is expected to be maintained indefinitely, with the calves produced at this stage of the composite crossbreeding expected to wean at 517 lb. A weaning weight of about 517 lb is comparable to that achieved for the various rotational systems previously discussed. The weight represents a retention of 75% of the total heterosis from the crossing of these four breeds. The retention of such a high percentage of the maximal heterosis through additional generations, however, depends upon the continual availability of bulls that are not closely related to the cows - but of the same breed composition - each generation.

The retention of heterosis in composite populations has been extensively studied at the U.S. Meat Animal Research Center (MARC) in Clay Center, Nebraska. The results reported to date at MARC have shown very close associations between the amount of heterosis expected to be retained based on genetic theory and that actually retained in animals from later generations of composite breeding. The MARC results for composite breeds involving four or more breeds have indicated that heterosis is maintained comparably to that of rotational crossbreeding (that is, at least 75%). None of the composites studied at MARC, however, have had any *Bos indicus* influence. Unfortunately, data from studies in Texas and Florida using two-breed crosses of Brahman and *Bos taurus* breeds (the 2nd and 3rd generations of matings of Brahman x Angus, for example) have not been as encouraging as the MARC studies. At the Ona AREC and in a similar study in Texas, all heterosis for weaning weight was lost in the F_3 calves from F_2 (F_1 x F_1) crossbred cows bred to F_2 bulls, resulting in performance equal to that of purebreds maintained under the same conditions.

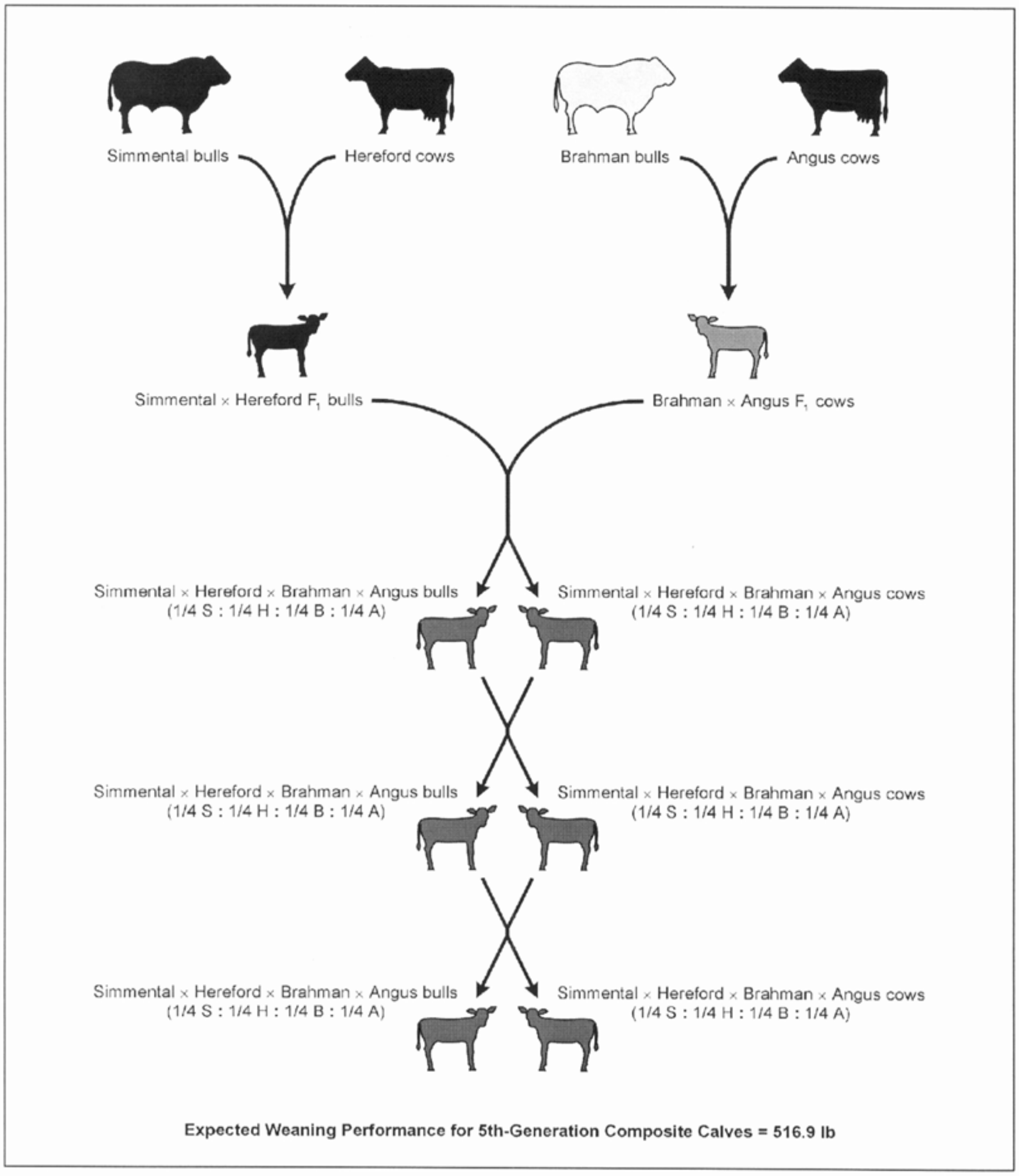

Figure 7. Four-breed composite cross using Simmental, Hereford, Brahman, and Angus breeds.

Perhaps epistatic effects, interactions between genes at different loci, are more important in *Bos indicus* x *Bos taurus* crosses than they are for *Bos taurus* x *Bos taurus* composite crosses. If this proves to be true, composite systems may need to be modified somewhat for the Southeast, where *Bos indicus* breeding is utilized.

While the currently available composite breeds developed from a two-breed (3/8:5/8) base may not maintain sufficient heterosis in the Southeast to be suitable as commercial cattle, they can, however, be very useful in rotational crosses, as has been previously discussed in this bulletin. A composite population that has not been investigated to date but that may be sufficiently productive to be useful as commercial cattle is one composed of 25% Angus, 25% Brahman, 25% Simmental or Hereford (depending upon the nutritional level intended to be provided), and 25% Senepol or other tropically adapted *Bos taurus* such as the Tuli from Africa. The rationale for the choice of these breeds as a potentially useful composite population is that the productivity of a composite crossbred population depends upon the additive contribution (essentially how the breed performs as a purebred) of each breed in the cross and the amount of heterosis that is generated and maintained. The Brahman is utilized because of its adaptation to tropical and subtropical conditions, its desirable maternal traits, including calving ease, and the extremely high levels of heterosis obtained from its crosses with *Bos taurus* breeds. Only 25% Brahman is incorporated to avoid problems with acceptability of the feeder calves and to reduce the possibility of producing carcasses with unacceptable tenderness and marbling. Research at Ona and other locations in the state has shown that cows with 25% Brahman breeding have high levels of fertility and can produce calves with acceptable weaning weights. The reasons for incorporating an adapted *Bos taurus* breed among the breeds utilized include the facts that the F_1 progeny of breeds like the Senepol and the Tuli and *Bos taurus* breeds adapted to temperate climates, like the Hereford and the Angus have been proven to show excellent heat tolerance and also produce meat that is tender. Also, very low levels of heterosis have been obtained from the crossing of unadapted *Bos taurus* breeds (Hereford x Angus, for example) in the Southeast. In a composite composed of 25% Brahman and 75% three unadapted *Bos taurus* breeds, half of the heterosis possible would originate from *Bos taurus* x *Bos taurus* heterozygosity, which would not be expected to yield much if any heterosis. Preliminary data from crosses of the Senepol with the Hereford at the Subtropical Agricultural Research Station at Brooksville, however, have shown substantial levels of heterosis, even higher than those obtained from *Bos taurus* x *Bos taurus* crosses in temperate environments. Inclusion of the Senepol as one of the breeds used to produce the composite should, therefore, result in higher levels of retained heterosis than use of and unadapted *Bos taurus* breed, and at the same time, increase the heat tolerance of the composite. Composites of this nature are now being developed on the R.A. Brown Ranch in Texas (the Hotlander breed which is 1/4 Senepol: 1/4 Red Angus: 5/16 Simmental: 3/16 Brahman) and by Bent Tree Farms in Alabama, where the Southpol breed composed of Barzona, Hereford, Senepol and Red Angus is being developed.

It should be re-emphasized that even though a composite crossbreeding system can be utilized in small herds, this is only possible under situations where unrelated replacement bulls of the same breed composition can be purchased on a regular basis. If related bulls are used, all retained heterosis is likely to be lost. Therefore, small operations can use this system only if a larger herd or herds are producing bulls that may be purchased. A herd size of around 300 to 500 cows (12 to 16 bulls per generation) is necessary if one wishes to develop a new composite population (breed) without the cooperation of other herds. Alternatively, new crosses of animals from the four original breeds could continually be made for use in the composite population, thus allowing a somewhat smaller number of cows to be maintained in the composite population.

Bull Selection for Use in Crossbreeding Systems

Regardless of the system of mating and breeds used, care must be take to select superior purebred animals to initiate and (or) continue a crossbreeding program. Selection of bulls is especially important because in just three generations they will account for 87.5% of the genetic makeup of the herd. When considering the traits required in the bulls used, it is important to consider what will be required of their progeny as the final product, the slaughter steers and heifers and their carcasses, and the replacement females.

The finished carcass should weigh between 620 and 800 lb and have .4 to .5 in fat over the rib eye. This translates into a live weight at slaughter of approximately 1000 to 1250 lb. Cattle that reach this weight range at .4 to .5 in fat are frame score 5 to 6. Unfortunately, cattle with frame scores as high as 8 or more are still being promoted. Animals with frame sizes this high (or even their progeny) are not likely to be useful in crossbreeding systems as they will produce progeny that will need to be fed too long and will weigh too much at slaughter, resulting in price docks due to overweight carcasses. Use of extreme-frame-size animals has been justified in purebred herds in the past, based on the assumption that the average cow size was too small and high-frame-score bulls were needed to increase the size of the commercial bulls to be sold. While this justification may have been valid in the past, I do not think that enough little cows are out there anymore (especially in purebred herds) to justify the use of such bulls. They certainly do not appear to exist in any quantity in the Brahman-influenced, commercial cow herds of the Southeast. The bulls of each breed to be utilized in crossbreeding systems in the future must be moderate sized, with approximate frame scores of 5 to 6. By using bulls of uniform frame size, all the crossbred steers produced should yield carcasses of acceptable weight.

So far I have documented only one of the many traits necessary for consideration in selecting bulls to be used in crossbreeding systems: a measure of mature size. Next, you want the carcasses produced from slaughter steers and heifers to grade "Choice" and the meat to be palatable. The primary component of palatability is tenderness. Producing crossbred carcasses that consistently grade "Choice" and are tender is not going to be as easy a task as producing carcasses of the proper size. The answer lies in the genetic evaluation for these traits in *Bos taurus* breeds, and more importantly, Brahman and Brahman-influenced cattle. Good data need to be collected and made available on the genetic potential for marbling and tenderness of the sires in these breeds.

Several carcass measurements can be made on the live animal: estimation of rib eye area fat thickness and intramuscular fat, measured using ultrasound. This technology provides measurements that are far more accurate than previous methods. Because rib eye area is a component in determining yield grade of the carcass, it affects carcass value. rib eye areas from 12 to 15 in^2 are most desired; cattle that produce carcasses with significantly smaller, or larger, rib eyes will be discriminated against. (Selection for rib eye area also tends to effectively select for animals that, on visual inspection, appear to be more heavily muscled and thus more appealing to buyers). A criterion for selecting yearling bulls is at least 1.2 in^2 rib eye area per 100 lb live weight, estimated using ultrasound procedures. So, a 1200 lb bull would would need to have at least 14.4 in^2 rib eye area. It should be noted, however, that the increase in rib eye area is not proportional to weight gain. Thus, a standard lower than 1.2 in^2 rib eye area per 100 lb live weight should be utilized for heavier bulls.

With regard to fat thickness, intermediate values are probably the best. Bulls that have too little fat may be difficult to maintain in adequate body condition ("hard keepers") and bulls that are too fat many produce progeny that fatten at weights that are too light. In recent years, ultrasound estimation of intramuscular fat had become utilized as a method of selecting for increased marbling. The greater the percent intramuscular fat, the higher the expected degree of marbling. Thus, when selecting among bulls with ultrasound estimation of intramuscular fat available, it would be recommended that bulls with above average levels of intramuscular fat predictions be preferred.

Florida's feeder calves must also retain sufficient genetic potential for postweaning growth in order to produce marketable carcasses relatively rapidly. Calves produced in Florida and sold to western feedlots must have the ability to gain at least 3.5 lb per day when full-fed. Feedlot gain cannot be improved simply be selecting taller bulls; some cattle grow slowly to large frame sizes. To help ensure that Florida calves have predictably high growth rates, it is necessary that they be sired by performance-tested bulls with above-average growth potential, as measured by their performance relative to the herd average, or - better still - by their EPDs for weaning and yearling weight.

Expected progeny difference values are the most accurate way to compare genetic potential for growth of bulls of the *same* breed from different herds. They represent the predicted difference in weaning and yearling weight of a bull's calves, compared to calves of a proven breed-average bull. A bull with a weaning weight EPD of +35 lb is expected to sire calves 20 lb heavier than calves sired by a bull of the same breed with an EPD of +15 lb. High positive EPDs are more important in the Bristish breeds (Hereford, Angus, Shorthorn) than in the larger Continental breeds (Charolais, Simmental, Gelbvieh), for which EPDs near zero - or even low negative EPDs - can be satisfactory. This illustrates that EPDs are not directly comparable across breeds; they are calculated within each breed, relative to some past breed average. So, a Simmental bull with a weaning weight EPD of +2 lb will likely sire heavier calves from the same set of crossbred cows than will an Angus bull with an EPD for weaning weight of +30 lb.

Understanding differences in EPDs *between* breeds is particularly important when selecting bulls for rotational crossbreeding programs. Uniformity (in terms of birth weight, milk production, and growth traits of bulls) among all breeds utilized in the rotation is critical for efficient management of the cow herd and consistency in feeder calves produced for market. Uniformity can be achieved through selection of bulls with comparable EPD values; but these values must be adjusted to allow comparisons between the breeds utilized in the system. Table 5 lists some EPD adjustment values, which are used to "adjust" EPD values for one breed in order to calculate comparable EPDs for another breed. To obtain EPD values for bulls of another breed that produce calves whose growth/milk potential is comparable to the potential of selected Angus bulls' calves, simply subtract the EPD adjustment values for that breed, given in Table 5, from the EPD values of the Angus bulls selected for use.

If, for example, you are using a Hereford x Angus rotation and wish to utilize Angus bulls with EPD values of +4 for birth weight, +40 for weaning weight, +60 for yearling weight, and +15 for milk, then you need to select Hereford bulls that will sire calves with similar birth and weaning weights and whose daughters will demonstrate milking ability comparable to the daughters of the Angus bulls. How is this done? To calculate comparable EPD values for Hereford bulls, subtract the value listed in Table 5 for the Hereford breed for each trait from the corresponding EPD values desired for Angus bulls. The resulting EPD for the Hereford is comparable to the Angus' EPD, and calves produced by both sire breeds should, therefore, be comparable. So, EPD values needed for Hereford sires are -.7 for birth weight (4 - 4.7), +36.3 for weaning weight (40 - 3.7), +62.4 for yearling weight (60-[-2.4]), and +21.7 for milk (15-[-6.7]). Hereford bulls with such weaning- and yearling-weight EPDs are available. However, it would be quite difficult to find Hereford bulls with these growth EPDs that also had low EPD values for birth weight and such high values for milk EPDs.

If an Angus x Simmental rotation is desired, it would be even more difficult to select comparable bulls. A Simmental bull would need EPD values of -7.7 for birth weight (4 - 11.7), -14.8 for weaning weight (40 - 54.8), -29.4 for yearling weight (60 - 89.4), and -14.3 for milk (15 - 29.3) to match EPDs desired for the Angus. While Simmental bulls with these EPDs may exist, they likely would be slaughtered due to inferior growth relative to the breed average. As a compromise, Simmental bulls with the lowest frame scores and lower growth and milk values could be used in an attempt to produce cattle comparable to the Angus-sired calves. Obviously, rotational systems require selection of breeds that are of comparable biological type (growth and milking ability) in order to achieve uniformity among the progeny.

It is also necessary to examine the birth weight of the bull and(or) his EPD for birth weight to make sure that it is not excessive. Use of bulls with high birth weights (>90 lb) or high birth-weight EPDs should be avoided in *Bos taurus*, and especially in Brahman or Brahman-influenced, breeds. The special precaution for birth weights on Brahman and Brahman-influenced bulls is mentioned because the birth weights of calves from dams with *Bos indicus* breeding are reduced by intrauterine effects of such dams. Thus birth weights from bulls from dams with *Bos indicus* influences ought to be considered as "underestimates." A list of general requirements for bulls to be used in crossbreeding programs is shown in Table 6.

At this point, it is necessary to discuss the other critical product of the crossbreeding system: the replacement heifer. In designing crossbreeding systems for Florida and in selecting the bulls to use in them, we cannot forget the fact that most systems that are producing feeder calves must also produce replacement heifers, and this is where it gets more complicated. We cannot just consider growth and carcass traits, we also have to consider fertility, milk production, and adaptation of the replacement heifer. What is needed is a heifer that will reach puberty early enough to be bred to calve at 2 years of age and rebred each year thereafter while producing environment that is economically feasible. So, how do you go about getting such a cow? Milk production and adaptation

Table 5. Across-breed EPD adjustment values[a].

Breed	Birth Wt	Weaning Wt	Yearling Wt	Milk
Hereford	4.7	3.7	-2.4	-6.7
Angus	0.0	0.0	0.0	0.0
Shorthorn	8.4	25.8	36.3	12.1
Brahman	15.0	32.5	-15.6	27.4
Simmental	11.3	47.2	73.8	30.4
Limousin	7.7	29.6	24.1	-3.9
Charolais	10.6	39.0	55.5	3.8
Maine-Anjou	12.4	37.7	51.0	26.3
Gelbvieh	10.0	44.4	49.0	28.4
Pinzgauer	9.1	27.0	25.9	9.7
Tarentaise	5.7	29.5	12.8	20.6
Salers	6.6	26.1	32.4	14.8

[a]For breeds shown, to calculate EPD values that are comparable to known values for the Angus, subtract the adjustment value for each trait from the corresponding EPD desired for the Angus.

Table 6. Selection criteria for bulls chosen as sires in crossbreeding programs.

Birth weight	< 85 lb < 80 lb, if used on heifers EPD appropriate for the breed
Weaning weight	> 500 lb +EPD above breed average[a]
Yearling weight	Ration > 100 +EPD[a]
Frame score	5 or 6
Scrotal circumference	> 32 cm, by 12 months of age + EPD above breed average[b]
Rib-eye area	> 1.2 in^2 per 100 lb body weight + EPD above breed average[b]
Maternal milk	EPD appropriate for the breed

[a] Exceptions to the positive-EPD rule could be made for large breeds (such as Simmental, Charolais, Gelbvieh) when EPDs close to zero would be appropriate for Florida conditions.
[b] In breeds for which EPDs for scrotal circumference or rib-eye area are available, select bulls with positive EPD values for these traits.

are clearly improved by crosses involving Brahman or Brahman-influenced cattle. Heterosis from properly designed crossbreeding systems using Brahman or Brahman-influenced cattle can increase fertility as well. The drawback from the use of Brahman breeding in crossbreeding programs is that it will tend to delay puberty, making successful breeding of yearlings more difficult, especially under marginal nutrition.

There does appear to be an easy way to handle the problem of delayed puberty in cattle. The solution seems to be to select bulls for scrotal circumference as yearlings or a bit later - at 15 months of age - as was recommended for bull selection. Bulls that have reached puberty early will have larger scrotal circumferences at this age than bulls that are later in reaching puberty. Since scrotal circumference is highly heritable and also correlated with age at puberty in related females, bulls with high scrotal measurements and/or high EPDs for scrotal circumference tend to produce daughters that will reach puberty earlier, making it easier to get them pregnant as yearlings early in the breeding season. Heifers that breed early as yearlings will have a greater likelihood of rebreeding as 2 year olds and tend to calve earlier throughout their lifetimes. Selection against the extreme-frame-score animals (>=7) should also help in lowering age at puberty and in improving the rebreeding efficiency of young cows.

Table 6, which lists criteria for bull selection, recommends that bulls be selected for a maternal-milk EPD "***appropriate*** for the breed." This wording is used because - as with other EPD values - maternal-milk EPDs are calculated relative to a known breed average for the trait, and in breeds with high milking ability (such as Simmental) it may be desirable to select bulls with average or even below-average (negative) maternal-milk EPDs. In other breeds with lower milking abilities (such as Hereford and Limousin), it is important to select bulls with high milk EPDs. For example, the milk production of daughters of high-milk-EPD Simmental bulls could be so high that they would wean heavy first calves but lose so much condition while lactating that they might be unable to cycle and breed back. Therefore, their milk production would be above that *appropriate* for the level of nutrition economically available. On the other hand, the milk production of daughters of negative-milk-EPD Limousin bulls may not be adequate for acceptable growth-to-weaning of their calves.

Conclusions

A successful crossbreeding program must be approximately designed and used consistently over a number or years. The following considerations indicate the appropriateness of a system:

- Can it be effectively utilized given the size of your herd? (If your herd is less than 50 cows, rotational systems probably won't work).
- Do the breeds chosen produce cows that are adapted to the climate and that you can afford to feed under your conditions?
- Do the breeds chosen produce steers that will exhibit rapid postweaning growth under either stocker or feedlot management and produce carcasses that are desired by the meat industry?

Equally important as selection of the crossbreeding system itself is selection of bulls within each of the breeds chosen. Bulls selected should be animals superior within their breeds, and they should have passed breeding soundness evaluations. In addition, bulls should be selected (based on their EPD values) to produce progeny that are uniform across all breeds utilized in the system. This will make feeding and management of the cow herd easier and increase the value of your calf crop.

Appendix

Procedure for Calculating Predicted Weaning Weight

Crossbred-calf performance can be predicted for *any* crossbreeding system. The basic prediction method used for systems illustrated in Figure 1 through Figure 7 is outlined in this Appendix for readers interested in applying the method to their own crossbreeding systems. To apply this method to the crossbreeding program that interests you, you must have the following information: (1) breed of the sire if he is purebred of his breed composition if he is a composite breed or crossbred bull, (2) breed or breed composition of the dam, and (3) if the dam is crossbred, you must also know the breed composition of her sire and dam.

Breed composition of the calf is determined by averaging the breed compositions of its sire and dam. Each component of breed composition also represents the percentage of the *total* g^I value, per breed, which is used to calculate expected performance of the calf. So the calf's breed composition provides coefficients for g^I values and, likewise, the dam's breed composition provides coefficients for g^M values (Appendix Table I). To determine the effects of heterozygosity on calf performance, multiply breed-composition values of the sire by those of the dam; this measures the likelihood that genes from one breed will combine with those of another at a given locus. These values serve as coefficients for the h^I values. And coefficients for h^M values are obtained by multiplying breed-composition values of the *dam's* parents (Appendix Table II).

To illustrate, we will use this procedure to predict the performance of crossbred calves produced in a typical crossbreeding scenario and predict calf weaning weights expected from 50% Brahman: 50% Angus bulls bred to 75% Hereford: 25% Brahman cows. We know these cows were produced by Hereford bulls mated to 50% Brahman: 50% Hereford cows.

Based on this information, we can calculate coefficients for g^I, G^M, h^I, and h^M values. For g^I values, the coefficients represent *breed composition* of the calves produced (expressed as decimal percentages). So, given 50% Brahman: 50% Angus bulls and 75% Hereford: 25% Brahman cows, *breed composition* of the calves produced (expressed as decimal percentages) would be 37.5% Brahman: 37.5% Hereford: 25% Angus.

Sire breed %		Dam breed %		Calf breed %
50% Brahman	+	25% Brahman	÷ 2 =	37.5% Brahman
0% Hereford	+	75% Hereford	÷ 2 =	37.5% Hereford
50% Angus	+	0% Angus	÷ 2 =	25.0% Angus

Converted to decimal format, this yields the following coefficients for g^I values:

$$.375\ g^I(B) + .375\ g^I(H) + .25\ g^I(A)$$

For g^M values, the coefficients represent breed composition of the *dams* (75% Hereford: 25% Brahman), which yields the following:

$$.75\ g^M(H) + .25\ g^M(B)$$

To calculate the coefficients for h^I values, multiply *each* breed-composition value for the sire by *each* corresponding value for the dam. The h^I values can be readily calculated by making a table that lists sire and dam breed composition in matrix format and multiplying row x column (Appendix Table III). Notice that the Brahman x Brahman combination is discounted (=0) in calculation of h^I values (so the coefficient is not used); this is true for all same-breed combinations and for both types of heterosis, because such combinations yield no heterosis.

Coefficients for h^M values are calculated by the same procedure used for h^I coefficients, but breed-composition values are from the *dam's* sire and dam. This is a simpler calculation because the dam's sire was a purebred Hereford, bred to a 50% Hereford: 50% Brahman cow. And as with h^I values, the Hereford x Hereford same-breed combination is discounted. So the only relevant combination is the 1.00 Hereford .50 Brahman, which yields the sole component of this h^M value:

$$.50\ h^M(HxB)$$

Next, apply coefficients to the corresponding components of breed composition for g^I, g^M, h^I, and h^M values to yield the formula for predicted weaning weight of calves:

450 lb[7] + .375 g^I(B) + .375 g^I(H) + .25 g^I(A)

+ .75 g^M(H) + .25 g^M(B)

+.375 h^I(BxH) + .375 h^I(AxH) + .125h^I(AxB)

+ .50 h^M (HxB)

Substitute actual values from Appendix Table I and Appendix Table II for each breed or breed combination:

450 lb + .375 (6) + .375(7) + .25(0)

+ .75(-21) + .25(8)

+.375(52) + .375(11) + .125(52)

+ .50(45)

The result is 493.75 lb, almost a 44 lb increase over the 450 lb predicted weaning weight for Angus calves.

This is the same basic method by which expected performance was calculated in Figure 1 through Figure 7. The principles are the same in each case:

Step 1. Determine breed composition for each type of *calf* produced by a system; then multiply each component of the calf's breed composition (g^I coefficient) by its corresponding g^I value. Add the products of (%)g^I.

Step 2. Determine breed composition for each type of *cow* produced by a system; then multiply each component of the dam's breed composition (g^M coefficient) by its corresponding g^M value. Add the products of (%)g^M.

Step 3. Calculate the coefficients for individual heterosis (h^I) values by cross-multiplying sire breed composition by dam breed composition (as shown in the Appendix Table III example); then multiply each coefficient by the h^I value corresponding to the breed combination. Add the products.

Step 4. Calculate the coefficients for maternal heterosis (h^M) values using the procedure from Step 3, but substitute breed compositions of the *dam's* sire and dam; then multiply each coefficient by the h^M value corresponding to the breed combination. Add the products. Last, add the sums from Step 1 through Step 4.

For predicted Weaning Weight Calculations see Appendix Table IV.

Endnotes

1. An F_1 cross is produced when two breeds are crossed, such as Brahman bulls mated to Angus cows.

2. ***Heritability*** is the degree to which a trait is controlled by additive genes--as opposed to environmental and other factors.

3. Expected progeny difference values (EPDs) are discussed in the section "Bull Selection for Use in Crossbreeding Systems."

4. Yearling first-exposure heifers, and perhaps even 2-year-old heifers, should not be bred to Charolais bulls unless they have low birth-weight EPDs with high levels of accuracy; they should instead be bred to bulls of a breed more noted for calving ease. Hereford bulls with low birth-weight EPDs would be appropriate to use on such heifers.

5. Predicted weaning weights of an Angus calf--the standard of comparison.

Appendix Table I.

Breed	g^{I} [a]	g^{M} [b]
Angus	0	0
Brahman	6	8
Hereford	7	-21
Simmental	80	20
Charolais	80	9

[a] The g^I values represent the difference (lb) in weaning weight between Angus calves and specific-breed calves that is attributed to additive genetic effects.
[b] The g^M values represent the difference (lb) in effect of maternal ability on calf weaning weight between Angus cows and specific-breed cows that is attributed to additive genetic effects.

Appendix Table II. Heterotic effects for individual and maternal components of calf growth-to-weaning.

Crossbred Combination	h^{I} [a]	h^{M} [b]
Angus-Brahman	52	45
Angus-Hereford	11	10
Angus-Simmental	8	15
Angus-Charolais	8	15
Brahman-Hereford	52	45
Brahman-Simmental	42	35
Brahman-Charolais	42	35
Hereford-Simmental	5	15
Hereford-Charolais	5	15
Simmental-Charolais	0	8

[a] The h^I values represent the effect on calf weaning weight (lb) attributed to F_1 crossbreeding for each breed combination.
[b] The h^M values represent the effect on calf weaning weight (lb) attributed to F_1 crossbreeding of the dam for each breed combination.

Appendix Table III. Example of method to calculate coefficients for heterosis (h^I) values, using progeny of 1/2 Brahman: 1/2 Angus bulls x 3/4 Hereford: 1/4 Brahman cows.

Sire[a] Breed Composition	Dam[b] Breed Composition	
	.75 Hereford	**.25 Brahman**
.50 Brahman	.50*.75=.375 (BxH)	.50*.25=.125 (BxB)[c]
.50 Angus	.50*.75=.375 (AxH)	.50*.25=.125 (AxB)

[a] Sire of calf for h^I coefficients; use sire of *dam* for h^M coefficients.
[b] Dam of calf for h^I coefficients; use dam of *dam* for h^M coefficients.
[c] Not included: (BxB)=0; same-breed "combinations" yield no heterosis.

Appendix Table IV. Predicted weaning weight calculations.

Figure 1 - Two-Breed Terminal Cross[1]

Charolaisx**Angus F_1 Calves**

Expected weaning performance
$= 450\text{ lb} + .5g^I(C) + .5g^I(A) + g^M(A) + h^I(CxA)$
$= 450\text{ lb} + .5(80) + .5(0) + (0) + (8)$
$= 498\text{ lb}$

Explanation: Calves produced by the terminal cross are 1/2 Angus: 1/2 Charolais. Each component of breed composition is multiplied by the g^I value corresponding to that breed: .5(0) + .5(80). The calves are 100% Charolais x Angus, and so the total h^I value for that breed combination (8 lb) is applied to their expected performance.

Figure 2 - Three-Breed Terminal Cross[2]

This cross has two phases: the first produces Brahman x Angus replacement heifers; the second produces Charolais-sired calves from these crossbred dams.

Brahmanx**Angus F_1 Calves**

Expected weaning performance
$= 450\text{ lb} + .5g^I(B) + .5g^I(A) + h^I(BxA)$
$= 450\text{ lb} + .5(6) + .5(0) + (52)$
$= 505\text{ lb}$

Charolais-Sired Calves[3]

Expected weaning performance
$= 450\text{ lb} + .5g^I(C) + .25g^I(B) + .25g^I(A) + .5g^M(B) + .5g^M(A) + .5h^I(CxB) + .5h^I(CxA) + h^M(BxA)$
$= 450\text{ lb} + .5(80) + .25(6) + .25(0) + .5(8) + .5(0) + .5(42) + .5(8) + (45)$
$= 565.5\text{ lb}$

Explanation: Terminal-cross calves are 1/2 Charolais: 1/4 Angus: 1/4 Brahman, breed composition yielding g^I coefficients for the four component breeds; their dams are 1/2 Angus: 1/2 Brahman, yielding g^M coefficients for two breeds. Heterotic combinations for calves from a Charolais sire and Brahman x Angus F_1 cows are .5(CxA) and .5(CxB); the dams express the full effect of (BxA) heterozygosity, contributing 45 lb to their calves' expected performance.

Hereford-Sired Calves from 2-Year-Old Heifers[4]

Expected weaning performance
$= 450\text{ lb} + .5g^I(H) + .25g^I(B) + .25g^I(A) + .5g^M(B) + .5g^M(A) + .5h^I(HxB) + .5h^I(HxA) + h^M(BxA)$
$= 450\text{ lb} + .5(7) + .25(6) + .25(0) + .5(8) + .5(0) + .5(52) + .5(11) + (45)$
$= 535.5\text{ lb}$

Figure 3 - Two-Breed Rotational Cross[5]

Brahman-Sired Calves

Calf breed composition is .67 Brahman: .33 Angus; the dams are .67 Angus: .33 Brahman.

Appendix Table IV. Predicted weaning weight calculations.

Expected weaning performance
$= 450 \text{ lb} + .67g^{I}(B) + .33g^{I}(A) + .67g^{M}(A) + .33g^{M}(B) + .67h^{I}(BxA) + .67h^{M}(AxB)$
$= 450 \text{ lb} + .67(6) + .33(0) + .67(0) + .33(8) + .67(52) + .67(45)$
$= 521.7 \text{ lb}$

Angus-Sired Calves

Calf breed composition is .67 Angus: .33 Brahman; the dams are .67 Brahman: .33 Angus.

Expected weaning performance
$= 450 \text{ lb} + .67g^{I}(A) + .33g^{I}(B) + .67g^{M}(B) + .33g^{M}(A) + .67h^{I}(AxB) + .67h^{M}(BxA)$
$= 450 \text{ lb} + .67(0) + .33(6) + .67(8) + .33(0) + .67(52) + .67(45)$
$= 522.3 \text{ lb}$

Average Performance for all Calves=522.0 lb

Figure 4 - Three-Breed Rotational Cross[6]

Angus-Sired Calves

Expected weaning performance
$= 450 \text{ lb} + .57g^{I}(A) + .29g^{I}(H) + .14g^{I}(B) + .57g^{M}(H) + .29g^{M}(B) + .14g^{M}(A) + .57h^{I}(AxH) + .29h^{I}(AxB) + .57h^{M}(HxB) + .29h^{M}(HxA)$
$= 450 \text{ lb} + .57(0) + .29(7) + .14(6) + .57(-21) + .29(8) + .14(0) + .57(11) + .29(52) + .57(45) + .29(10)$
$= 493.1 \text{ lb}$

Brahman-Sired Calves

Expected weaning performance
$= 450 \text{ lb} + .57g^{I}(B) + .29g^{I}(A) + .14g^{I}(H) + .57g^{M}(A) + .29g^{M}(H) + .14g^{M}(B) + .57h^{I}(BxA) + .29h^{I}(BxH) + .57h^{M}(AxH) + .29h^{M}(AxB)$
$= 450 \text{ lb} + .57(6) + .29(0) + .14(7) + .57(0) + .29(-21) + .14(8) + .57(52) + .29(52) + .57(10) + .29(45)$
$= 512.9 \text{ lb}$

Hereford-Sired Calves

Expected weaning performance
$= 450 \text{ lb} + .57g^{I}(H) + .29g^{I}(B) + .14g^{I}(A) + .57g^{M}(B) + .29g^{M}(A) + .14g^{M}(H) + .57h^{I}(HxB) + .29h^{I}(HxA) + .57h^{M}(BxA) + .29h^{M}(BxH)$
$= 450 \text{ lb} + .57(7) + .29(6) + .14(0) + .57(8) + .29(0) + .14(-21) + .57(52) + .29(11) + .57(45) + .29(45)$
$= 528.9 \text{ lb}$

Average Performance for All Calves = 511.6 lb

Explanation: Calculation of values is based on the fact that, after the proportions have stabilized, calves will have a breed composition of 4/7:2/7:1/7 each generation. For example, the Angus-sired calves are .57 Angus: .29 Hereford: .14 Brahman; their dams are .57 Hereford: .29 Brahman: .14 Angus. The h^{I} values for Angus-sired calves are $.57h^{I}(AxH) + .29h^{I}(AxB)$ because sires were Angus and dams were .57 Hereford: .29 Brahman: .14 Angus. The h^{M} values for Angus-sired calves are $.57h^{M}(HxB) + .29h^{M}(HxA)$ because *dams* of these calves were produced by Hereford bulls bred to .57 Brahman: .29 Angus: .14 Hereford cows.

Figure 5 - Three-Breed Rotational Cross Using Brahman-Derivative Breeds[7]

Brangus-Sired Calves

Expected weaning performance
$= 450 \text{ lb} + .37g^{I}(B) + .36g^{I}(A) + .18g^{I}(H) + .09g^{I}(S) + .37g^{M}(B) + .36g^{M}(H) + .18g^{M}(S) + .09g^{M}(A) + .225h^{I}(AxH) + .1125h^{I}(AxS) + .265h^{I}(AxB) + .135h^{I}(BxH) + .0675h^{I}(BxS) + .225h^{M}(HxS) + .1125h^{M}(HxA) + .265h^{M}(HxB) + .135h^{M}(BxS) + .0675h^{M}(BxA)$
$= 450 \text{ lb} + .37(6) + .36(0) + .18(7) + .09(80) + .37(8) + .36(-21) + .18(20) + .09(0) + .225(11) + .1125(8) + .265(52) + .135(52) + .0675(42) + .225(15) + .1125(10) + .265(45) + .135(35) + .0675(45)$
$= 510.9 \text{ lb}$

Simbrah-Sired Calves

Expected weaning performance
$= 450 \text{ lb} + .37g^{I}(B) + .36g^{I}(S) + .18g^{I}(A) + .09g^{I}(H) + .37g^{M}(B) + .36g^{M}(A) + .18g^{M}(H) + .09g^{M}(S) + .225h^{I}(SxA) + .1125h^{I}(SxH) + .265h^{I}(SxB) + .135h^{I}(BxA) + .0675h^{I}(BxH) + .225h^{M}(AxH) + .1125h^{M}(AxS) + .265h^{M}(AxB) + .135h^{M}(BxH) + .0675h^{M}(BxS)$
$= 450 \text{ lb} + .37(6) + .36(80) + .18(0) + .09(7) + .37(8) + .36(0) + .18(-21) + .09(20) + .225(8) + .1125(5) + .265(42) + .135(52) + .0675(52) + .225(10) + .1125(15) + .265(45) + .135(45) + .0675(35)$
$= 531.0 \text{ lb}$

Braford-Sired Calves

Appendix Table IV. Predicted weaning weight calculations.

Expected weaning performance

$$= 450\text{ lb} + .37g^{I}(B) + .36g^{I}(H) + .18g^{I}(S) + .09g^{I}(A) + .37g^{M}(B) + .36g^{M}(S) + .18g^{M}(A) + .09g^{M}(H)$$
$$+ .225h^{I}(HxS) + .1125h^{I}(HxA) + .265h^{I}(HxB) + .135h^{I}(BxS) + .0675h^{I}(BxA)$$
$$+ .225h^{M}(SxA) + .1125h^{M}(SxH) + .265h^{M}(SxB) + .135h^{M}(BxA) + .0675h^{M}(BxH)$$
$$= 450\text{ lb} + .37(6) + .36(7) + .18(80) + .09(0) + .37(8) + .36(20) + .18(0) + .09(-21) + .225(5) + .1125(11)$$
$$+ .265(52) + .135(42) + .0675(52) + .225(15) + .1125(15) + .265(35) + .135(45) + .0675(45)$$
$$= 526.0\text{ lb}$$

Average Performance for All Calves = 522.7 lb

Figure 6 - Rota-Terminal Cross

Brangus-Sired Calves

Expected weaning performance

$$= 450\text{ lb} + .42g^{I}(A) + .37g^{I}(B) + .21g^{I}(S) + .42g^{M}(S) + .37g^{M}(B) + .21g^{M}(A) + .2625h^{I}(AxS)$$
$$+ .31h^{I}(BxA) + .1575h^{I}(BxS) + .2625h^{M}(SxA) + .31h^{M}(BxS) + .1575h^{M}(BxA)$$
$$= 450\text{ lb} + .42(0) + .37(6) + .21(80) + .42(20) + .37(8) + .21(0) + .2625(8) + .31(52) + .1575(42)$$
$$+ .2625(15) + .31(35) + .1575(45)$$
$$= 527.1\text{ lb}$$

Simbrah-Sired Calves

Expected weaning performance

$$= 450\text{ lb} + .42g^{I}(S) + .37g^{I}(B) + .21g^{I}(A) + .42g^{M}(A) + .37g^{M}(B) + .21g^{M}(S) + .2625h^{I}(SxA)$$
$$+ .31h^{I}(BxS) + .1575h^{I}(BxA) + .2625h^{M}(AxS) + .31h^{M}(BxA) + .1575h^{M}(BxS)$$
$$= 450\text{ lb} + .42(80) + .37(6) + .21(0) + .42(0) + .37(8) + .21(20) + .2625(8) + .31(42) + .1575(52)$$
$$+ .2625(15) + .31(45) + .1575(35)$$
$$= 539.7\text{ lb}$$

Average Performance for SimbrahxBrangus Rotational-Cross Calves = 533.4 lb

Charolais-Sired Calves from Simbrah-Sired Dams

Expected weaning performance

$$= 450\text{ lb} + .5g^{I}(C) + .21g^{I}(S) + .19g^{I}(B) + .1g^{I}(A) + .42g^{M}(S) + .37g^{M}(B) + .21g^{M}(A)$$
$$+ .42h^{I}(CxS) + .37h^{I}(CxB) + .21h^{I}(CxA) + .2625h^{M}(SxA) + .31h^{M}(BxS) + .1575h^{M}(BxA)$$
$$= 450\text{ lb} + .5(80) + .21(80) + .19(6) + .1(0) + .42(20) + .37(8) + .21(0) + .42(0) + .37(42) + .21(8)$$
$$+ .2625(15) + .31(35) + .1575(45)$$
$$= 558.4\text{ lb}$$

Charolais-Sired Calves from Brangus-Sired Dams

Expected weaning performance

$$= 450\text{ lb} + .5g^{I}(C) + .21g^{I}(A) + .19g^{I}(B) + .1g^{I}(S) + .42g^{M}(A) + .37g^{M}(B) + .21g^{M}(S)$$
$$+ .42h^{I}(CxA) + .37h^{I}(CxB) + .21h^{I}(CxS) + .2625h^{M}(AxS) + .31h^{M}(BxA) + .1575h^{M}(BxS)$$
$$= 450\text{ lb} + .5(80) + .21(0) + .19(6) + .1(80) + .42(0) + .37(8) + .21(20) + .37(42) + .21(0)$$
$$+ .2625(15) + .31(45) + .1575(35)$$
$$= 548.6\text{ lb}$$

Average Performance for Charolais-Sired Terminal-Cross Calves = 553.5 lb

Figure 7 - Four-Breed Composite Cross

AngusxBrahmanxHerefordxSimmental Calves[8]

Expected weaning performance

$$= 450\text{ lb} + .25g^{I}(S) + .21g^{I}(H) + .25g^{I}(B) + .25g^{I}(A) + .25g^{M}(S) + .25g^{M}(H) + .25g^{M}(B) + .2g^{M}(A)$$
$$+ .125h^{I}(SxH) + .125h^{I}(SxB) + .125h^{I}(SxA) + .125h^{I}(HxB) + .125h^{I}(HxA) + .125h^{I}(BxA)$$
$$+ .125h^{M}(SxH) + .125h^{M}(SxB) + .125h^{M}(SxA) + .125h^{M}(HxB) + .125h^{M}(HxA) + .125h^{M}(BxA)$$
$$= 450\text{ lb} + .25(80) + .25(7) + .25(6) + .25(0) + .25(20) + .25(-21) + .25(8) + .25(0) + .125(5) + .125(42)$$
$$+ .125(8) + .125(52) + .125(11) + .125(52) + .125(15) + .125(35) + .125(15) + .125(45) + .125(10)$$
$$+ .125(45)$$
$$= 516.9\text{ lb}$$

Appendix Table IV. Predicted weaning weight calculations.

1. Charolais bulls x Angus cows.
2. Charolais bulls x (Brahman x Angus) cows.
3. Terminal-cross calves, progeny of the Brahman x Angus cows.
4. *Yearling* Brahman x Angus heifers should be bred to Hereford bulls, note that this result would predict the weaning weight of mature B x A cows mated to Hereford bulls.
5. Angus x Brahman, after proportions have stabilized following several generations of crossbreeding.
6. Angus x Brahman x Hereford, after the proportions have stabilized following several generations of crossbreeding.
7. Brangus x Simbrah x Braford.
8. Fifth generation.