Crossbreeding-One of the Tools to Increase Profitability

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There are a multitude of issues currently facing National Cattle Evaluation, and thus numerous researchable questions that need answers in order to advance the tools used by seedstock and commercial bull buyers alike. Among these are the refinements of methodology for the inclusion of genomic information into NCE, the development of bio-economic index values that include more input traits, and the development of genetic predictors for novel traits such as feed intake, disease susceptibility, and others. Instead, in 2013, US Beef Producers representing a > $79 billion industry find themselves in a circular debate over the benefits of exploiting non-additive genetic effects in the pursuit of profitability. Despite well-documented benefits of heterosis and breed complementarity, the majority of germplasm utilized in the US has migrated towards a single breed. In 2012, the National Association of Animal Breeders (NAAB) reported that Angus semen accounted for over 74% of domestic semen sales. The second most was Simmental with 8.4% of the semen sales market. As a point of reference, domestic dairy semen sales are dominated by Holstein (86.7%) followed by Jersey (10.7%). The 2011-2012 report from the National Pedigreed Livestock Council (NPLC) summarized the annual registrations of 15 beef breeds. From this, 47.8% of registered beef cattle were Angus. From 1995 to 2010, the percentage of fed cattle marketed that were black hided doubled reaching 64%. Furthermore, some surveys have suggested that upwards of 60% of bull turn out is Angus. Although a uniform distribution of semen sales and breed registrations is not expected, nor necessarily desired, some degree of balance relative to commercial bull breed composition is beneficial.

The lack of utilization of crossbreeding can be broken down into those issues that are logistical in nature and those that represent a knowledge gap. Logistical issues revolve around developing a sustainable crossbreeding system that optimizes resources with gains in breed complementarity and heterosis. Failed crossbreeding programs can often be attributed to unnecessary complexity and failures in planning and implementation. Knowledge gaps exist relative to the biological benefits of heterosis, implementation of crossbreeding, and the economic benefits of crossbreeding. One of the most incorrect assumptions regarding heterosis is the inability to maintain phenotypic uniformity. Data from the US Meat Animal Research Center (USMARC) has illustrated (see Table 1) the similarity in the coefficient of variation for several growth and carcass traits between composites and their purebred contemporaries (Gregory et al., 1999).

The pervasive thought that one breed can excel in all areas of production in a segmented and geographically diverse industry is simply not logical. Every breed has strengths and weaknesses relative to an individual firm's production and marketing goals. That is the benefit of crossbreeding, blending strengths from various breeds to meet production goals while fitting within environmental constraints, and heterosis becomes the reward for having done so. Consequently, knowledge of current breed differences, not historic generalizations, and honest accounting of environmental constraints coupled with identified marketing goals are among the first steps in developing a sustainable and profitable breeding system.

Table 1. Coefficients of variation for purebred vs. composite steers[a]

Trait	Purebreds	Composites
Birth weight	0.12	0.13
Wean weight	0.10	0.11
Carc. weight	0.08	0.09
Retail Product %	0.04	0.06
Marbling	0.27	0.29
Shear Force	0.22	0.21

[a]Adapted from Gregory et al., 1999.

Large differences exist today in the relative performance of various breeds for most economically important traits. These breed differences represent a valuable genetic resource for commercial producers to use in structured crossbreeding systems to achieve an optimal combination of traits matching the cowherd to their production environment and to use sire selection to produce market-targeted progeny. As such, the selection of the 'right' breed(s) to use in a breeding program is an important decision for commercial beef producers. The determination of the 'right' breed(s) to use is highly dependent on a number of characteristics of a farm or ranch such that not every operation should use the same breed or combination of breeds.

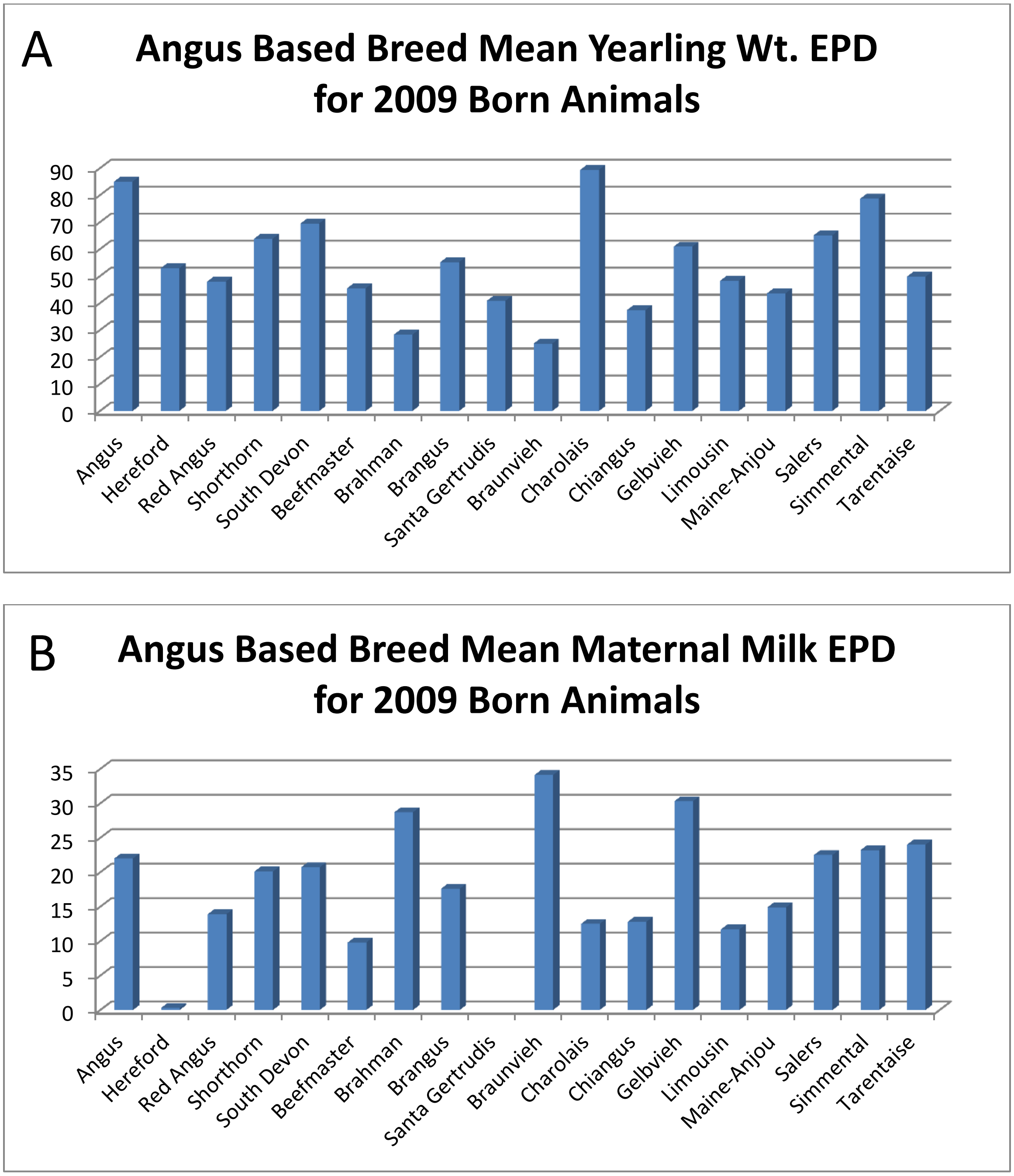
Beef Breed and Composite Characterization

A great deal of research has been conducted over the last 30 years at various federal and state experiment stations to characterize beef breeds in the U.S. . These studies have been undertaken to examine the genetic merits of various breeds in a wide range of production environments and management systems. During this time, researchers at the U.S. Meat Animal Research Center (MARC) have conducted the most comprehensive studies of sire breed genetic merit via their long term Germplasm Evaluation (GPE) project. This project evaluated over 30 sire breeds in a common environment and management system. The data summarized by the MARC scientists consisted of records on more than 20,000 animals born between 1978 and 1991, with a re-sampling of the most popular sire breeds in 1999-2000. The various sire breeds evaluated were mated to Angus, Hereford and crossbred cows. Thus, the data reported were for crossbred progeny. During the study, Angus-Hereford crossbred calves were produced in the study as a control for each cycle of the GPE project.

One of the major outcomes of the GPE project was the characterization of sire breeds for a wide variety of economically important traits. Because all of the animals were in a common management system and production environment, the average differences observed in performance were due to genetic differences. Following the analysis of progeny data, the breeds can be divided into groups based on their biological type for four criteria: 1) Growth rate and mature size 2) Lean to fat ratio 3) Age at puberty, and, 4) Milk production. The breeds evaluated at MARC are grouped by biological type in Table 2. Historically, British breeds such as Hereford, Angus, Red Angus and Shorthorn have been evaluated as moderate in growth and mature size, relatively higher in carcass fat composition, reach puberty at relatively younger ages and are moderate in milk production. However, with the dramatic changes growth rate and lactation potentials of several popular British breeds, these views need updated. Contemporary evaluations of lactation potential and growth rate to a yearling endpoint suggest that some British breeds have closed the gap that once existed between British and Continental breeds. Figure 1 panel A and B illustrate the Angus based breed mean Yearling Weight and Maternal Milk EPD for 2009 born animals for a number of breeds resulting from the application of the US MARC 2012 across-breed EPD adjustment factors. Continental European breeds, with a heritage that includes milk production, including Simmental, Maine-Anjou, and Gelbvieh tend to have high growth rates, larger mature sizes, moderate ages at puberty and relatively high levels of milk production. Another group of Continental European breeds, with a heritage of meat and draft purposes, including Charolais, Chianina and Limousin tend to have high growth rate, large mature size, older ages at puberty, very lean carcasses and low milk production. Cundiff et al. (2007) summarized a large body of data collected at US MARC for a variety of traits. The most recent reported sampling of breed germplasm suggests that there are no differences among the major British and Continental breeds for mature weight of cows with the exception of Gelbvieh sired cows, which were significantly lighter. Angus and Simmental sired calves had similar final carcass weights. These results stand in stark contrast to observations made among these breeds 30 years earlier (Cundiff et al., 2007). Although the convergence of breed means might erode complementarity, it does not mean we have witnessed and erosion in heterosis.

Another way to compare the relative genetic merit of breeds for various performance traits is through conversion of their EPD to a common base. This can be accomplished using the across breed EPD adjustments published each year in the proceedings of the Beef Improvement Federation’s annual meeting. These adjustments are generated by researchers at MARC. Table 3 presents the average across breed EPD of animals born in 2010 as reported from 2011 genetic evaluations from the most widely used breeds on a common genetic base (Angus). Differences in across breed EPD averages represent genetic differences for each trait. Table 3 provides a more contemporary look at the differences in breed genetic potential for various traits and accounting for genetic trends occurring in each breed due to selection. Due to selection pressure placed on growth and maternal traits over time, many breeds have made considerable gains in those traits. In some cases, the large gains in performance have resulted in subtle changes in the overall biological type of a breed.

Figure 1. Angus based breed mean Yearling Wt. and Maternal Milk EPD.[a]



[a]Adapted from breed means (Kuehn and Thallman, 2012a) and Across Breed EPD Adjustment factors (Kuehn and Thallman, 2012b).

Table 2. Breeds grouped into biological type by four criteria.[a,b]

Breed Group	Growth rate and mature size	Percent retail product	Age at puberty	Milk production
Jersey	X	X	X	XXXXX
Longhorn	X	XXX	XXX	XX
Angus	XXX	XX	XX	XXX
Hereford	XXX	XX	XXX	XX
Red Poll	XX	XX	XX	XXX
Devon	XX	XX	XXX	XX
Shorthorn	XXX	XX	XXX	XXX
Galloway	XX	XXX	XXX	XX
South Devon	XXX	XXX	XX	XXX
Tarentaise	XXX	XXX	XX	XXX
Pinzgauer	XXX	XXX	XX	XXX
Brangus	XXX	XX	XXXX	XX
Santa Gertrudis	XXX	XX	XXXX	XX
Sahiwal	XX	XXX	XXXXX	XXX
Brahman	XXX	XXX	XXXXX	XXX
Nellore	XXX	XXX	XXXXX	XXX
Braunvieh	XXXX	XXXX	XX	XXXX
Gelbvieh	XXXX	XXXX	XX	XXXX
Holstein	XXXX	XXXX	XX	XXXXX
Simmental	XXXXX	XXXX	XXX	XXXX
Maine Anjou	XXXXX	XXXX	XXX	XXX
Salers	XXXXX	XXXX	XXX	XXX
Piedmontese	XXX	XXXXX	XX	XX
Limousin	XXX	XXXX	XXXX	X
Charolais	XXXXX	XXXX	XXXX	X
Chianina	XXXXX	XXXX	XXXX	X

[a] Adapted from Cundiff et al., 1993
[b] Increasing number of X's indicate relatively higher levels of trait

Table 3. Average Across-Breed EPD for animals born in 2009 by breed from 2011 genetic evaluations and 2012 US-MARC Across-Breed EPD adjustment factors[a].

	Birth Wt. EPD	Weaning Wt. EPD	Yearling Wt. EPD	Maternal Milk EPD
Angus	1.8	47	85	22
Hereford	6.3	41.2	52.9	0.3
Red Angus	2.3	31.4	48	13.9
Shorthorn	8.4	30.7	63.8	20.1
South Devon	6.8	43.7	69.5	20.7
Beefmaster	7	43.3	45.5	9.8
Brahman	12.8	57.2	28.3	28.7
Brangus	4.4	36	55.2	17.6
Santa Gertrudis	8	42.7	40.9	
Braunvieh	4	21.7	25	34.1
Charolais	9.2	64.3	89.4	12.5
Chiangus	5.3	21.9	37.4	12.8
Gelbvieh	5.2	45.7	60.9	30.3
Limousin	5.3	44.5	48.3	11.7
Maine-Anjou	5.8	26.4	43.6	14.9
Salers	3.6	38.2	65.1	22.5
Simmental	5.9	55.7	78.7	23.2
Tarentaise	3.6	49.1	49.8	24

[a]Adapted from Kuehn and Thallman, 2012a,b

Use of Breeds and Composites for Genetic Improvement

Inclusion or exclusion of germplasm from a breed (or composite) is a valuable selection tool for making rapid directional changes in genetic merit for a wide range of traits. Changes in progeny phenotype that occur when breeds are substituted in a breeding program come from two genetic sources.

The first source of genetic impact from a substitution of a breed comes through changes in the additive genetic effects or breeding values that subsequent progeny inherit from their sire and dam. Additive genetic merit is the portion of total genetic merit that is transmissible from parent to offspring and on which traditional selection decisions are made. In other words, additive genetic effects are heritable. EPD are estimates of one-half of the additive genetic merit. The difference in average performance for a trait observed between two breeds is due primarily to differences in additive genetic merit.

The second source of genetic change is due to non-additive genetic effects. Non-additive effects include both dominance and epistatic effects. Dominance effects arise from the interactions of paired genes at each locus. Epistatic effects are the interaction of genes across loci. The sum of these two interactions result in heterosis observed in crossbred animals. Since each parent only contributes one gene to an offspring and dominance effects depend on the interaction of a pair of genes, a parent cannot transmit dominance effects to its progeny within a breed. However, the selection of which breeds and how much of each breed to incorporate into progeny has a large impact on dominance (or heterosis) effects which affect phenotype. Because epistatic effects arise from the interaction of genes at different loci, independent segregation of chromosomes in the formation of gametes causes pairings of genes not to always stay together from one generation to the next. Like dominance effects, epistatic effects are not impacted by mate selection but by the frequency of different alleles and their dominance effects across breeds.

Both additive and non-additive genetic effects can have a significant impact on a particular phenotype; therefore, it is important that both are considered during breed selection. Due to their different modes of inheritance, different tactics must be employed to capture the benefits of each.

Additive genetic merit may be selected for in two distinct ways. First, by the selection of individuals within a breed which have superior genetic merit for the trait under selection. Typically this is achieved through the use of EPD to identify selection candidates, although it can also be done through selection for specific alleles using DNA markers. The rate of improvement in phenotypes due to selection within breed is limited by the heritability of the trait. Heritability describes the proportion of phenotypic variation that is controlled by additive genetic variation. So, for traits with moderate to high heritability, considerable progress in progeny phenotype may be achieved through selection of superior animals within the breed as parent stock. The second approach to change additive genetic merit is through the selection of animals from a different breed(s) that excels in the trait under selection. Across breed selection can provide rapid change in progeny phenotype given that large differences exist between breeds in a number of economically relevant traits. Selection of superior parent stock from a different breed that excels in a trait is often more effective than selection within a breed (Gregory et al., 1999) as the breed differences have a heritability of nearly 100%.

The use of breed differences to achieve the best overall results across multiple traits may be achieved through the utilization of breed complementarity. Breeds are complementary to each other when they excel in different traits and their crossbred progeny have desirable levels of performance in a larger number of traits than either of the parent breeds alone. Making breed and mating selections that utilize breed complementarity provide an effective way to aggregate the core competencies of two or more breeds in the progeny. Moreover, use of breed complementarity can be a powerful strategy to genetically match cows to their production environment and progeny to the market place. For example, a crossbreeding system that mates Charolais bulls to Hereford-Angus crossbreed cows utilizes breed complementarity. The Charolais bull contributes growth and carcass yield to progeny genetics while the Hereford-Angus crossbred cows have many desirable maternal attributes and contribute genetics for carcass quality. When considering crossbreeding from the standpoint of producing replacement females, one could select breeds that have complementary maternal traits such that females are most ideally matched to their production environment. Matings to produce calves for market should focus on complementing traits of the cows and fine tuning calf performance (growth and carcass traits) to the market place.

One of the challenges of breed selection is the interaction of the animal's genotype with its production environment. Table 4 describes common production environments by level of feed availability and environmental stress and lists optimal levels of a variety of performance traits (Gosey, 1994). Here, feed availability refers to the regular availability of grazed or harvested forage and its quantity and quality. Environmental stress includes parasites, disease, heat and humidity. Ranges for mature cow size are low (800 to 1,000 lb.), medium (1000 to 1,200 lb.), and high (1,200 to 1,400 lb.) Clearly, breed choices should be influenced by the production environment in which they are expected to perform.

Table 4. Matching Genetic Potential for Different Traits to Production Environments[1]

Production Environment		Traits					
Feed Availability	Stress[2]	Milk Production	Mature Size	Ability to Store Energy[3]	Resistance to Stress[4]	Calving Ease	Lean Yield
High	Low	M to H	M to H	L to M	M	M to H	H
	High	M	L to H	L to H	H	H	M to H
Medium	Low	M to H	M	M to H	M	M to H	M to H
	High	L to M	M	M to H	H	H	H
Low	Low	L to M	L to M	H	M	M to H	M
	High	L to M	L to M	H	H	H	L to M
Breed role in terminal crossbreeding systems							
Maternal		M to H	L to H	M to H	M to H	H	L to M
Paternal		L to M	H	L	M to H	M	H

L = Low; M = Medium; H = High.
[1]Adapted from Gosey, 1994.
[2]Heat, cold, parasites, disease, mud, altitude, etc.
[3]Ability to store fat and regulate energy requirements with changing (seasonal) availability of feed.
[4]Physiological tolerance to heat, cold, internal and external parasites, disease, mud, and other factors.

Crossing of breeds or lines is the primary method to exploit beneficial non-additive effects called heterosis. Heterosis refers to the superiority of the crossbred animal relative to the average of its straightbred parents and heterosis results from an increase in heterozygosity of a crossbred animal's genetic makeup. Heterozygosity refers to a state where an animal has two different forms of a gene. It is believed that heterosis is primarily the result of gene dominance and the recovery from accumulated inbreeding depression of pure breeds. Heterosis is, therefore, dependent on crossbred animals having a greater percentage of heterozygous animals than is present in straightbred animals. The level of heterozygosity an animal has depends on the random inheritance of copies of genes from its parents. In general, animals that are crosses of unrelated breeds, such as Angus and Brahman, exhibit higher levels of heterosis due to more heterozygosity, than do crosses of more genetically similar breeds such as a cross of Angus and Hereford.

Generally, heterosis generates the largest improvement in lowly heritable traits (Table 5). Moderate improvements due to heterosis are seen in moderately heritable traits. Little or no heterosis is observed in highly heritable traits. Traits such as reproduction and longevity have low heritability. These traits respond very slowly to selection since a large portion of the variation observed in them is due to environmental effects and non-additive genetic effects, and a small percentage is due to additive genetic differences. But, heterosis generated through crossbreeding can significantly improve an animal's performance for lowly heritable traits, thus the importance of considering both additive and non-additive genetics when designing mating programs. Crossbreeding has been shown to be an efficient method to improve reproductive efficiency and pre-weaning productivity in beef cattle.

Table 5. Summary of heritability and level of heterosis by trait type.[a]

Trait	Heritability	Level of Heterosis
Carcass/end product Skeletal measurements Mature weight	High	Low (0 to 5%)
Growth rate Birth weight Weaning weight Yearling weight Milk production	Medium	Medium (5 to 10%)
Maternal ability Reproduction Health Cow longevity Overall cow productivity	Low	High (10 to 30%)

[a]Adapted from Kress and MacNeil. 1999.

Improvements in cow-calf production due to heterosis are attributable to having both a crossbred cow (maternal heterosis) and a crossbred calf (individual heterosis). Differing levels of heterosis are generated when various breeds are crossed. Similar levels of heterosis are observed when members of the *Bos taurus* species, including the British (e.g. Angus, Hereford, Shorthorn) and Continental European breeds (e.g. Charolais, Gelbvieh, Limousin, Maine-Anjou, Simmental), are crossed. Much more heterosis is observed when *Bos indicus,* or Zebu, breeds like Brahman, Nelore and Gir, are crossed with *Bos taurus* breeds. The increase in heterosis observed in British by *Bos indicus* crosses for a trait is usually 2-3 times as large as the heterosis for the same trait observed in *Bos taurus* crossbreds (Koger, 1980). The large increase is especially true with heterosis observed in the crossbred cow. The increase in heterosis is sensible as there are more genetic differences between species than within a species. Table 6 below details the individual (crossbred calf) heterosis and Table 7 describes the maternal (crossbred cow) heterosis observed for various important production traits in *Bos taurus* crossbreds. These heterosis estimates are adapted from a report by Cundiff and Gregory, 1999, and summarize crossbreeding experiments conducted in the Southeastern and Midwest areas of the US. Table 8 describes the expected individual heterosis of *Bos taurus* by *Bos indicus* crossbred calves, while

Table 9 details the estimated maternal (dam) heterotic effects observed in *Bos taurus* by *Bos indicus* crossbred cows. *Bos taurus* by *Bos indicus* heterosis estimates were derived from breeding experiments conducted in the southern US.

Table 6. Units and percentage of heterosis by trait for *Bos taurus* crossbred calves.

	Heterosis	
Trait	**Units**	**Percentage (%)**
Calving Rate, %	3.2	4.4
Survival to Weaning, %	1.4	1.9
Birth Weight, lb.	1.7	2.4
Weaning Weight, lb.	16.3	3.9
Yearling Weight, lb.	29.1	3.8
Average Daily Gain, lb./d	0.08	2.6

Table 7. Units and percentage of heterosis by trait for *Bos taurus* crossbred dams.

	Heterosis	
Trait	**Units**	**Percentage (%)**
Calving Rate, %	3.5	3.7
Survival to Weaning, %	0.8	1.5
Birth Weight, lb.	1.6	1.8
Weaning Weight, lb.	18.0	3.9
Longevity, years	1.36	16.2
Lifetime Productivity		
Number of Calves	.97	17.0
Cumulative Weaning Wt., lb.	600	25.3

Table 8. Units and percentage of heterosis by trait for *Bos taurus* by *Bos indicus* crossbred calves.[1]

	Heterosis
Trait	**Units**
Calving Rate, %[1]	4.3
Calving Assistance, %[1]	4.9
Calf Survival, %[1]	-1.4
Weaning Rate, %[1]	1.8
Birth Weight, lb.[1]	11.4
Weaning Weight, lb.[1]	78.5

[1]Adapted from Franke et al., 2005; numeric average of Angus-Brahman, Brahman-Charolais, and Brahman-Hereford heterosis estimates.

Table 9. Units and percentage of heterosis by trait for *Bos taurus* by *Bos indicus* crossbred dams.[1,2]

	Heterosis	
Trait	**Units**	**Percentage (%)**
Calving Rate, %[1]	15.4	--
Calving Assistance Rate, %[1]	-6.6	--
Calf Survival, %[1]	8.2	--
Weaning Rate, %[1]	20.8	--
Birth Weight, lb. [1]	-2.4	--
Weaning Weight, lb. [1]	3.2	--
Weaning Wt. per Cow Exposed, lb.[2]	91.7	31.6

[1]Adapted from Franke et al., 2005; numeric average of Angus-Brahman, Brahman-Charolais, and Brahman-Hereford heterosis estimates.
[2]Adapted from Franke et al., 2001.

The heterosis adjustments utilized by multi-breed genetic evaluation systems are another example of estimates for individual (due to a calf) and maternal (due to a crossbred dam) heterosis. These heterosis adjustments are presented in Table 10 below and illustrate the differences in expected heterosis for various breed-group crosses. In general the Zebu (Bos indicus) crosses have higher levels of heterosis than the British-British, British-Continental, or Continental-Continental crosses.

Table 10. Individual (calf) and maternal (dam) heterosis adjustments for British, Continental European, and Zebu breed groups for birth weight, weaning weight and post weaning gain.

	Birth Weight (lb)		Weaning Weight (lb)		Postweaning Gain (lb)
Breed Combinations	Calf Heterosis	Dam Heterosis	Calf Heterosis	Dam Heterosis	Calf Heterosis
British x British	1.9	1.0	21.3	18.8	9.4
British x Continental	1.9	1.0	21.3	18.8	9.4
British x Zebu	7.5	2.1	48.0	53.2	28.2
Continental x Continental	1.9	1.0	21.3	18.8	9.4
Continental x Zebu	7.5	2.1	48.0	53.2	28.2

(Wade Shafer, Am. Simmental Association, personal communication)

Why is it so important to have crossbred cows?

The production of crossbred calves yields advantages in both heterosis and the blending of desirable traits from two or more breeds. However, the largest economic benefit of crossbreeding to commercial producers comes from the crossbred cow. Dam heterosis improves both the environment a cow provides for her calf as well as improves her longevity and durability. The improvement of the maternal environment a cow provides for her calf is manifested in improvements in calf survivability to weaning and increased weaning weight. Crossbred cows exhibit improvements in calving rate of nearly 4% and an increase in longevity of more than one year due to heterotic effects. Heterosis results in increases in lifetime productivity of approximately one calf and 600 pounds of calf weaning weight over the lifetime of the cow. Crossbreeding can have positive effects on a ranch's bottom line by not only increasing the quality and gross pay weight of calves produced but also by increasing the durability and productivity of the cow factory.

The effects of dam heterosis on the economic measures of cow-calf production have been shown to be very positive. The added value of maternal heterosis ranges from approximately $50/cow/year to nearly $100/cow/year depending on the amount of maternal heterosis retained in the cowherd (Ritchie, 1998). The value of increased productivity for crossbred cows to a weaning endpoint using current calf prices is estimated to be $150 per cow-calf pair per year. Heterosis expressed by dams accounted for an increase in net profit per cow of nearly $75/cow/year (Davis et al., 1994). Their results suggested that the benefits of dam heterosis on profit were primarily the reduced cost per cow exposed. Crossbred cows had higher reproductive rates, longer productive lives, and required fewer replacements than straightbred cows in their study. All of these factors contribute to reduced cost per cow exposed. Further, they found increased outputs, including growth and milk yield, were offset by increased costs.

Crossbreeding's impact on profit

Enhanced profit is likely one of the strongest motivators for producers to implement effective structured crossbreeding systems. The substantial improvements in production efficiency measured as weaning weight per cow exposed supports improved profit and operational sustainability. Improved profit potential is realized through the simultaneous improvement in gross revenue stream to the ranch while decreasing costs of production through reduced replacement female requirements. Enhanced reproductive efficiency, especially in harsh environments, favorably decreases breakeven unit cost of production. Getting more calves to market endpoint, marketing heavier calves and selling a larger percentage of the calf crop through the benefits of individual and maternal heterosis, enhances gross revenue. Increasing revenue while decreasing or maintaining costs improves profit assuming constant inventories.

While most producers sell calves at weaning, this endpoint doesn't describe the total economic benefit to either an integrated beef producer that retains ownership to harvest and sells animals on a value based marketing grid or, if calves are marketed at weaning, describing the value of crossbred animals to downstream participants in the beef value chain. In an era of expanding demand for premium quality beef and declining fed cattle and cow herd inventories, it is essential that profit minded producers develop a clear understanding of the economic tradeoffs of concentrating the percentage of one breed in a breeding system and the corresponding decreased heterosis and associated reduced production efficiency. System or operation profit should be the metric by which breeding systems are evaluated. Relying on the value (revenue) per hundred weight of calves or carcasses sold or 'premiums' as indicators of profit is naïve. A number of simulation studies have been conducted to evaluate the value of breed differences and heterosis to integrated beef production systems. These projects (Notter et al, 1979; Tomson et al., 2001) concluded that breeding systems which used breed complementarity and individual and maternal heterosis are the most profitable. Mating systems that produced individual heterosis were shown to be more economically efficient than straight-breeding systems. Likewise systems that utilize maternal heterosis were more economically efficient than the use of straight bred dams (Notter et al., 1979).

What are the keys to successful crossbreeding programs?

If you implement a crossbreeding system, do not be fooled into the idea that you no longer need to select and purchase quality bulls or semen for your herd. Heterosis cannot overcome low quality genetic inputs. The quality of progeny from a crossbreeding system is limited by the quality of the parent stock that produced them. Conversely, do not believe that selection of extremely high quality bulls or semen or choosing the right breed will offset the advantages of effective crossbreeding system. Crossbreeding and sire selection are complementary and should be used in tandem to build an optimum mating system in commercial herds. (Bullock and Anderson, 2004)

Many of the challenges that have been associated with crossbreeding systems in the past are the result of undisciplined implementation of the system. With that in mind, one should be cautious to select a mating system that matches the amount of labor and expertise available to appropriately implement the system. Crossbreeding systems range in complexity from very simple programs such as the use of composite breeds, which are as easy as straight breeding, to elaborate rotational crossbreeding systems with four or more breed inputs. The biggest keys to success are the thoughtful construction of a plan and then sticking to it! Be sure to set attainable goals. Discipline is essential.

Crossbreeding Systems

Practical crossbreeding systems implemented in a commercial herd vary considerably from herd to herd. A number of factors determine the practicality and effectiveness of crossbreeding systems for each operation. These factors include herd size, market target, existing breeds in the herd, the level of management expertise, labor availability, grazing system, handling facilities and the number of available breeding pastures. It should be noted that in some instances the number of breeding pastures required can be reduced through the use of artificial insemination. Additional considerations include the operator's decision to purchase replacement females or select and raise replacements from the herd. Purchasing healthy, well developed replacement females of appropriate breed composition can be the simplest and quickest way for producers, especially small operators, to maximize maternal heterosis in the cowherd. Regardless of the crossbreeding system selected, a long-term plan and commitment to it is required to achieve the maximum benefit from crossbreeding. A variety of crossbreeding systems are described on the following pages. These systems are summarized in Table 11 by their productivity advantage measured in percentage of pounds of calf weaned per cow exposed. Additionally the table includes the expected amount of retained heterosis, the minimum number of breeding pastures required, whether purchased replacements are required, the minimum herd size required for the system to be effectively implemented, and the number of breeds involved. A more thorough discussion of various crossbreeding systems may be found in the *NBCEC Beef Sire Selection Manual, 2nd Edition* (http://www.nbcec.org/producers/sire.html).

A primary concern of many commercial producers is the increase in phenotypic variation and thus discounts for lack of uniformity in crossbred calf crops. As Table 1 illustrates, the coefficients of variation (variation standardized by the mean) have been shown to be very similar between composites and purebreds. Although the thought that a single breed, and even individuals within a breed, must be suited for all scenarios is common, this common thought leads to gross inefficiency of beef production. A much more progressive paradigm would include utilizing, and some in cases reestablishing, maternal breeds/composites that excel in maternal traits that are moderate in mature size. Within these populations, individuals exceling in breed strengths would be utilized as dams in terminal commercial beef production. Terminal sires would then be developed from terminal breed crosses that excel in growth and carcass merit. This simple, yet elusive thought process is a giant leap forward from the pervasive thought that one breed fits all and that a "good" bull must excel in all economically relevant traits. As producers seek to produce environmentally adapted crossbred cows and market targeted progeny, separation in sire selection decisions for dams that will produce replacements and dams that produce terminal progeny is encouraged.

Table 7. Summary of crossbreeding systems by amount of advantage and other factors.[a]

Type of System	% of Cow Herd	% of Marketed Calves	Advantage (%)[b]	Retained Heterosis (%)[c]	Minimum # of Breeding Pastures	Minimum Herd Size	Number of Breeds
2-Breed Rotation							
A*B Rotation	100	100	16	67	2	50	2
3-Breed Rotation							
A*B*C Rotation	100	100	20	86	3	75	3
2-Breed Rotational / Terminal Sire							
A*B Rotational	50	33			2		
T x (A*B)	50	67			1		
Overall	100	100	21	90	3	100	3
Terminal Cross with Straightbred Females[d]							
T x (A)	100	100	8.5	0[e]	1	Any	2
Terminal Cross with Purchased F1 Females							
T x (A*B)	100	100	24	100	1	Any	3
Rotate Bull every 4 years							
A*B Rotation	100	100	12-16	50-67[f]	1	Any	2
A*B*C Rotation	100	100	16-20	67-83[f]	1	Any	3
Composite Breeds							
2-breed	100	100	12	50	1	Any	2
3-breed	100	100	15	67	1	Any	3
4-breed	100	100	17	75	1	Any	4
Rotating Unrelated F_1 Bulls							
A*B x A*B	100	100	12	50	1	Any	2
A*B x A*C	100	100	16	67	1	Any	3
A*B x C*D	100	100	19	83	1	Any	4

[a]Adapted from Ritchie et al.,1999
[b]Measured in percentage increase in lb. of calf weaned per cow exposed,
[c]Relative to F_1 with 100% heterosis,
[d]Gregory and Cundiff, 1980.
[e]Straightbred cows are used in this system which by definition have zero (0) percent maternal heterosis; calves produced in this system exhibit heterosis which is responsible for the expected improvement in weaning weight per cow exposed.
[f]Estimates of the range of retained heterosis. The lower limit assumes that for a two breed system with stabilized breed fractions of 50% for each breed; three breed rotation assumes animals stabilize at a composition of 1/3 of each breed. Breed fractions of cows and level of maternal heterosis will vary depending on sequence of production.

Two- or Three-Breed Rotation:

A two-breed rotation is a simple crossbreeding system requiring two breeds and two breeding pastures. The two-breed rotational crossbreeding system is initiated by breeding cows of breed A to bulls of breed B. The resulting heifer progeny (A*B) chosen as replacement females would then be mated to bulls of breed A for the duration of their lifetime. Note the service sire is the opposite breed of the female's own sire. These progeny are then ¼ breed A and ¾ breed B. After several generations the amount of retained heterosis stabilizes at about 67% of the maximum calf and dam heterosis, resulting in an expected 16% increase in the pounds of calf weaning weight per cow exposed above the average of the parent breeds (Ritchie et al., 1999). This system is sometimes called a crisscross. A three-breed rotational system achieves a higher level of retained heterosis than a two-breed rotational crossbreeding system does. After several generations the amount of retained heterosis stabilizes at about 86% of the maximum calf and dam heterosis, resulting in an expected 20% increase in the pounds of calf weaning weight per cow exposed above the average of the parent breeds (Ritchie et al., 1999).

Considerations: For a two-breed rotation, the minimum herd size is approximately 50 cows with each half being serviced by one bull of each breed. Scaling of herd size should be done in approximately 50 cow units to make the best use of service sires, assuming 1 bull per 25 cows. Replacement females are mated to herd bulls in this system so extra caution is merited in sire selection for calving ease to minimize calving difficulty. Resources (pastures and cows) increases proportionally as the number of breeds in the rotation increases.

Breeds used in rotational systems should be of similar biological type to avoid large swings in progeny phenotype due to changes in breed composition. The breeds included have similar genetic potential for calving ease, mature weight and frame size, and lactation potential to prevent excessive variation in nutrient and management requirements of the herd. Using breeds of similar biological type and color pattern will produce a more uniform calf crop which is more desirable at marketing time. If animals of divergent type or color pattern are used additional management inputs and sorting of progeny at marketing time to produce uniform groups may be required.

Terminal Cross with Purchased F_1 Females

The terminal cross system utilizes crossbred cows and bulls of a third breed. This system is an excellent choice as it produces maximum heterosis in both the calf and cow. As such, calves obtain the additional growth benefits of hybrid vigor while heterosis in the cows improves their maternal ability. The terminal-cross system is one of the simplest systems to implement and achieves the highest use of heterosis and breed complementarity. All calves marketed will have the same breed composition. A 24% increase in pounds of calf weaned per cow exposed is expected from this system when compared to the average of the parent breed. The terminal cross system works well for herds of any size if high quality replacement females are readily available from other sources. Only one breeding pasture is required. No special identification of cows or groups is required.

Considerations: Since replacement females are purchased care should be given in their selection to ensure that they are a fit to the production environment. Their adaptation to the production environment will be determined by their biological type, especially their mature size and lactation potential. Through an added two-breed rotational component, the ranch could produce their own replacements (two-breed rotational/ terminal sire; see *NBCEC Beef Sire Selection Manual*), this option requires additional resources, adds complexity, and produces two different types of calves to market: one set from the maternally focused rotational system and one from the terminal sire system. With the availability of sexed semen, there exists the potential to alleviate this issue. Admittedly the cost is currently a deterrent for most, but the pairing of advanced reproductive technologies with breeding systems allows for greater efficiencies and is worth consideration

Success of the purchased F_1 female system is dependent on being able to purchase a bull of a third breed that excels in growth and carcass traits. If virgin heifers are selected as replacements, they should be mated to an easy calving sire to minimize dystocia problems, although purchasing 3-year old females alleviates this issue.. Some producers become concerned over the purchase price of replacement females. Although the return on investment should be careful determined, it should be fairly compared against what the individual producer's true costs of developing replacements heifers is and the opportunity cost associated utilizing bulls that are expected to produce replacement females and terminal offspring, likely exceling in neither. Disease issues are always a concern when introducing new animals to your herd. Be sure that replacement heifers are from a reputable, disease-free source and that appropriate bio-security measures are employed. Johne's, brucellosis, tuberculosis, bovine viral diarrhea (BVD) are diseases you should be aware of when purchasing animals. Another consideration and potential advantage of the terminal-cross system is that replacement females do not need to be purchased each year depending on the age stratification of the original cows. In some cases replacements may be added every 2-5 years providing an opportunity to purchase heifers during periods of lower prices or more abundant supplies. Heifers could also be developed by a professional heifer development center or purchased bred to easy calving bulls.

Composite Breeds

The use of composite populations in beef cattle has seen a surge in popularity recently. Aside from the advantages of heterosis retention and breed complementarity, composite population breeding systems are as easy to manage as straightbreds once the composite is formed. The simplicity of use has made composites popular among very large, extensively managed operations and small herds alike. When two-, three- or four-breed composite are formed they retain 50%, 67%, and 75% of maximum calf and dam heterosis and improve productivity of the cowherd by 12%, 15%, and 17%, respectively. Thus, these systems typically offer a balance of convenience, breed complementarity and heterosis retention.

A large herd (500 to 1000 cows) to form your own composite or a source of composite bulls or semen is required. In closed populations inbreeding must be avoided as it will decrease heterosis. To help minimize inbreeding in the closed herd where cows are randomly mated to sires the foundation animals should represent 15-20 sire groups per breed and 25 or more sires should be used to produce each subsequent generation (Ritchie et al., 1999). Similar recommendations would be made to seedstock breeders wishing to develop and merchandize bulls of a composite breed.

In small herds, inbreeding may be avoided through purchase of outside bulls that are unrelated to your herd. F_1 bulls provide a simple alternative to the formulation of composite breeds. Additionally, the F1 systems may provide more opportunity to incorporate superior genetics as germplasm can be sampled from within each of the large populations of purebreds rather than a smaller composite population. The use of unrelated F_1 bulls, each containing the same two breeds, in a mating system with cows of the same breeds and fractions will result in retention of 50% of maximum calf and dam heterosis and an improvement in weaning weight per cow exposed of 12%. A system that uses F_1 bulls that have a breed in common with the cow herd (A*B x A*C) results in heterosis retention of 67% and an expected increase in productivity of 16%. While the use of F_1 bulls that don't have breeds in common with cows made up of equal portion of two different breeds (A*B x C*D) retains 83% of maximum heterosis and achieves productivity gains of 19%. This last system is nearly equivalent to a three breed rotational system in terms of heterosis retention and productivity improvement, but much easier to implement and manage.

The use of F_1 bulls requires a seedstock source from which to purchase. The bulls will need to be of specific breed combinations to fit your program. These programs fit a wide range of herd sizes. The use of F_1 bulls on cows of similar genetic make-up is particularly useful for small herds as they can leverage the power of heterosis and breed complementarity using a system that is as simple as straight breeding. Additionally, they can keep their own replacement females.

Considerations: The inclusion of a third or fourth breed in the systems takes more expertise and management. To prevent wide swings in progeny phenotype, breeds B and C should be similar in biological type, while breeds A and D should be similar in biological type.

Crossbreeding Challenges

Although crossbreeding has many advantages, there are some challenges to be aware of during your planning and implementation as outlined by Ritchie et al., 1999.

1. **More difficult in small herds**
   Crossbreeding can be more difficult in small herds. Herd size over 50 cows provides the opportunity to implement a wider variety of systems. Small herds can still benefit through utilization of terminal sire, composite or F_1 systems.

2. **Requires more breeding pastures and breeds of bulls**
   Purchasing replacements and maximum use of A.I. can reduce the number of pastures and bulls. However, most operations using a crossbreeding system will expand the number of breeding pastures and breeds of bulls.

3. **Requires more record keeping and identification of cows**
   Cow breed composition is a determining factor in sire breed selection in many systems.

4. **Matching biological types of cows and sire**
   Breed complementarity and the use of breed differences are important advantages of cross breeding. However, to best utilize them care must be given in the selection of breeds and individuals that match cows to their production environment and sires to market place. Divergent selection of biological type can result in wide swings in progeny phenotype in some rotational systems. These swings may require additional management input, feed resources, and labor to manage as cows or at marketing points.

5. **System continuity**
   Replacement female selection and development is a challenge for many herds using crossbreeding systems. Selection of sires and breeds for appropriate traits (maternal or paternal traits) is dependent of ultimate use of progeny. Keeping focus on the system and providing labor and management at appropriate times can be challenging. Discipline and commitment are required to keep the system running smoothly.

Summary

Without question, at the individual firm level, errors have been made in correct breed utilization and in the development of crossbreeding systems. Simply mating animals of different breeds does not constitute a breeding program. However, the movement towards straightbreeding in an attempt to simplify breeding systems assumes that somehow firms that made incorrect decisions in breed selection and individual animal selection when crossbreeding immediately make more educated decisions when choosing animals with a single breed. Point being, incorrect selection decisions are made by those that crossbreed and those that straightbreed. Judicious breed selection and animal selection within breeds is critical. However, the economic benefits of crossbreeding are clear and the production system efficiencies that can be gained are tremendous, ranging from improved longevity, fertility, disease resistance, and growth. Every breed has strengths and weaknesses relative to an individual commercial operation’s production and marketing goals. That is the benefit of crossbreeding, blending strengths from various breeds to meet production goals while fitting within environmental constraints, and heterosis becomes the reward for having done so. Climatic conditions are an important consideration when choosing breeds to utilize in a crossbreeding program and caution should be used to ensure environmental fitness is addressed. It is important to remember that successful crossbreeding programs focus on optimums, not maximums or minimums, to achieve breeding and marketing goals that fit within the production environment.

Moving forward there are researchable questions related to crossbreeding and heterosis that need to be addressed. One is updated estimates of global heterosis, or heterosis pooled across several breed pairings, and another is breed specific estimates of heterosis, or the heterotic benefit of pairing breed A with Breed B as opposed to breed C. Global estimates of heterosis will need to be estimated for “novel” traits that we are just now collecting phenotypes for (feed intake, susceptibility to certain diseases, microbial community, etc.). As most breeds now have, or will shortly, included genomic predictors into NCE we have surely just scratched the surface of what genomic information can do to aid in beef cattle breeding and management. Some loci no doubt influence the phenomenon of heterosis more than others, and the use of this in breeding systems holds tremendous benefits in the pairing of breeds and individuals. Finally, from a more applied perspective, the coupling of advanced reproductive technologies with the design and implementation of breeding systems holds tremendous advantages from a beef industry efficiency perspective. The ability to produce composite females, selected from maternal lines, and mated to terminal sires for the production of market bound progeny is a general concept that has eluded the beef industry while our animal protein competitors have mastered it. If we can then avoid the undesirable sex (heifers in the terminal system and bulls in the maternal system) the advantages become even greater.

While these possibilities are exciting, the fundamentals still hold. Pair breeds to take advantage of breed complementarity when possible, utilize heterosis, and select animals within the chosen breeds using EPD and Bio-economic index values. Without these fundamentals, advancing technology has no chance of success.

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