SDSU Extension

BEEF

Chapter 39

Breeding Systems in Commercial Beef Production

Warren Rusche and
Michael G. Gonda

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Introduction

Few subjects in beef production generate as much debate and passion as does the subject of genetics, especially pertaining to breeds and how they are utilized in commercial breeding systems. Allowing science to cut through the haze caused by tradition and breed stereotypes can be difficult. Rather than attempt to determine which system is "correct" or "best", this chapter will discuss the scientific principles behind the various systems, and the considerations necessary to improve the chances of success.

Heterosis

Heterosis is defined as the difference in the performance of a crossbred animal compared to the average of the two purebred parents. For example, crossbred Angus x Hereford calves may be expected to weigh about 5% heavier at weaning than would be expected from the average weaning weight of purebred Angus and Hereford calves (Dearborn et al., 1987).

It's important to remember that this does not mean that a crossbred will necessarily be superior to one or both of the purebred parents. An extreme example would be a cross between a Longhorn and a Holstein; progeny from this cross will likely produce more milk than would be expected from the average performance of both breeds. However, it's highly doubtful that a cow resulting from such a mating would produce more milk than a Holstein.

It's also important to recognize the differences between heterosis and heritability. In general, traits that are higher in heritability show less response to heterosis. Little to no heterosis would be expected in highly heritable traits, whereas those traits that are difficult to change through genetic selection will show the greatest changes due to increased heterosis. A summary of the heritability estimates and level of heterosis for various traits is shown in Table 1 (Weaber, 2010b).

Key Points

- Heterosis can influence maternal, individual, and paternal performance. Of these three, maternal heterosis has the most impact on the total productivity of a production system.
- A number of breeding systems have been developed to take advantage of the effects of heterosis and breed complementarity. These systems can be categorized by the number of breeds utilized and how herd replacements are generated.
- Some of these systems can be challenging to implement. To address these challenges strategies such as purchasing female replacements to facilitate specific crossing systems or use of composites have been developed.
- One of the greatest challenges and opportunities facing cow-calf producers is developing systems that integrate genetics, management, and marketing so that both outputs and inputs are optimized.

Table 1: Summary of heritability and level of heterosis by trait type. *Adapted from Weaber, 2010b.*

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

Improvements in performance can be attributed to heterosis effects from having a crossbred cow, a crossbred calf, and possibly from use of crossbred sires. Generally, it is most important to capture heterosis in the cowherd because traits expected to benefit from heterosis the most (e.g., fertility, offspring survivability) are expressed by the cows and heifers. Heterosis in the calf, however, should not be ignored. Also, heterosis may be manifested more readily under mildly stringent than under optimal environmental conditions (Vetukhiv and Beardmore, 1958). We will discuss three types of heterosis in-depth below.

Maternal Heterosis

Maternal heterosis refers to the performance improvements to the entire system as a result of crossbred cows. When the entire beef production system is taken into account, approximately two-thirds of the improvements in productivity are caused by maternal effects (Gosey, 2005). Reproductive traits are typically characterized by low heritability; however these same traits show the largest response to heterosis. The average impact of heterosis between Bos taurus breeds on maternal productivity measures is shown in Table 2 (Weaber, 2010b). The net result of changes in reproductive rates and calf survival, calf performance, and cow longevity results in an advantage in total lifetime productive of 25% for the crossbred cow (Cundiff and Gregory, 1977; Arthur et al., 1999).

One of the most striking changes in maternal performance due to heterosis as shown in Table 2 is increased cow longevity. In a study utilizing British × British crossbred cows, the effect of heterosis was to increase cow longevity by one year (Nuñez-Dominguez, et al., 1991). Those results showed that differences in survivability comparing crossbred to straightbred cows were apparent after the first year, with fewer replacements needed to maintain herd size. Other work using economic analysis of lifetime productivity and performance of Hereford × Simmental cows with a fixed feed base showed that maternal heterosis reduced total costs and breakeven prices by 20 and 15%, respectively (Davis, et al., 1994), primarily because fewer replacement females were required.

Table 2: Units and percentage of heterosis by trait for Bos taurus crossbred cows. *Adapted from Weaber, 2010b.*

Trait	Heterosis	
	Units	%
Calving rate, %	3.5	3.7
Survival to weaning, %	0.8	1.5
Birth weight, lb	1.6	1.8
Weaning weight, lb	18	3.9
Longevity, years	1.36	16.2
Lifetime Productivity	---	---
Number of calves	0.97	17
Cumulative weaning wt, lb	600	25.3

Survival in beef cows depends upon a number of factors, but typically reproductive failure is the most common reason for cows to be culled. One possible explanation as to why crossbred females tend to remain in the herd longer is heterosis effects on body condition. Gregory et al., (1992) found that composite and F1 cows had body condition scores that were 0.3 and 0.9 units higher respectively, compared to their straightbred counterparts. Body condition plays a key role in the probability of whether or not a cow becomes pregnant (Pruitt and Momont, 1988; Houghton et al., 1990).

Differences in "fitness" traits may also offer an explanation for the increased longevity and productivity of crossbred cows. Nuñez-Dominguez and co-workers (1991) noted that the teeth of crossbred cows showed less evidence of wear compared to straightbreds. These researchers also noted that fewer crossbred cows died or were culled due to emaciation, prolapse, or cancer eye.

Individual Heterosis

Heterosis effects in the individual performance of crossbred calves fall in this category and are what many people think of first when discussing the effects of heterosis. Some examples of estimated average effects of individual heterosis between Bos taurus breeds as reported by Weaber (2010b) are shown in Table 3. Many of the traits that contribute to performance differences caused by heterosis are also traits that are at least moderately heritable, such as growth traits. The result is that changes in performance can result from both genetic selection and from crossbreeding. However, heterosis can be captured for highly heritable traits (e.g., carcass traits) as well (Retallick et al., 2013) and should not be ignored when designing crossbreeding strategies.

Table 3: Individual units and percentage of heterosis by trait for Bos taurus crossbred calves. *Adapted from Weaber, 2010b.*

Trait	Heterosis	
	Units	%
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
ADG, lb/d	0.08	2.6

Paternal Heterosis

Compared to maternal and individual heterosis, much less work has been done quantifying the differences in performance due to a crossbred sire. It would stand to reason that some of the advantages in longevity and fitness observed in crossbred cows would also apply to crossbred sires; however, there's a lack of research data available to support that assumption. In a review of published research studying crossbred beef bulls, Thrift and Aaron (1987) did note that utilizing Bos taurus crossbred bulls was reported to result in calves being born 10 days earlier, implying an increase in conception rates. Some studies have also suggested that crossbred bulls may have an advantage in libido and mating capacity; however, it would be unlikely that any such differences would result in changes in pregnancy rates unless the cow to bull ratio were stretched to 40:1 or greater (Gosey, 2005). The impact of paternal heterosis, although present, does not contribute greatly to overall changes in cowherd

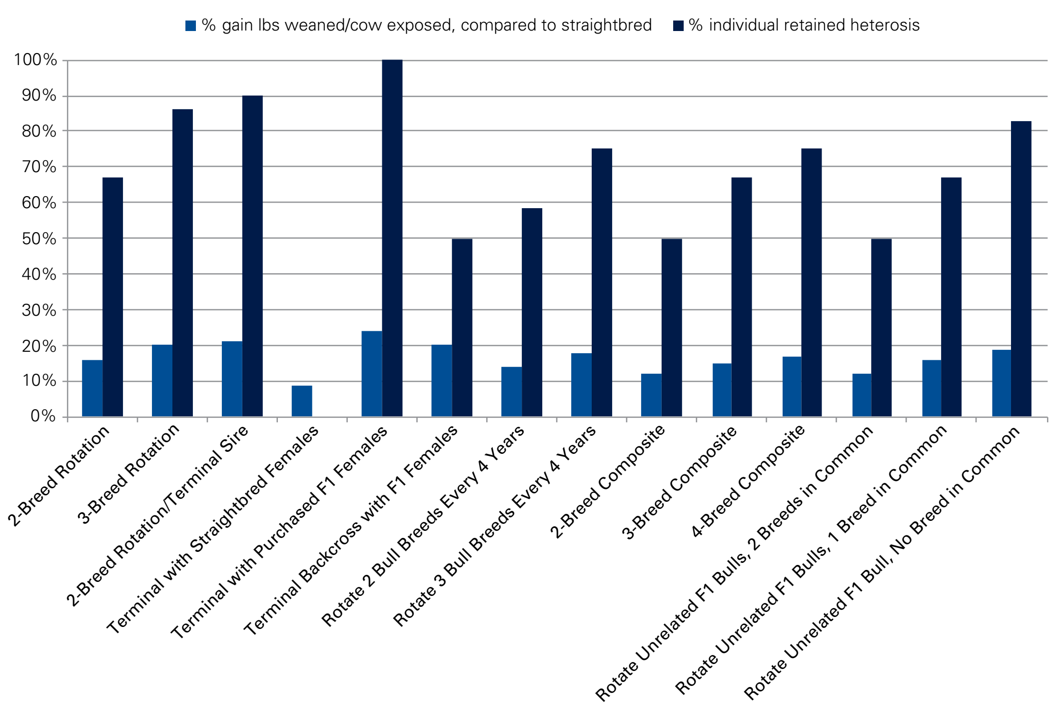

Figure 1: Comparison of % gain in lbs of weaned calf per cow exposed and % retained heterosis among crossbreeding strategies.

Table 4: Summary of the characteristics and restrictions of breeding systems. *Adapted from Weaber, 2010b.*

Type of System		% of Cow Herd	% of Marketed Calves	Advantage in pounds weaned/ cow exposed, %	Retained Heterosis[a], %	Minimum Number of Pastures[b]	Minimum Herd Size[b]
Straightbreeding	A	100	100	0	0	1	Any
Rotational Systems that generate replacements							
2-Breed Rotation	A × B	100	100	16	67	2	50
3-Breed Rotation	A × B × C	100	100	20	86	3	75
2-Breed Rotation/ Terminal Sire	A × B	50	33	---	---	2	---
	T × (A × B)	50	67	---	---	1	---
	Overall	100	100	21	90	3	100
Terminal Systems that do not generate replacements							
Terminal with Straightbred Females	T × A	100	100	8.5	0	1	Any
Terminal with purchased F_1 Females	T × (A × B)	100	100	24	100	1	Any
Terminal Backcross with F_1 Females	A × (A × B)	100	100	20[c]	[d]100 Maternal 50 Direct	1	Any
Simplified or Single Pasture Systems that generate replacements							
Rotate Bull Breeds every 4 years	A × B	100	100	12-16	50-67	1	Any
	A × B × C	100	100	16-20	67-83	1	Any
Composite	2-breed	100	100	12	50	1	Any
	3-breed	100	100	15	67	1	Any
	4-breed	100	100	17	75	1	Any
Rotating Unrelated F_1 Bulls	(A × B) × (A × B)	100	100	12 50	1	Any	---
	(A × B) × (A × C)	100	100	16	67	1	Any
	(A × B) × (C × D)	100	100	19	83	2	Any

[a] Relative to F1 with 100% heterosis.
[b] Minimum number of pastures and minimum herd size assumes that all breeding will be done by natural service. The use of AI could reduce the minimum number required.
[c] Adjusted advantage for Terminal with Purchased F1 females less 50% of the direct heterosis effects from Terminal × Straightbred
[d] If purchased F1 females are used, retained maternal heterosis would be 100%

productivity for most current cow-calf production systems. However, cow-calf producers who are willing to increase their cow to bull ratio may be able to take greater advantage of paternal heterosis for fertility.

Breeding Systems

For the purposes of this discussion, a breeding system encompasses the choice of breed or breeds, how they are utilized, and how replacements are generated. A general overview of various systems and their characteristics is shown in Table 4 and Figure 1 (Weaber, 2010b).

Straightbreeding

As the name implies, a straightbreeding system involves using the same breed for both the sire and dam to produce both replacements and cattle to be sold. This system is utilized for the production of purebred seedstock bulls and as a source of females to generate commercial F1 replacements. In commercial production straightbreeding may be justified when a single breed provides the optimal type for both cow and calf (Marshall, 1997). An obvious limitation to this system is the inability to capture any benefits from either heterosis or breed complementarity.

As discussed earlier, heterosis is particularly effective in improving maternal traits that are difficult to change through direct selection, although some of those differences can be compensated for by increasing inputs and costs. Breed complementarity functions by combining breeds so each breed's strengths and weaknesses balance to result in progeny that better fit a given market or environment. An example of how various traits may fit into possible production environments is shown in Table 5 (Weaber, 2010a). Although it may be possible with enough time and generations to develop a group of cattle using direct selection within one breed that would meet all the desired criteria for a given situation, the ability to combine breeds and capitalize on strengths offers a faster solution.

Another drawback of utilizing straightbred systems is a greater vulnerability for calves expressing genetic abnormalities, such as arthrogryposis multiplex (AM) in Angus or osteopetrosis in Red Angus. These abnormalities are inherited as simple recessive traits where if two carriers are mated there is a 1 in 4 chance of producing a calf with that abnormality. Some abnormalities result in obvious visual deformities; others result in early embryonic loss that is often attributed to reproductive failure for that estrous cycle. A few abnormalities, such as contractural arachnodactyly (fawn calf syndrome), result in deformities that may not be immediately apparent. Advancements in the ability to select superior sires and increase their usage through AI

Table 5: Genetic potential for various traits matched with production environments. *Adapted from Weaber, 2010a.*

Production Environment	**Traits**						
Feed Availability	**Stress**[a]	**Milk Production**	**Mature Size**	**Ability to Store Energy**[b]	**Resistance to Stress**[c]	**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.
[a] Heat, cold, disease, mud, altitude, etc.
[b] Ability to store fat and regulate energy requirements with changing (seasonal) availability of feed.
[c] Physiological tolerance to heat, cold, internal and external parasites, disease, mud, and other factors.

Table 6: Breed composition of an example three-breed rotation. *Adapted from Gosey, 2005.*

Generation	Breed of Sire	Percent Breed Composition		
		Simmental	Hereford	Angus
1	Simmental	50	0	50
2	Hereford	25	50	25
3	Angus	12	25	62
4	Simmental	56	12	31
5	Hereford	28	56	16
6	Angus	14	28	58
7	Simmental	57	14	29
8	Hereford	29	57	14
9	Angus	14	29	57
10	Simmental	57	14	29
Equilibrium	---	14-57	14-57	14-57

have resulted in popular sires being used much more widely than in the past. As the usage within a breed increases, the likelihood of a mating between two carriers increases as well. Utilizing genetics from more than one breed greatly minimizes the probability that both parents would be carriers of a given genetic abnormality because usually only a single breed is segregating any specific genetic abnormality (Garrick, 2013).

Rotational Systems

Rotational systems involve the use of two or more breeds. For instance, a two breed rotation of Angus × Hereford would involve using Angus bulls on Hereford cows and the F_1 daughters of that cross would then be bred back to Hereford bulls. A three-breed rotation might use Gelbvieh bulls on the Angus × Hereford females. The Gelbvieh-Angus-Hereford replacement females would then be mated back to the Angus bulls. Each cow will be bred to the breed of bull that represents the least percentage of her genetic makeup. These systems require that the sire breed for each female in the herd be recorded so that she can be assigned to the correct breeding group.

One of the challenges with this system is that the resulting progeny will have variable breed compositions. This point is illustrated in Table 6 (Gosey, 2005). In that example, the breed composition in a three-breed rotation ranges from 12 to 62%, depending on breed of the bull and breed composition of the females. Furthermore, when a breed is repeated in the rotation (backcrossed) a portion of the effects of heterosis are lost. The effect of these backcrosses is shown in the Retained Heterosis column of Table 4.

Because of these swings in breed composition, the breeds selected should be relatively similar in biological type in order to manage phenotype variation and avoid the challenges of marketing and managing non-uniform groups of cattle. This requirement limits the ability to utilize widely divergent breed types that would maximize the effect of breed complementarity.

Rotational crossbreeding systems can also pose some challenges in day-to-day ranch management, especially in herds using natural service. These systems require at least one breeding pasture per breed of bulls used. Additional breeding pastures may be necessary for mating calving ease bulls to heifers. Breeding groups also need to be sized in multiples of 20 to 25 to make the most efficient use of herd sires. These requirements for optimum use of rotational systems may conflict with the realities of ranch resources and the proper stewardship of pasture and range resources. The net result is that compromises need to be made in some aspects of the ranch system, resulting in less than optimum results. Using artificial insemination would allow more flexibility in which cows were grouped together and help to avoid some management challenges caused by herd sizes that aren't well suited to the available pastures.

Terminal Crossbreeding Systems

A terminal sire system offers the largest opportunity to capitalize on breed complementarity. Because the terminal sire will not be producing replacements, sires or breeds with superior growth and end-product characteristics that would otherwise be rejected because of factors such as expected milk production, mature size, and female fertility can still be utilized. Crossbreeding systems can also take maximum advantage of both maternal and direct heterosis. The two systems in Table 4 with the greatest percentage advantages in weaning weight per cow are terminal sire on purchased F1 females followed closely by a system where one-half the cows are in a two-breed rotational system and the other half are mated to terminal sires (a "rota-terminal" system). The former system offers some significant advantages from a ranch economics standpoint as resources do not have to be devoted to developing replacement females, provided that a reliable source of quality F1 females is available.

Variants of a terminal sire scheme that do not capture as much benefit from heterosis are also used by beef producers. The most straightforward of these is using bulls of one breed on purebred cows of another breed (such as Hereford bulls on Angus cows). The most serious drawback to this approach is that there is no benefit to the system from maternal heterosis. However, if a particular market niche was being targeted, such as the production of F1 black baldy heifers, the market premiums realized may be enough to offset some of the opportunity costs of straightbred cows.

The terminal backcross is another variant that is sometimes used as a way to meet certain marketing goals. For instance, Angus × Simmental F1 cows might be bred to Angus bulls that have been intensively selected based on a terminal index such as $B, without having to consider any maternal traits other than making sure that excessive calving difficulty was avoided. Only 50% of the effects of heterosis on calf performance would be retained in this system, but there would be no difference in the level of maternal heterosis which from a systems standpoint is the most valuable. Intense direct selection pressure can be placed on the terminal sires to at least partially compensate for the reduction in heterosis for growth traits and make maximum progress in traits such as marbling and carcass merit where heterosis is expected to be the lowest. Managers do need to stay disciplined and avoid retaining daughters from terminal matings despite the similar breed make-up, especially if the terminal sires being used have some undesirable maternal genetics. To avoid retaining daughters from terminal matings, producers could cross Charolais bulls with crossbred females in which the "dilutor" locus is not segregating.

Simplified Crossbreeding Systems that Generate Replacements

As alluded to in the earlier discussions, some of the previously discussed crossbreeding systems are not particularly "rancher friendly". Heterosis and breed differences need to be balanced with ranch management and seeking optimum rather than maximum levels of heterosis will have a higher probability of success (Gosey, 2005). Various strategies have been developed to help producers achieve that optimum level while keeping cattle and grazing management as simple as possible.

Composite or F_1 Bulls

These terms are often used interchangeably to refer to bulls with genetics from multiple breeds. Technically speaking F1 bulls are the product of two purebred parents while composites can be made up of two or more breeds and are typically more than a single generation removed from purebred parents. Composites with the same breed composition can be mated together, resulting in progeny with the same level of heterosis and breed complementarity as the parents. From a practical ranch management standpoint there is very little difference between an F1 bull and a composite; in fact, use of F1 bulls over multiple generations results in a cow herd that is a composite with breed composition 50% A and 50% B.

The competitive advantage of these systems lies in the combination of simplicity, heterosis, and breed complementarity. Adopting these plans would allow for a single breeding pasture. All females would be bred to the same sire type, so the careful record keeping required of a rotational system is not needed. A two-, three-, or four-breed composite would retain 50%, 67% and 75% of maximum heterosis as shown in Table 4. Breeds could be introduced to the system at the desired level (¼, ½, etc.) without increasing variability in the breed makeup of the calf crop.

One of the common concerns about these systems is that there will be an increase in variability because of the use of multi-breed sires. When the variation in composite vs. purebred steers was studied at USMARC, the variability was shown to be virtually identical between the two populations as shown in Table 7 (Gregory et al., 1995). These traits are controlled by multiple genes. For traits such as coat color that are controlled by a single gene, variability in the genetics of the parents could result in increased variability of the calf crop. Fortunately, composite or F1 bulls that are homozygous for traits such as color and polled status are much more common than in previous years so that producing a set of calves out of composite bulls that all have the same "look" shouldn't be any more difficult than by using purebred bulls.

Table 7: Coefficients of variation for purebred vs. composite steers. *Adapted from Gregory et al., 1995.*

Trait	Purebreds	Composite
Birth Weight	0.12	0.13
Weaning Weight	0.10	0.11
Feedlot ADG	0.10	0.10
Carcass Weight	0.08	0.09
Dressing Percentage	0.03	0.03
Marbling Score	0.12	0.12
Rib Eye Area	0.10	0.10

Another criticism of these systems has been that the selection tools available in the purebred population, particularly EPDs, are sometimes not as available or as accurate in composite cattle. Those concerns are being alleviated as several breed associations (Simmental, Red Angus, Gelbvieh and others) do publish EPDs and selection indices for the hybrid animals in their database. At press time, genomic testing has not been adopted for composite animals, but research is ongoing to develop genomic tests in some composites.

Rotating Sire Breeds (Purebred or Composite)

Another strategy for simplifying management while still taking advantage of the benefits of heterosis would be to rotate the breed of bulls that are being used every four or five years (a "rotation-in-time"). This type of system could be used with either purebred or composite bulls and provides for simpler management while at the same time taking advantage of heterosis and breed complementarity. Much like the rotational systems outlined earlier, the breeds being considered should be relatively similar in biological type to minimize some of the type changes that might occur if widely divergent breeds or lines were used. Another consideration is that unless a ranch's seedstock provider raises multiple breeds, there would potentially be a need to seek a new bull supplier every four to five years. Both the rotation-in-time and composite/F1 breeds are systems which can be implemented by producers with small cowherds.

Crossbreeding Challenges – Or Why Isn't Crossbreeding More Widely Used?

In spite of several decades of research and effort by Extension systems and others advocating the use of crossbreeding in commercial beef cattle production, the adoption of these genetic principles has not achieved anything close to that seen in competing animal protein sectors, particularly poultry and pork. Depending upon the dataset that is used, 50 to 70% of the nation's cowherd is high-percentage or straightbred British breeds (Speer, 2013). That's also consistent with the much higher annual registrations of purebred Angus cattle reported compared to competing breeds.

The beef industry is a highly diverse industry that operates under a wide variety of environmental conditions and business models. As such, offering simple reasons why technologies are or are not adopted is a daunting prospect. However, there are some factors that should be considered as potential barriers to the adoption of breeding systems that could improve productive efficiencies (Daley, 2013):

- Inappropriate selection of breeds in the system. Initial efforts at crossbreeding were too often undertaken with little or no plan with breed combinations that were often detrimental. In response many firms have adopted a straightbreeding system to "fix" the resulting problems and phenotypic variation.

- Uniformity in traits such as color and the ability to meet defined carcass targets have real and distinct advantages in the marketplace.
- Industry emphasis on single trait selection, such as growth, lean yield, or marbling. In most cases these traits are highly heritable. Therefore, a tremendous amount of progress is possible without crossbreeding, especially when EPDs are used.
- The measurement of outputs is easier than measuring inputs. There is a wide range of opinions and measures regarding cowherd efficiency, while on the other hand measuring growth performance or carcass data is relatively straightforward.
- Heterosis is difficult to visualize and even more difficult to measure, especially for maternal traits. Very real differences in reproductive function and longevity may not be readily apparent without large datasets to analyze.
- The long-held belief that effective crossbreeding systems must be complicated.
- The tendency of producers and the beef industry to simply modify the environment by providing more feed or other resources to support cattle that otherwise wouldn't perform at acceptable levels.
- The failure of our education and technology transfer systems to convince beef producers to adopt crossbreeding.
- Unlike swine and poultry production, the "purebred" tradition is deeply ingrained within the beef production community.

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