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CROSSBREEDING STRATEGIES: INCLUDING TERMINAL VS. MATERNAL CROSSES

R.L. Weaber

Department of Animal Science and Industry
Kansas State University

INTRODUCTION

The dramatic changes and volatility cow-calf production system input costs and calf values have many producers wondering about the value of heterosis in today's beef industry pricing structure. Many producers are seeking ways to improve cow-calf production efficiency and profitability. Profitability may be enhanced by increasing the volume of production (i.e. the pounds of calves you market) and/or the value of products you sell (improving quality). The reduction of production costs, and thus breakeven prices, can also improve profitability. Better yet, improving the input:output ratio should enhance profit. For commercial beef producers, the implementation of technologies and breeding systems that increase the quality and volume of production and reduce input costs is essential to maintain or improve the competitive position of the operation. Some producers are thinking of establishing a more conventional straight breeding system to improve end-product value traits and want to understand the value they are giving up as they sacrifice heterosis, while other producers are considering the establishment of a planned crossbreeding system to capture the value of hybrid vigor. Either way, to make an informed decision, producers need to know the value generated in their herd by heterosis or hybrid vigor.

To fully understand the trade-offs, it is essential to know what it is you sell and how you sell it. The lure of premiums for high quality beef carcasses is appealing; it gets lots of trade publication promotion and it can be profitable. No doubt growing the top-line of the beef value chain and satisfying customers is important. That said, if you are producer that sells calves at weaning you have very limited opportunity to capture the value of selection pressure you place on end-product quality at the expense of other traits or loss in heterosis. It is also true that even if you own the cattle to harvest and are paid on a grid, you only get a fraction of the value of the improvement, albeit bigger than the calf premium. Conversely, the value of heterosis affects every cow on your outfit and it is value that you can capture every year no matter how you sell calves. More importantly, it's not a $20 or $40 or $60 premium per head you might get for selling calves or carcasses…the heterosis premium is much, much more.

The use of crossbreeding offers two distinct and important advantages over the use of a single breed. First, crossbred animals have heterosis or hybrid vigor. Second, crossbred animals combine the strengths of the parent breeds. The term 'breed complementarity' is often used to describe breed combinations that produce highly desirable progeny for a broad range of traits. With useful across breed EPDs and adjustment factors, we can effectively select for improvement in a wide range of traits including carcass traits, while seeking to build environmentally adapted cows that leverage the power and value of heterosis.

Moreover, commercial producers continue to receive market signals to increase growth rate, performance and carcass value by downstream value chain participants while simultaneously facing increased production costs and selection of less fit replacement heifers produced by bulls with diminished emphasis on maternal traits or appropriate biological type for the production environment. It is becoming progressively more difficult to find bulls for use in commercial production that meet all the goals of being a suitable sire for terminal calves and desirable replacement females due to the growing antagonisms in the value chain between traits in the terminal and maternal objectives. The desire to produce environmentally adapted replacement females that are appropriate for mature weight and lactation potential (both of which establish maintenance requirement) in a given forage environment and management system that maybe trying to reduce the use of harvested feedstuffs while simultaneously producing high value market targeted feeder cattle has challenged the thinking of many producers.

One potential solution that may help optimize the selection of sires that produce desirable maternal trait attributes and market targeted calves is to separate this into two distinct breeding decisions. Doing so increases the selection intensity of both sire groups as they are no longer bounded by the demands of balancing the trait groups. For many years, pork and poultry producers have benefited from this strategy that allows optimal combinations of breeds and line for maternal animals with males selected from combinations of breeds or lines that complement the maternal animals. Within both the maternal or paternal groups, breeders are able to make breed/line and individual selections that produce ideal combinations of breed and heterotic effects (i.e. selection for additive and non-additive genetic merit) that maximizes the value or profit in the system.

HETEROSIS EFFECT

Improvements in cow-calf production due to heterosis are attributable to having both a crossbred cow and a crossbred calf. The tables 1-4 below detail the individual (crossbred calf) and maternal (crossbred cow) heterosis observed for various important production traits for Bos taurus crosses and Bos indicus crosses. These heterosis estimates are adapted from a report by Cundiff and Gregory, 1999, and Franke et al., 2005. They summarize crossbreeding experiments conducted in the South-eastern and Mid-west areas of the US and the Gulf coast, respectively. Heterosis generates the largest improvement in lowly heritable traits. Traits such as reproduction and longevity, essential for cow-calf profitability, have low heritability. These traits respond very slowly to selection but heterosis generated through crossbreeding can significantly improve an animal’s performance. The largest economic benefit (roughly 66%) of crossbreeding to commercial producers comes from having crossbred cows (Table 2.) Crossbreeding has been shown to be an efficient method to improve reproductive efficiency and productivity in beef cattle.

Table 1. Units and percentage of heterosis by trait for Bos taurus crossbred calves.

Trait	Heterosis Units	Heterosis 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 2. Units and percentage of heterosis by trait for Bos taurus crossbred dams.

Trait	Heterosis Units	Heterosis 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 3. Units and percentage of heterosis by trait for Bos taurus by Bos indicus crossbred calves.[1]

Trait	Heterosis 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 4. Units and percentage of heterosis by trait for Bos taurus by Bos indicus crossbred dams.[1,2]

Trait	Heterosis Units	Heterosis 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 5 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 5. 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)

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.

A variety of crossbreeding systems yield 20-30% improvements in weaning weight per cow exposed not including the additional value generated through sire selection within breed. This represents a substantial change in output given relatively constant input. Simple examples of a 23% increase in weaning weight per cow exposed using a terminal sire/F1 (two cross) cow can generate $150-250 additional revenue per cow per year. I'm not aware of any set of calves that have generated carcass premiums of $150 premium per cow exposed regardless of breed or grid. In today's calf prices the value of heterosis for a herd of 100 cows is $15,000 to $25,000 per year and represents a decrease in breakeven costs of more than $30/cwt on 600 lb calves.

A well-constructed crossbreeding system 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. As you make your decision to straight-breed or cross-breed make sure you don't give away a couple hundred dollars per cow to make a $20-60 premium per calf sold at market or on the rail when you can go for both!

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; Tomsen 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.

NOTES

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 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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