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Fundamental Aspects of Crossbreeding of Sheep: Use of Breed Diversity to Improve Efficiency of Meat Production

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Introduction

The sheep industry competes against beef, pork, poultry, and fish for food dollars of consumers who have many choices of high-quality meats. To compete effectively, the industry needs to produce uniform, nutritious, lean lamb that satisfies the eating preferences of consumers and to improve reproductive efficiency and reduce labor requirements so that seedstock and commercial flocks are both practical and profitable under a range of production environments. Although this situation indeed represents a difficult challenge, sheep producers have an invaluable resource to make necessary changes - a wealth of biodiversity represented by numerous breeds. Breeds of sheep have evolved over many thousands of years, their utility and function guided by their ability to adapt and survive in specific environments and production systems. Following domestication, further diversification among breeds has stemmed from selection by man for numerous characteristics, for example, appearance, color, size, shape, or wool production. Consequently, breeds of sheep differ markedly in adaptability to different environments and in levels of performance for traits that influence efficiency of production and product quality. Characteristics of each breed have a genetic basis and can therefore be exploited in structured crossbreeding systems designed for specific production-marketing situations. The purpose of this manuscript is to provide guidelines to improve efficiency of meat production through the appropriate use of breeds in crossbreeding systems.

Breed Diversity

There are currently more than 50 recognized breeds of sheep in the U.S. Over the past 20 years, several breeds or strains have been imported from other countries due to specific characteristics. For example, Booroola Merino and Romanov were imported primarily for reproductive issues, Texel for carcass traits, East Friesian for milk production, and Dorper for easy-care attributes. It is likely that additional breeds will be imported in the future.

For any trait affecting efficiency of meat production, there is useful genetic variation among breeds. A good example is lambing rate, the number of lambs born per ewe lambing. Average lambing rates of breeds vary more than twofold, from perhaps 1.6 for mature Rambouillet ewes to about 3.7 for mature Romanov ewes. This variation does not imply that one breed is "better" than the other. The value of breed diversity is that producers can identify and use a breed or breeds that perform at a level consistent with marketing goals and with production resources such as feed availability, labor, facilities, and managerial skills. Therefore, flocks of Rambouillet ewes are common in arid regions of the U.S., whereas purebred or crossbred Romanov flocks exist in areas with greater feed resources.

Breed diversity is even greater if one considers several traits at once rather than a single trait. A breed that excels for daily gain and carcass traits may be less adaptable to harsh environments. Or, a breed that is parasite tolerant and has extended seasonality may not produce lean carcasses at typical market weights. Examples of breeds and traits are given in Table 1 to emphasize this very important characteristic of breed diversity. These specific four breeds were chosen because of their widespread use and to represent broad ranges in performance levels for key traits affecting efficiency of meat production. More comprehensive information on breeds and traits is provided in the Sheep Production Handbook. Ideally, the relative performance of breeds should be determined from objective, unbiased results of experiments done under relevant environments at state and federal research institutions. In practice, comparative information is limited and decisions about breed usage are often based on tradition and empirical evidence.

One can consider a breed as a package of genetic effects that influence many traits affecting efficiency of meat production. Often breeds have similar levels of performance for certain traits but differ for others, whereas some breeds may differ for most traits. The Finnsheep package is very different from Rambouillet (Table 1). When a producer selects a given breed to use, the total package of genetic effects on all traits is chosen collectively. One occasionally hears that breeds were combined to create a crossbred sheep that has only the desirable characteristics of each breed, avoiding the less attractive characteristics. This notion is not valid. One can't select and use only the specific favorable genetic effects of each breed, such as extended breeding season of Dorset, lambing rate of Finnsheep, hardiness of Rambouillet, and growth of Suffolk. Because each breed has relative strengths and weaknesses across traits, no single breed excels for all relevant traits. Therein lies the basis for strategic use of breeds in structured crossbreeding systems.

Sheep breeds can be classified in many different ways, for example, fineness of wool is a common method. Because this manuscript addresses use of breeds for meat production, breeds will be classified based on roles in crossbreeding systems, that is, as general purpose breeds, specialized dam breeds, and specialized sire breeds. Key traits used for classification purposes include adaptability, longevity, seasonality, age at puberty, lambing rate, mothering ability, lamb survival, leanness, and mature weight. There is disagreement on classification of some breeds, partly because comprehensive comparative results are limited, and the following assignment to a particular class should be considered as a useful guideline, not a definitive statement.

General purpose breeds tend to have acceptable, average levels of performance for most key traits, with extreme performance limited to very few, if any, traits. Examples of general purpose breeds include Cheviot, Columbia, Coopworth, Corriedale, Dorset, Montadale, and Texel. These breeds are occasionally used as specialized dam or sire breeds depending on the production-marketing situation. In fact, Dorsets are used in all three roles, but most commonly as a general purpose breed.

In contrast to general purpose breeds, specialized dam breeds and specialized sire breeds have clear strengths and weaknesses in key traits. Such breeds fit into dam or sire roles based largely on levels of performance for fitness, reproductive, and growth traits and are best used to complement other breeds.

Specialized dam breeds are used predominantly in terminal crossbreeding systems as the breeding flock to produce market lambs. This group of breeds therefore emphasizes fitness and reproductive traits and tends to be less extreme for carcass traits and mature weight. Breeds considered as specialized dam breeds include Merino, Polypay, Rambouillet, and Targhee. Adaptability, longevity, mothering ability, and average mature weight are common characteristics of these four specialized dam breeds that contribute greatly to commercial flocks in the U.S. In addition, Finnsheep and Romanov are used exclusively as specialized dam breeds primarily due to young age at puberty and very high lambing rates (about 3.0 and 3.7 lambs per ewe lambing for mature Finnsheep and Romanov ewes, respectively).

Rams of specialized sire breeds are mated to purebred or crossbred ewes of specialized dam breeds to produce market lambs in terminal crossbreeding systems. Specialized sire breeds should excel for fertility and longevity of rams and survival of crossbred lambs. In addition, sire breeds should produce crossbred lambs that have desirable carcasses and growth rates that are optimal for specific production-marketing situations. For example, Southdown are early maturing and capable of siring lambs of acceptable finish at a light weight on grass. Hampshire, Oxford, Shropshire, Southdown, and Suffolk rams are commonly used as terminal sires.

Heterosis Effects

Effects of heterosis greatly impact productivity of crossbred sheep. Each breed represents a specific package of genetic effects resulting in characteristics that distinguish one breed from another. Sheep with two copies of the same form of a particular gene are said to be homozygous for that gene, whereas sheep with two different forms of the gene are heterozygous. During evolution and development, each breed becomes homozygous for some genes and heterozygous for other genes, creating a unique set of genetic information. For each breed, the average degree of heterozygosity considering all genes (sheep may have roughly 30,000 genes) is a reflection of the genetic history of that breed. When breeds are crossed, new combinations of gene forms are created in crossbred sheep. Therefore, crossbred sheep have increased heterozygosity relative to breeds that produced the crossbred. The increase in heterozygosity is the basis for heterosis or hybrid vigor. Heterosis is defined as the average performance of crossbred sheep relative to the average performance of pure breeds that produced the cross.

Effects of heterosis can be realized through crossbred lambs, ewes, and rams. Lamb heterosis represents the performance of crossbred lambs raised by purebred ewes relative to purebred lambs raised by purebred ewes. An example of lamb heterosis for weaning weight is given in Table 2 to illustrate the concept. The average weaning weight of breed A lambs is 53 pounds and of breed B lambs is 63 pounds. Therefore, the weaning weight of purebred lambs of both breeds averages 58 pounds. The average weaning weight of crossbred lambs by these two breeds is 61 pounds. The effect of heterosis, due to increased heterozygosity, is to increase weaning weight by 3 pounds or 5.2% relative to the average of pure breeds. In this example, the average weaning weight of crossbred lambs (61 pounds) does not exceed the average weaning weight of breed B (63 pounds), the best pure breed. Crosses between other breeds may produce crossbred lambs that are heavier than the best pure breed.

Effects of ewe heterosis represent the performance of crossbred ewes producing crossbred lambs relative to purebred ewes producing crossbred lambs; for example, Rambouillet-Dorset crossbred ewes mated to Hampshire rams compared to Rambouillet and Dorset purebred ewes mated to Hampshire rams. An example for lambing rate is presented in Table 3. The lambing rates of purebred ewes of breeds A and B are 1.70 and 1.90, respectively, giving an average of 1.80 lambs for the two pure breeds. The average lambing rate of crossbred ewes is 1.86 lambs, indicating that the effect of ewe heterosis is 0.06 lambs or 3.3%. The lambing rate of crossbred ewes is greater than the average lambing rate of purebred ewes due to increased heterozygosity of crossbred ewes.

As illustrated in Tables 2 and 3, experiments can be designed to estimate effects of lamb and ewe heterosis on key traits. Such estimates are required to guide optimal use of breed diversity in crossbreeding systems. Differences between pure breeds in levels of performance relative to lamb and ewe heterosis effects determine efficiencies of various crossbreeding systems. Because such information is essential, scientists throughout the world have directed many experiments to estimate effects of heterosis. Results of numerous experiments were summarized by Nitter (1978) to provide consensus estimates of lamb and ewe heterosis effects on numerous traits (Table 4).

Favorable effects of lamb heterosis, particularly on preweaning survival and growth traits, were reported. There was little, if any, evidence that lamb heterosis affected carcass traits. Crossbred ewes had greater conception rates and their progeny grew more rapidly than the average of pure breeds. Effects of lamb heterosis differ among traits, as do effects of ewe heterosis. Furthermore, effects of lamb and ewe heterosis on a specific trait may differ considerably. For example, the heterosis effect on preweaning survival is greater for crossbred lambs (9.8%) than crossbred ewes (2.7%). Heterosis effects on individual traits accumulate so that the combined effect on an overall measure of productivity is greatly enhanced. Crossbred lambs increase litter weaning weight per ewe exposed by 17.8% relative to the average of pure breeds, while the corresponding value for crossbred ewes is 18.0%. In summary, favorable effects of lamb and ewe heterosis greatly increase overall productivity of crossbred sheep beyond the average of pure breeds.

Crossbred rams may also benefit from increased heterozygosity relative to purebred rams, but less is known about effects of ram heterosis than effects of lamb and ewe heterosis. It is likely that ram heterosis influences fitness traits such as libido, conception rate, hardiness, and longevity. Increased fertility of crossbred rams used in spring breeding has been reported, that is, ewes exposed to crossbred rams had greater conception rates than ewes exposed to purebred rams. The usefulness and value of crossbred rams is not fully recognized by the sheep industry.

Complementarity

Complementarity greatly improves efficiency of meat production by mating ewes of specialized dam breeds to rams of specialized sire breeds. The basis of complementarity is that ewes and rams do not equally influence the performance of offspring because lambs are produced, reared, and nurtured by ewes. Breed diversity is the resource that allows producers to benefit from complementarity. As discussed, many breeds have strengths and weaknesses for key traits that result in different merit whether used in dam or sire crossbreeding roles. Specialized dam breeds excel in fitness and reproductive traits, and have moderate feed requirements (maintenance costs) because of light-to-average mature weight. In contrast, specialized sire breeds are superior for growth and carcass traits. By separating dam and sire roles, complementarity allows favorable traits of breeds to be realized while minimizing or completely avoiding less desirable traits in production of market lambs.

Mating Polypay ewes to Suffolk rams is an example of matching complementary strengths of breeds to optimize efficiency of a production system. This cross takes advantage of the high reproductive capacity and moderate maintenance costs of Polypay ewes while producing Suffolk-sired lambs to meet market requirements. The efficiency of this cross would be much greater than the reciprocal mating of Suffolk ewes to Polypay rams. The latter cross would produce genetically equivalent market lambs (half Suffolk and half Polypay), but fewer lambs would be sold and production costs greatly increased due to higher feed requirements of heavy Suffolk ewes compared to Polypay ewes. Therefore, one way to understand the concept of complementarity is to consider the relative production costs and productivity of reciprocal matings between two breeds (Polypay ewes with Suffolk rams compared to Suffolk ewes with Polypay rams). Furthermore, the systematic efficiency of the complementary cross (Polypay ewes and Suffolk rams) would be significantly greater than straightbred systems using Polypay or Suffolk as pure breeds. Producers of market lambs should use terminal crossbreeding systems to benefit from complementary effects of specialized dam and sire breeds.

Crossbreeding Systems

Crossbreeding is a traditional practice that is widely used as a rapid and cost-effective method to improve efficiency of meat production by mating ewes and rams of two or more pure breeds. All crossbreeding systems are based on breed diversity and, therefore, heterosis influences performance. Some crossbreeding systems also benefit from complementarity. The practical objective of crossbreeding is to improve efficiency relative to the pure breed that performs best in a given production environment and marketing situation.

General-purpose crossbreeding systems. Four genetic types of breeding ewes are used in structured crossbreeding systems: purebred, first cross, rotation, and composite. Mating systems that produce these types of breeding ewes are discussed in the context of general-purpose crossbreeding systems (Table 5). The purebred mating system is included because productivity of purebred sheep serves as a standard for evaluation of all crossbreeding systems.

A purebred flock is managed as a single flock because all ewes and rams are of the same pure breed. A purebred mating system therefore does not benefit from ewe or lamb heterosis effects. Purebred flocks produce replacements and surplus lambs are marketed. There are situations, generally associated with adaptability of a local breed to extreme environmental conditions or a very specialized market, where a purebred mating system is superior to crossbreeding. Such situations are uncommon and use of crossbreeding systems is strongly recommended to improve efficiency of meat production.

Because only a portion of any ewe flock is required to produce replacement ewes, remaining ewes can be mated to rams of a different breed to produce first-cross lambs. This first-cross system requires ewes of only one breed (A) and rams of two breeds (A and B). As all breeding ewes are purebred, ewe heterosis does not exist. The system uses two flocks and is more complex than a purebred system, but has the advantage of 100% lamb heterosis in first-cross lambs.

In a two-breed rotational system, rams of breeds A and B are used in alternating generations. Ewes sired by breed A rams are mated to breed B rams, while ewes by breed B rams are always mated to breed A rams. As all ewes and lambs are crossbred, the system exploits effects of lamb and ewe heterosis. After several generations of rotational crossing, the system will average 67% of possible lamb and ewe heterosis effects. Inclusion of a third breed into the rotational system increases use of lamb and ewe heterosis to 86%. Rotational systems use lamb and ewe heterosis very effectively which is a significant advantage. However, the rotational approach that provides for heterosis also has drawbacks. The two-breed system requires separation of ewes into two flocks during breeding, one mated to breed A rams and the other to breed B rams. Three flocks are necessary for the three-breed system. Sheep produced in rotational systems also vary considerably in breed composition. In the two-breed rotation, one flock will be 67% A and 33% B and the other 33% A and 67% B. Breed composition of flocks in the three-breed rotation will be 57% A, 29% B, and 14% C for the first flock, 57% B, 29% C, and 14% A for the second flock, and 57% C, 29% A, and 14% B for the third flock. Unless breeds have similar levels of performance, especially for lambing rate and mature weight, variation in breed composition can create different managerial requirements among flocks. For this reason, general-purpose breeds are typically used in rotational crossbreeding systems.

Composite breeds provide a simple method to address problems associated with rotational crossbreeding systems. The base generation of a composite breed is formed by making crosses among two or more foundation breeds. Subsequent generations descend from crossbred parents and selection is often practiced to establish distinct characteristics of the new breed. Although the composite breed is managed thereafter as a single flock, it benefits from lamb and ewe heterosis effects and also any heterosis effects that may exist for ram fertility traits. The percentage of lamb and ewe heterosis maintained in the composite breed increases as more breeds contribute to the crossbred foundation (Table 5). One must be careful to include only breeds that optimize the combined effects of breed composition and heterosis, as inclusion of a marginal breed to gain additional heterosis is counterproductive. In contrast to rotational crossbreeding, breed composition is equivalent among all sheep within a composite breed. Therefore, foundation breeds with diverse performance can be used without creating complexity due to different managerial requirements. Thus, throughout the world, prolific breeds like Finnsheep and Romanov contribute to many composites involving well-adapted, general-purpose breeds. Composite breeds can be designed and developed to serve as general purpose breeds, specialized ewe breeds, and specialized sire breeds. Although rotational systems achieve higher levels of heterosis than composites for a given number of breeds (Table 5), composites are managed as a single flock, maintain very beneficial levels of heterosis, and have stable breed composition. For these practical reasons, many popular breeds in the U.S. originated in this manner. Columbia, Corriedale, Montadale, Polypay, and Targhee are examples of composite breeds.

Long-term expression of heterosis effects in a composite breed depends on maintaining heterozygosity. After the base generation of crossbred sheep is produced, a composite is managed as a closed breed and heterozygosity decreases due to eventual mating of related ewes and rams (inbreeding). To maintain levels of heterosis, a composite breed should use at least 25 rams each generation. Assuming 20 ewes per ram, a flock of at least 500 ewes is suggested. Therefore, creation of a new composite breed is a major undertaking, requiring substantial resources of a single producer or group of producers sharing a common vision. An excellent example of development of a composite breed by private industry is included in this issue of the Sheep and Goat Research Journal (Use of Finnsheep in a Western Commercial Sheep Operation).

Terminal crossbreeding systems.
Mating types, products, and levels of lamb and ewe heterosis are presented in Table 6 for each type of terminal crossbreeding system. Rams of specialized sire breeds are mated to purebred, first cross, rotational, or composite ewes to produce terminally-sired market lambs that express 100% of lamb heterosis. While general-purpose crossbreeding systems exploit genetic effects of breed diversity and heterosis, terminal crossbreeding systems also take advantage of complementarity. Because specialized sire breeds focus on growth and carcass traits, the genetic merit of terminally-sired lambs is different than other replacement and market lambs produced within a system. Terminal crossbreeding systems are more complex to manage than general-purpose crossbreeding systems because an additional flock (ewes mated to the specialized sire breed) is present, but terminal systems have powerful genetic advantages of greater use of lamb heterosis and complementarity.

Terminal crossbreeding systems are generally feasible due to the reproductive rate of sheep. Depending on circumstances, only 15 to 40% of ewes in the breeding flock are required to produce replacements. Remaining ewes can be bred to rams of specialized sire breeds. A key determinant of the relative efficiency of self-contained crossbreeding systems is the percentage of ewes needed to produce replacements. As reproductive rate increases due to use of more prolific breeds and heterosis effects, a greater percentage of ewes can be mated to terminal sires and the system becomes more efficient.

Relative production of crossbreeding systems.
Information provided in Tables 5 and 6 reveals that crossbreeding systems vary considerably in complexity of management, products, and use of lamb heterosis, ewe heterosis, and complementarity. To decide among crossbreeding systems, it is necessary to account for impact of these various genetic effects. It is not possible to directly compare all crossbreeding systems through experimentation with sheep due to limited resources available for research. However, the productivity of crossbreeding systems can be predicted by using reliable estimates of heterosis effects (Table 4), reasonable assumptions about production levels, and crossbreeding theory. A number of assumptions are necessary to predict the productivity of each crossbreeding system.

1. The ewe replacement rate is 20% per year.
2. All replacement ewes are produced within each system, rams are purchased as needed.
3. Averaged across breeds, purebred ewes wean 1.4 purebred lambs per ewe exposed.
4. Effects of lamb heterosis on lambs weaned per ewe exposed is 15% (Table 4).
5. Effects of ewe heterosis on lambs weaned per ewe exposed is 15% (Table 4).
6. Averaged across breeds, purebred lambs weigh 50 pounds at weaning.
7. Effects of lamb heterosis on weaning weight is 5% (Table 4).
8. Effects of ewe heterosis on weaning weight is 6% (Table 4).
9. Use of a specialized sire breed increases weaning weight of lambs by 5%.

The above assumptions were used to predict the total weaning weight produced by each crossbreeding system. The predicted value of purebred flocks was set at 100 and values for other systems expressed relative to purebred flocks. Results are given in Table 7.

Although effects of lamb heterosis and ewe heterosis on individual traits may seem small, effects accumulate to have significant impact on a measure of overall productivity, such as litter weaning weight per ewe exposed. Furthermore, combined effects of lamb heterosis, ewe heterosis, and complementarity can increase production by 40 to 50% relative to the average of purebred flocks of different breeds.

Lamb heterosis in the first-cross, general-purpose system increases production 17% relative to purebred flocks. Rotational and composite general-purpose systems create both lamb and ewe heterozygosity, thereby being more productive than purebred and first-cross general-purpose systems. General-purpose rotational systems achieve greater levels of heterosis than composite systems for a given number of breeds and therefore are more productive. The two-breed rotation has a value of 134 compared to 125 for the two-breed composite. Corresponding values are 143 for the three-breed rotation compared to 131 for the three-breed composite. A four-breed composite is intermediate (138) to two- and three-breed rotational systems (134 and 143, respectively). Similar relationships between rotational and composite programs are predicted in terminal crossbreeding systems. As discussed, composites are less complex to manage than rotational systems and also have stable breed composition.

Comparison between general-purpose and terminal crossbreeding systems within rotational or composite programs, demonstrates effects of increased lamb heterosis and use of complementarity. For example, productivity of the two-breed rotational, general-purpose system is increased from 134 to 146 in the two-breed rotational, terminal system. The increase is partly due to weaning more lambs, but primarily to heavier weaning weight of terminally-sired lambs. Advantages of terminal systems are greater in composite than rotational programs because rotational general-purpose systems achieve greater levels of lamb heterosis than composite general-purpose systems. That is, lamb heterosis increases from 67 to 100% in a two-breed rotation by use of terminal sires, but from 50 to 100% in a two-breed composite. Productivity of the purebred general-purpose system is increased from 100 to 122 in the purebred terminal system.

The first-cross terminal system is also referred to as a three-breed cross or a static terminal-sire system. This is the only system that uses crossbred ewes expressing 100% of ewe heterosis effects (Table 6). The productivity (150) is high and similar to two-breed (146) and three-breed (153) rotational terminal systems and three-breed (145) and four-breed (150) composite terminal systems. The managerial complexity of the first-cross terminal system is less than the three-breed rotational terminal system, equal to the two-breed rotational terminal systems, but greater than composite terminal systems.

In summary, crossbreeding systems vary in degree of complexity and use of lamb heterosis, ewe heterosis, and complementarity. Crossbreeding exploits these genetic effects and significantly increases productivity relative to purebred flocks. Efficiency of meat production is maximized in terminal crossbreeding systems by use of specialized sire breeds to complement characteristics of crossbred ewes.

Choice of Breeds

Tables 5, 6, and 7 provide information to evaluate advantages and disadvantages of numerous crossbreeding systems. Obviously, breeds used within any specific crossbreeding system greatly influence efficiency of meat production. Selection of breeds should be made only after careful forethought. Initially, production resources and limitations should be identified. Understanding resources such as labor, facilities, land, feedstuffs, managerial skill, etc., helps to define an appropriate production system. Sheep characteristics that most impact efficiency in the production system should be determined and reasonable target levels of performance established for each characteristic. This process provides a blueprint to describe ideal rams, ewes, and lambs for the specific production system and marketing goal. The blueprint guides selection of suitable breeds based on knowledge of breed characteristics in the relevant environment and determination of proper breed composition of crossbred sheep. At this point, crossbreeding systems can be evaluated to determine the system that most efficiently produces the ideal sheep, especially crossbred replacement ewes.

An important factor affecting efficiency of meat production is lambing rate. Because breeds of sheep vary greatly for lambing rate, it is critical to design the breed composition of crossbred ewes to meet target levels. Preliminary results from research at the U.S. Meat Animal Research Center illustrate the effect of breed composition on lambing rate. Dorset and Finnsheep rams were mated to Rambouillet ewes to produce contemporary first-cross ewes for comparison. Both types of crossbred ewes were terminally-sire mated to Suffolk rams. The average lambing rate of mature Dorset-Rambouillet ewes was 1.70 lambs, whereas, mature Finnsheep-Rambouillet ewes produced an average of 2.46 lambs. It is essential to select breeds and determine breed composition that achieve the targeted lambing rate of the production system.

Use of Crossbred Rams

Crossbred rams may benefit from increased fertility associated with ram heterosis, particularly in spring breeding, but their primary value is to optimize breed composition of crossbred ewes. Two-breed crossbred rams (AB) mated to ewes of a third breed (C) produce lambs that are 25% A, 25% B, and 50% C. This approach requires a producer to have a flock of breed C ewes and to buy crossbred AB rams. A more complex method to produce the same three-breed cross uses only purebred rams. A producer would mate breed A ewes to breed B rams to produce AB replacement ewes that are in turn mated to breed C rams. Use of crossbred rams simplifies production of sheep where less than 50% contribution of a breed is optimal.

The most common use of crossbred rams is to produce replacement ewes that are either 25% Finnsheep or Romanov. For example, a target lambing rate of 2.10 lambs might be well-suited for a given production system. Finnsheep-Rambouillet crossbred rams mated to Targhee ewes would produce replacement ewes that average about 2.10 for lambing rate. The value of Finnsheep and Romanov breeds is greatly enhanced by the productivity of quarter-blood ewes in production systems that support that level of prolificacy. There is an opportunity for seedstock producers to develop and market specific types of crossbred rams more effectively.

Production of Replacement Ewes

It is generally possible to produce crossbred ewes of similar or equivalent breed composition by use of first-cross, rotation, or composite systems. Suppose a producer decides that a crossbred ewe of 50% Cheviot and 50% Columbia is appropriate. Crosses between the two pure breeds would produce a first-cross replacement ewe. A two-breed rotation of Cheviot and Columbia rams would result in two flocks, one flock 67% Cheviot and 33% Columbia and the other flock 33% Cheviot and 67% Columbia. As Cheviot and Columbia are both general-purpose breeds, performance and therefore managerial requirements of the two flocks would be fairly similar. Finally, a composite breed could be developed that is 50% Cheviot and 50% Columbia; in fact, the Montadale is such a breed. First-cross, rotation, and composite ewes would express 100, 67, and 50% ewe heterosis, respectively, with performance related to the degree of heterosis as discussed (Table 7).

An intensive production system might support a crossbred ewe with very high lambing rate. Romanov ewes could be mated to Dorset-Rambouillet crossbred rams to produce first-cross replacement ewes that are 50% Romanov, 25% Dorset, and 25% Rambouillet. Another approach to produce ewes of similar breed composition is to use crossbred rams in a rotation system. Romanov-Dorset and Romanov-Rambouillet crossbred rams could be used in alternating generations. Resulting replacement ewes would always be 50% Romanov and either 33% Dorset and 17% Rambouillet or 17% Dorset and 33% Rambouillet. A three-breed composite that is 50% Romanov, 25% Dorset, and 25% Rambouillet could also be developed. Breed composition of first-cross, rotation, and composite ewes would be very similar and corresponding levels of ewe heterosis would be 100, 67, and 62.5%, respectively. Differences among these systems in use of heterosis would affect performance (Table 7).

These examples illustrate production of two-breed and three-breed replacement ewes in first-cross, rotational, and composite programs. In practice, the best system of producing replacement ewes is often relatively simple. If the system is too complex for the producer to manage, an efficient type of crossbred ewe may be abandoned. The problem may lie in the system of production, not the breed composition. Producers should carefully consider the long-term practical ramifications of different crossbreeding systems before developing a specific plan.

Changing breed composition of crossbred ewes in a commercial flock requires several years if 10 to 20% of ewes are replaced annually. Because younger ewes are less productive than older ewes, the impact on overall flock productivity is realized even less gradually. This situation emphasizes the importance of determining appropriate breed composition in a timely manner, as it is inefficient to repeatedly pursue a changing goal. Once the need to alter breed composition is apparent, one should immediately develop breeding plans to implement change.

Seedstock and Commercial Production

Discussion of the relative merit of crossbreeding systems assumed systems are self-contained, that is, all replacement ewes are produced within the system and rams are purchased as necessary. An individual producer can operate a self-contained system or specialize in one or more distinct segments of a system. A first-cross terminal system serves as an example (Figure 1). Dorset ewes and rams are mated to produce purebred replacements, Dorset ewes are mated to Rambouillet-Finnsheep crossbred rams to produce first-cross replacement ewes, and first-cross ewes are mated to Suffolk rams to produce terminally-sired market lambs. This system consists of purebred seedstock, crossbred seedstock, and commercial segments.

In a self-contained system, all three segments would be used by a producer. Or, a producer could focus on seedstock production, selling purebred and/or crossbred seedstock. Many commercial producers like to raise their own crossbred replacement ewes and, therefore, buy purebred seedstock to produce replacements for their commercial flock. Other producers prefer to specialize in commercial production and buy crossbred replacement ewes for their commercial flocks.

Final Recommendations

Advantages and disadvantages of many crossbreeding systems have been presented. From an industry-wide perspective, which system provides the greatest opportunities to address challenges facing the sheep industry?

Use of first-cross terminal systems is recommended. Widespread implementation would require greater communication, cooperation, and integration to wisely use breed diversity and improve the genetic structure of the sheep industry. It would encourage producers and breed associations to understand roles of breeds in a crossbreeding context and, therefore, to practice selection for traits that are relevant for crossbred seedstock and market lambs. Purebred and crossbred Finnsheep and Romanov ewes can efficiently produce prolific first-cross ewes. Additionally, purebred and crossbred Finnsheep and Romanov rams can be mated to ewes of well-adapted breeds to produce first-cross replacement ewes. Adjustments to breed composition of first-cross ewes can be made quicky by simply changing sire breed of the first cross. First-cross ewes would express 100% of ewe heterosis that greatly impacts lifetime productivity.

If the sheep industry is not willing to integrate use of breed diversity and therefore is unable to broadly implement first-cross terminal systems, then composite terminal systems are an excellent alternative. Composite breeds can be designed and developed as specialized ewe breeds to achieve targeted levels of performance appropriate for environmental conditions and to complement characteristics of specialized sire breeds in terminal crossbreeding systems. The primary advantage of composite terminal systems is simplicity.

Suggested Additional Reading

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Table 1. Relative levels of performance of breeds for several traits.

Breed	Length of season	Age at puberty	Lambing rate	Mature weight	Hardiness
Dorset	long	average	average	average	average
Finnsheep	average	young	very high	light	average
Rambouillet	long	old	low	average	high
Suffolk	average	average	high	heavy	low

Table 2. Lamb heterosis for weaning weight (pounds).

	Purebred lambs		Crossbred lambs	
Item	A	B	BA	AB
Weight	53	63	62	60
Average	58		61	
Heterosis	3 pounds (61 - 58)			
	5.2% (3/58)			

Table 3. Ewe heterosis for lambing rate.

	Purebred ewes		Crossbred ewes	
Item	A	B	AB	BA
Lambing rate	1.70	1.90	1.84	1.88
Average	1.80		1.86	
Heterosis	0.06 lambs (1.86 - 1.80)			
	3.3% (0.06/1.80)			

Table 4. Estimates of lamb and ewe heterosis effects[a].

Trait	Lamb	Ewe
Birth weight	3.2	5.1
Weaning weight	5.0	6.3
Preweaning daily gain	5.3	-
Postweaning daily gain	6.6	-
Yearling weight	5.2	5.0
Conception rate	2.6	8.7
Lambing rate	2.8	3.2
Preweaning survival	9.8	2.7
Lambs born per ewe exposed	5.3	11.5
Lambs weaned per ewe exposed	15.2	14.7
Litter weaning weight per ewe exposed	17.8	18.0

[a]Effects expressed as a percentage of the purebred average (Nitter, G., 1978).

Table 5. Mating types, products, and heterosis realized in general purpose crossbreeding systems.

			Heterosis[a]	
Genetic type of lamb	Mating type[b]	Products[c]	Lamb	Ewe
Purebred	A x A	Replacement, market	0	0
First cross	A x A	Replacement, market	0	0
	A x B	Market	100	0
Rotation				
Two-breed	AB_R	Replacement, market	67	67
	BA_R	Replacement, market	67	67
Three-breed	ABC_R	Replacement, market	86	86
	BCA_R	Replacement, market	86	86
	CAB_R	Replacement, market	86	86
Composite				
Two-breed	AB_C	Replacement, market	50	50
Three-breed	ABC_C	Replacement, market	62	62
Four-breed	$ABCD_C$	Replacement, market	75	75

[a]Percentages of maximum possible lamb and ewe heterosis effects.
[b]A, B, C, and D represent breeds, subscripts R and C indicate rotation and composite, respectively.
[c]Products of matings are replacement ewes and market lambs.

Table 6. Mating types, products, and heterosis realized in terminal crossbreeding systems.

			Heterosis[a]	
Genetic type of ewe[b]	Mating type[c]	Products[d]	Lamb	Ewe
Purebred	A x A	Replacement, market	0	0
	T x A	Terminal market	100	0
First cross	A x A	Replacement, market	0	0
	A x B	Replacement, market	100	0
	T x AB	Terminal market	100	100
Rotation				
Two-breed	AB_R	Replacement, market	67	67
	BA_R	Replacement, market	67	67
	T x AB_R, BA_R	Terminal market	100	67
Three-breed	ABC_R	Replacement, market	86	86
	BCA_R	Replacement, market	86	86
	CAB_R	Replacement, market	86	86
	T x ABC_R, BCA_R, CAB_R	Terminal market	100	86
Composite				
Two-breed	AB_C	Replacement, market	50	50
	T x AB_C	Terminal market	100	50
Three-breed	ABC_C	Replacement, market	62	62
	T x ABC_C	Terminal market	100	62
Four-breed	$ABCD_C$	Replacement, market	75	75
	T x $ABCD_C$	Terminal market	100	75

[a]Percentages of maximum possible lamb and ewe heterosis effects.
[b]Genetic type of ewes mated to specialized sire breed.
[c]A, B, C, and D represent dam breeds, T represents a specialized sire breed, and subscripts R and C indicate rotation and composite, respectively.
[d]Products of matings are replacement ewes, market lambs, and terminally-sired market lambs.

Table 7. Relative production of different crossbreeding systems[a].

Genetic type	General purpose[b]	Terminal[c]
Purebred	100	122
First cross	117	150
Rotation		
Two-breed	134	146
Three-breed	143	153
Composite		
Two-breed	125	141
Three-breed	131	145
Four-breed	138	150

[a]Production relative to total pounds weaned from a purebred flock.
[b]See Table 5 for mating types, products, and heterosis associated with each genetic type.
[c]See Table 6 for mating types, products, and heterosis associated with each genetic type.

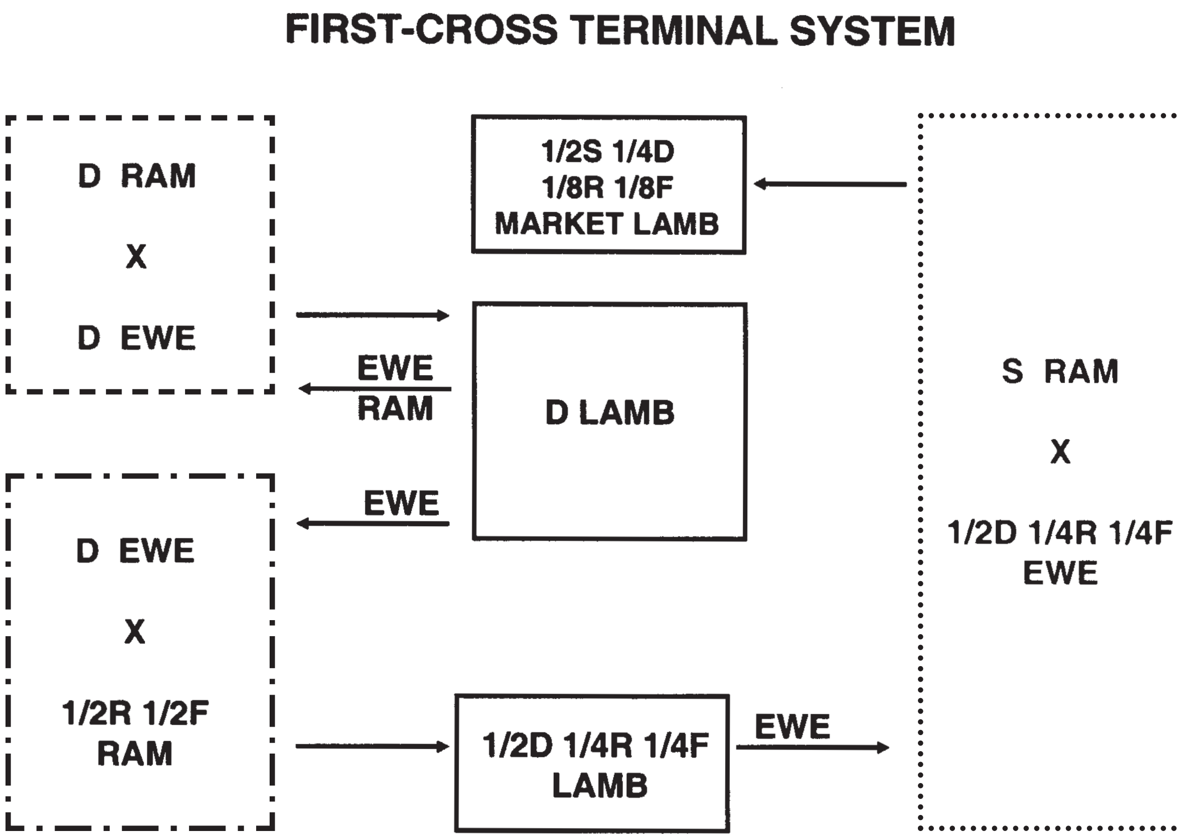

Figure 1. A first-cross terminal system using Dorset (D), Rambouillet (R), Finnsheep (F), and Suffolk (S). Matings to produce purebred replacements ( ), first-cross replacement ewes ( ), and terminally-sired market lambs ( ) are indicated.