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ABSTRACT: Objective genetic improvement in specialized meat breeds of sheep in Britain is based largely on the performance recording and genetic evaluation service provided by Signet and the Meat and Livestock Commission. This includes the use of ultrasonic scanning and a selection index to identify animals with high genetic merit for lean growth. More than 20 sire referencing schemes (SRS) have been established in Britain during the last 12 yr. About half of the performance-recorded flocks in Britain now belong to SRS. Sire referencing schemes create genetic links between flocks and years through the shared use of elite rams (reference sires), often via AI. Multitrait animal model BLUP is then used to provide across-flock genetic evaluations. These in turn allow increased selection intensities and increased response to selection. High responses to index selection for lean growth (about 1.75% per annum in the specialized meat breeds) and other measures of performance are being achieved.

Key Words: Carcass Composition, Genetic Improvement, Sheep

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Introduction

Lamb carcasses are often fatter than desired. Management and nutritional measures may influence carcass fatness, but genetic improvements offer a permanent, and usually cost-effective, means of matching carcass quality with consumer demand (Simm, 1992, 1994). Although using several measures in combination may be effective, genetic improvement is often one of the most practical routes for improving carcass composition in extensive systems.

National or regional performance-recording schemes are now available to sheep breeders in many countries. In Britain, performance-recording schemes were operated initially by the Meat and Livestock Commission (**MLC**), and more recently by Signet—a joint MLC/Scottish Agricultural College (**SAC**) company. As in other countries, genetic improvement of sheep in Britain is based on on-farm performance recording.

Sheep improvement programs are often hampered by relatively low use of performance recording, relatively small size of recorded flocks, and frequent lack of across-flock genetic evaluations. In several countries, cooperative breeding schemes have been formed to surmount some of these problems. Of the best known are group breeding schemes, originally widely used in New Zealand and Australia (James, 1977; Parker and Rae, 1982). Another type of cooperative breeding scheme, sire referencing, has gained popularity in Britain. Sire referencing schemes (**SRS**) have been formed for over 20 sheep breeds in Britain since the late 1980s, including all of the major specialized meat breeds. About half of performance-recorded flocks in Britain, and about two thirds of performance-recorded sheep, now belong to these schemes. Most of the schemes are achieving substantial rates of genetic progress. This article describes the role of SRS in selecting for improved carcass composition, their design and operation, the results achieved by some schemes, the benefits for participants and their clients, and possible future developments.

The Role of Sire Referencing Schemes

Over the last 20 yr or so, BLUP has become the preferred method of predicting breeding values for farm

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animals (Henderson, 1984). The BLUP approach disentangles genetics from management and feeding in the best possible way, and so predicts breeding values more accurately. Related animals in different herds or flocks (e.g., the progeny of the same sires) provide genetic links between them. When these links are sufficiently strong and BLUP is used, the EBV of animals can be compared fairly across herds or flocks. This has a positive effect on the number of animals that can be compared fairly, and thus on the selection intensity and genetic gain that can be achieved. These benefits are augmented when reproductive techniques such as AI are used to increase the use of elite parents. Because related animals are recorded in successive years, it is also possible to compare BLUP EBV across years, to estimate genetic trends in evaluated traits and associated indexes. This is valuable for breeders to monitor progress in their improvement programs, and for commercial producers to identify individual stud flocks or breeding schemes making most progress.

BLUP has begun to be used in genetic evaluation of sheep. However, the low use of AI in sheep has often resulted in weak genetic links among flocks. Consequently, BLUP evaluations are often performed within flocks, which means that EBV produced can only be compared fairly among animals in the same flock. Sire referencing schemes are cooperative breeding schemes creating genetic links among flocks, usually through the use of AI sires. Sire referencing schemes have been in operation in sheep or beef cattle in several countries for about 20 yr now (e.g., Willham, 1979; Ménissier et al., 1982; Morris and Baker, 1982). Interest in these schemes in Britain began in the late 1980s to enable across-flock genetic evaluations and so to accelerate rates of genetic improvement. Four key factors stimulated this interest: 1) national availability of relevant performance-recording services and selection criteria, especially the widespread use of ultrasonic scanning and the use of index selection for lean growth in performance-recorded terminal sire flocks; 2) improved success rates of laparoscopic AI in sheep using frozen-thawed semen, and access to specialist sheep AI services; 3) wider availability of computer software to perform BLUP evaluations and the lower relative cost of powerful computers to run this software; 4) research and interaction with breeders on the optimal design and operation of schemes.

Details of some of the SRS in specialized meat (terminal sire) breeds in Britain are shown in Table 1. Multitrait animal model BLUP evaluations have been used routinely in these schemes from the outset. Signet/MLC have also introduced within-flock BLUP evaluations for flocks not involved in SRS.

Breeding Objectives, Performance Recording and Genetic Evaluation

The U.K. sheep industry has a stratified structure. In the hills and mountains, ewes of hardy breeds, such as the Scottish Blackface, Welsh Mountain, and Swaledale, are usually bred to a ram of the same breed for four or five lamb crops. Ewes are then moved to lower ground, for crossing with a longwool or crossing breed such as the Bluefaced Leicester or Border Leicester. The F1 females resulting from these matings form the core of the commercial sheep industry in the uplands and lowlands. These F1 females are mated to rams of specialized meat breeds, or terminal sire breeds, such as the Suffolk, Texel and Charollais, to produce the slaughter generation of lambs. Meat production is the primary objective in each sector of the U.K. sheep industry, with all three breed types making important contributions to the genetic makeup of lambs slaughtered (39% terminal sire breed genes, 34% hill breed genes, 26% crossing breed genes; Maniatis and Pollot, 1998). However, breeding objectives vary among sectors, with growth and carcass traits being the most important traits in terminal sire breeds, while maternal characteristics are also important in the hill and crossing breeds.

Performance records collected by Signet include litter size at birth and weaning, live weights at a range of ages from weaning to breeding as measures of both the lamb's own merit for growth and its dam's milking and mothering ability, and ultrasonic measurements of fat and muscle depths in the loin region. Multitrait animal model BLUP EBV are produced for most of these individual traits, and these EBV are also used to calculate selection indexes relevant to each of the sectors of the industry.

In terminal sire breeds, a lean growth index is derived, which combines information on live weight, ultrasonic fat depth and ultrasonic muscle depth, all measured at about 20 wk of age (Simm and Dingwall, 1989). The breeding goal of this index comprises carcass lean weight and carcass fat weight, with relative economic values of +3 and −1, respectively. These relative economic values were chosen to achieve "desired gains" in the traits in the breeding goal, rather than being based on actual market returns. This approach was chosen because of the weak relationship between carcass price and fatness in Britain at the time the index was derived.

Optimal Design of Sire Referencing Schemes

The main goal of most SRS is to create a structure that accelerates the rate of genetic improvement, for an agreed objective, in members' flocks. To do this, genetic links are created across members' flocks by the use of AI rams on a portion of the ewes in each flock, or by sharing rams for natural service. Genetic links among flocks permit the use of across-flock BLUP methods to produce EBV for across-flock comparison. In a sense, SRS are a means to an end; they create the genetic links that would occur naturally if there was wider use of AI in purebred sheep flocks. However, if they are organized properly they can also result in faster rates

Table 1. Details of some sheep sire referencing schemes in meat breeds in Britain

Breed	Year scheme started (year of first lambing)	No. member flocks evaluated in 1999	No. lambs born in 1999	Reference sire use[a]
Suffolk	1990	66	10,148	AI
Charollais	1990	39	4,267	AI
Meatlinc	1991	4	1,001	AI/NS
Texel	1992	58	10,801	AI
Polled Dorset	1995	11	5,787	AI/NS

[a]AI = artificial insemination; NS = natural service.

of progress than would be achieved with the ad hoc use of AI.

Computer simulation has been used to study three factors in the design of SRS that affect rates of genetic response and inbreeding: the number of reference sires used (1, 2, or 3), the number of ewes per flock mated to reference sires (a total of 10, 15, or 30 ewes), and the selection intensity for reference sires in the scheme (highest ranking, or from the top sixth or top third available). Genetic progress increases with increasing intensity of selection and with increasing number of ewes per flock mated to reference sires (Lewis and Simm, 2000). However, this greater genetic gain can be achieved at acceptable levels of inbreeding because of the larger population size in SRS.

The SRS rely for their success on good genetic links between flocks. Recent research at SAC and the Roslin Institute in Edinburgh has produced a method of measuring the strength of genetic links (or "connectedness") between existing or potential new member flocks in SRS, in order to identify where reference sires need to be used more widely to allow reliable comparisons across all flocks (Lewis et al., 1999).

Practical Operation of Sire Referencing Schemes

The operation of SRS in Britain usually involves: 1) Selection of a panel of reference sires for use across members' flocks. To qualify as potential reference sires, in most schemes, animals must have high EBV or index scores and must be functionally sound. Qualifying animals are often brought to a central location where all members gather to view them and vote for their choice, based on their own preferred combination of EBV, index score, pedigree, conformation, and breed type. Depending on the scheme, semen may be purchased from the owner of the selected reference sire without transfer of ownership, or the scheme may purchase the ram, or a share in him. 2) Use of two or three reference sires from this panel, by AI or natural mating, on a proportion of the ewes in each member's flock. In schemes with a wide geographic spread of members, insemination with fresh semen is impractical, so laparoscopic AI with frozen-thawed semen is often used. In terminal sire breeds, a total of 30 ewes per flock is usually recommended for mating to reference sires, based on the simulation work described above. 3) Recording performance in appropriate traits via the Signet recording scheme outlined earlier. In terminal sire breeds, most emphasis is usually on growth and ultrasonic measurements, which are then used to calculate the lean index described earlier. In the hill and crossing breeds maternal performance is also important. 4) Evaluation of performance records using across-flock, multitrait animal model BLUP. This produces EBV that can be compared fairly across flocks and across years. 5) Use of these results to select the next generation of potential reference sires and to select sires and replacement females for the individual members' flocks.

The key participants in the operation of SRS are the individual breeder members, the agency responsible for performance recording and genetic evaluation, and the AI company. In some cases there is active involvement of the relevant breed society.

Even though SRS can undoubtedly help to accelerate genetic improvement, there are additional costs associated with membership, especially relating to the purchase of reference sires or semen and the use of AI. Also, members have less flexibility in mating decisions as a result of matings to reference sires. However, the level of cooperation and the financial and legal commitment required to make SRS work are less than in some other cooperative breeding schemes.

Evidence of Improvement

Estimated genetic trends in several of the SRS in meat breeds in Britain are shown in Figure 1. It is perhaps easiest to gauge the magnitude of the changes made by comparing them to those achieved in selection experiments. In most experiments, rates of genetic change in excess of 2% per annum have been achieved in fat depth or index score (Simm, 1994). These responses are close to the maximum expected values for the traits and flock sizes concerned. One of these experiments was carried out at SAC, in Suffolk sheep, where selection was on the index now used in SRS. Annual rates of change in (unscaled) index score of around 2% per annum were achieved. Annual responses in lean index score in SRS in most specialized meat breeds are only slightly less than this (i.e., rates of change of about 1.75% per annum in most schemes—though higher rates are being achieved in the Meatlinc breed). Because of the much larger size of the industry schemes,

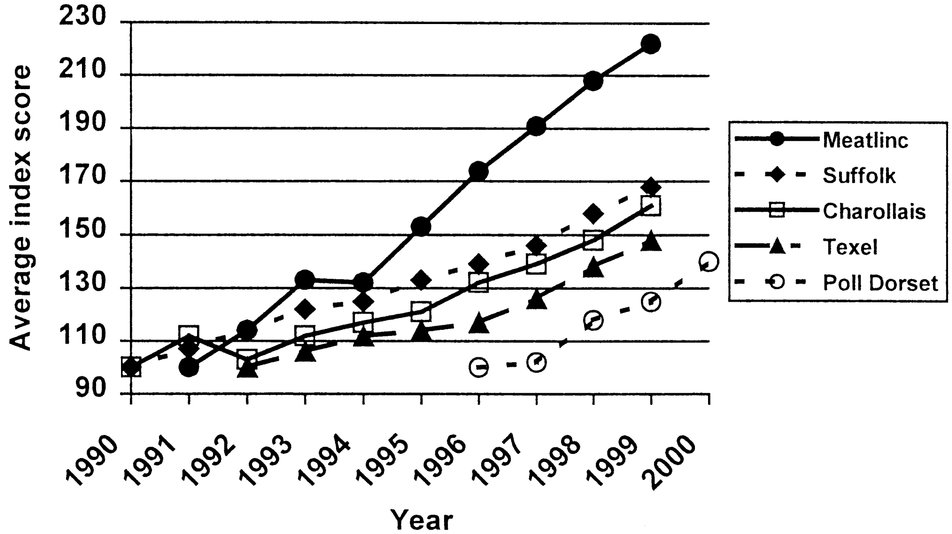

Figure 1. Genetic trends in lean growth index scores (SD of index = 40 points) in five sire referencing schemes in Britain. The graph shows the average index score of lambs born in the year concerned (mean in start year = 100).

they can achieve these similar responses in the index of objectively-measured traits, while taking account of visually assessed breed characteristics and conformation. Also, some breeders use the individual trait EBV to put additional selection emphasis on a component of the index.

In many industry flocks, and in several of the experiments mentioned, animals are tested under intensive feeding, whereas in the U.K., the majority of lambs are produced off grass. Two experiments have been conducted at SAC to test the effect of selection under intensive feeding on the response in an extensive regimen. The first of these experiments involved high- or low-index Suffolk rams, from the SAC selection experiment mentioned earlier, mated to Scottish Mule (Bluefaced Leicester × Scottish Blackface) ewes. Their lambs were reared at grass to produce carcasses at target weights of 16.5, 20.0, or 23.5 kg. Sample joint dissections on these carcasses showed that the progeny of high-index sires had about 1.0% more lean and about 3.5% less fat than the progeny of low-index sires (sires differed by 100 index points, or 2.5 standard deviations in index score; Lewis et al., 1996). A second experiment involved mating selection or control line Suffolk rams from the SAC experiment to Scottish Mule ewes, with lambs slaughtered at a target live weight of 42 kg (Simm and Murphy, 1996). Selection line progeny had significantly greater carcass saleable meat yield than control line progeny, both at an adjusted constant carcass weight (+0.10 kg) and an adjusted constant visually appraised subcutaneous-fat level (+0.25 kg; unpublished SAC result). On average, lamb carcasses from selection line sires achieved prices about $2.40 higher than those from control sires, and were slaughtered 11 d sooner; this earlier slaughter date would save about $0.96 in grazing costs. This financial advantage is worth up to $960 over the working life of a ram. In both these experiments, the progeny of high index sires had poorer visually appraised carcass conformation than the progeny of low index sires, at an adjusted constant carcass weight. However, this difference in conformation was largely explained by differences in carcass fatness at this fixed weight.

Possible Future Developments

Because SRS rely on the widespread use of a few elite rams, they have the ideal structure to exploit new technologies more cost-effectively than most individual breeders can. For example, techniques such as computer tomography (**CT**) have the potential to dramatically increase rates of genetic improvement in lean-meat production in sheep (e.g., allowing up to 50% faster progress in lean growth than that possible from selection on ultrasonic measurements; Simm and Dingwall, 1989). The use of CT also allows selection for additional carcass attributes (e.g., selection for increased muscularity and altered fat or muscle distribution). Following early experimental work in Norway, CT facilities for farm animals have been established in Australia, New Zealand, and Hungary, and more recently in Edinburgh, U.K. Recent SAC studies have shown that carcass lean and fat weights can be predicted with very high precision from two or three CT scans together with live weight (Young et al., 1999). Research is now in progress to design optimum two-stage selection programs that involve screening of large numbers of sheep using current ultrasonic methods, followed by more detailed CT measurements on a small proportion of these sheep. Two-stage selection schemes have begun in the five SRS mentioned in Table 1, plus the Hampshire Down SRS, with the top 10 to 20% of rams being identified in the field, based on ultrasonic measurements, for further CT measurements.

Similarly, it is likely that new molecular genetic or reproductive technologies will be helpful for identifying elite animals and then increasing their influence in future breeding programs. Already there has been a rapid uptake in the U.K., especially in SRS, of DNA-based genotyping to identify sheep that are genetically resistant to scrapie (Dawson et al., 1998). Marker-assisted selection for resistance to other diseases, or for other traits which are difficult to measure, such as meat quality, may follow. Research is in progress in several countries to identify potentially useful markers for sheep breeding. A study of this type began recently in the Roslin Institute, SAC, and the University of Edinburgh, in SRS in the Suffolk, Texel, and Charollais breeds.

In the decade or so over which SRS have existed in the U.K. sheep industry, they have contributed greatly to rates of genetic improvement in lean growth. The developments outlined above should ensure that they make an even greater contribution over the decades to come.

Implications

Sire referencing schemes are cooperative breeding schemes that create genetic links among participating flocks (or herds). These links are usually created through the use of artificial insemination from elite sires. In theory, sire referencing schemes permit across-flock genetic evaluation, increased selection intensity and, ultimately, increased rates of genetic gain. These schemes have had an important role in genetic improvement of several specialized meat breeds of sheep in Britain. Rates of improvement in lean growth being achieved in these industry schemes are close to the rates of gain achieved in experimental flocks. Selection for lean growth in seedstock flocks improves physical and economic performance of progeny in commercial flocks.

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