COSTS AND BENEFITS OF BREED UTILIZATION STRATEGIES IN SHEEP

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ABSTRACT

Problems involved in choosing appropriate criteria and procedures for economic analyses of breed and mating system evaluation experiments in sheep are described. Literature is reviewed of experiments in which biological or economic efficiency has been investigated. The range in relative economic merit from the poorest to the best group in an experiment typically is from 100 to 120, with values over 140 not uncommon for the best group in an experiment. Heterosis for economic traits per ewe mated has ranged from 2% to 26%. Suggestions are presented for consideration in future studies on the economic ramifications of mating system and breed utilization strategies. Particularly critical is the need to assess accurately the feed costs of individual grazing sheep. Also critically needed are bioeconomic simulation models for each major physical environment and management system for sheep production.

INTRODUCTION

Considerable effort has been expended internationally in breed and mating system evaluation experiments in sheep. The majority of published studies have a biological orientation. That is, comparisons generally are restricted to reproductive traits and/or production traits such as growth, carcass merit, fleece weight and wool quality. In relatively few studies has production been expressed per unit of some limiting input, to approximate biological efficiency; and in even fewer have the economic ramifications of breed choices, crossbreeding systems, breed substitutions or synthetic breed development been examined.

The objectives of this manuscript are to identify problems facing investigators appraising the economic ramifications of sheep mating system and/or breed evaluation experiments, to review the literature of studies in which some measure of biological or economic efficiency has been included and to present recommendations of economic traits and analytical approaches for consideration in future experimentation.

PROBLEMS IN ECONOMIC ANALYSES

Many complex problems need to be solved and many decisions made during the economic analysis of a sheep breeding experiment. First, it is difficult to identify the most appropriate criterion of economic merit. Most would agree that output variables alone (carcass weight or lambs weaned per ewe mated, for example) are not sufficient. That is, higher production does not necessarily lead to greater biological or economic efficiency (Wassmuth and Bueing, 1974; Atkins, 1980). Consideration should also be taken of the costs of production. "Profit" conveniently combines revenues and costs so is a logical candidate trait. Revenue is production times price; costs are inputs times their respective prices. This raises the question of what prices to use - current, past or those predicted for the future. Relative prices among outputs (lamb vs mutton
s wool and of wools of different grades) and among inputs are not stable across time, and results of economic comparisons are likely to be sensitive to the relative prices used (Wassmuth and Bueing, 1974; Miller and Pearson, 1979).

Should mating systems be designed to maximize profit per animal, per hectare, per unit of labor input, per farm or per unit of monetary investment? Genetic decisions economically optimum for one class of producers, farmers selling all lambs except potential replacements at weaning for example, might not coincide with those in the best interests of other segments of the industry, e.g. lamb feeders and grazers. Mating system and breed rankings might well change according to the profit maximization goal that is chosen (Miller and Pearson, 1979; Wilton, 1979; Rae, 1982; Brascamp et al., 1985).

For many producers and firms, consideration of risk associated with a given level of profit would also be important (Wilton, 1979). Systems that maximize profit in good or average years might, for example, be disastrous in drought years. This introduces another level of complexity.

What time frame is appropriate? We are accustomed to an annual frame of reference, but mating plans are a long term proposition. Current expenditure in anticipation of future returns, the time schedule for adoption of a mating system and the timing of changes in revenues and costs need also to be considered. This introduces yet another complexity, the proper discounting of costs and returns across time (Smith, 1978; Miller and Pearson, 1979).

If the consumer rather than the producer of agricultural commodities is meant to be the ultimate beneficiary of agricultural research, then minimum cost per unit of product rather than profit per se might be the economic criterion of choice (Dickerson, 1970; Miller and Pearson, 1979; Wilton, 1979; Brascamp et al., 1985). In the long term, however, if markets for sheep meat and wool are sufficiently competitive, then benefits of profit enhancing technologies (such as optimum mating system and breed choices) will be passed on to consumers (Harris, 1970); and there will be limited conflict of interest between producers and consumers.

Finally, even once an economic criterion has been chosen, the cost data to allow accurate computations often will be inadequate. It is difficult, for example, to quantify the extra labour required in high as opposed to average prolificacy sheep flocks (Sorrenson and Scott, 1978). Particularly vexing is the problem of assessing feed intake and, consequently feed cost, of individual grazing animals (Atkins, 1980; Carter, 1982). Availability of accurate and inexpensive devices to achieve controlled release of indigestible markers into the rumen (R. Barlow, private communication) is awaited with great interest, as they will allow estimation of relative and, possibly actual feed intakes. Although it still will be necessary to determine the monetary costs associated with the intakes, such technology will greatly enhance our ability to apply economic analyses to animal breeding experiments.

BREED AND MATING SYSTEM EFFECTS ON PRODUCTION EFFICIENCY

Biological efficiency - output/input.

In this section, rather than to review experiments in which production has been expressed per unit of some input, a range of efficiency numerators and denominators will be described, and problems associated with choosing a meaningful efficiency ratio will be presented.
Numerators have included the number of lambs born or weaned, the weight of weaned, the weight of lamb marketed (Boaz et al., 1980), carcass weight (et al., 1979) and wool production. Generally, production is adjusted for direct effects not the "fault" of the production unit (lamb sex on preweaning weight for example), but not for effects that could be considered to be dependent on the genetic potential of the production unit (ewe weight or type of birth and kidding effects on litter weight, for example).

Production has been expressed per ewe entering an experiment at a standard weight (Ch'ang and Evans, 1982) or per ewe exposed to mating (Ch'ang and Evans, 1982) or per ewe lambing (Cochran et al., 1984). Denominators have included ewe weight (Dahman et al., 1978); ewe weight to the 0.73 power (Mann et al. 1984); ewe organic matter intake (Kleeman and Young, 1978); ewe plus lamb feed consumption (Smith et al., 1979); and land area (Rattray et al., 1978). Most experiments report efficiency on an annual basis, but some are based upon several cumulative years of production.

Considering all the permutations of numerators and denominators, a very large number of efficiency estimates would be possible. All of them, including those employed by my students and me, are subject to valid criticisms and limitations. Using the ewe as a denominator, for example, ignores her weight; using her weight ignores any nonlinear relationship of weight and maintenance feed requirement; using ewe metabolic weight ignores any extra feed associated with her productivity, and using organic matter intake ignores any difference in fat of feed calories between classes of stock and across time, as well as any differences among groups in efficiency in harvesting and utilization of standing feed. Using as the numerator only weaned lamb ignores wool, weight gains of feeder lambs and cull ewe value. The legitimate criticisms could continue ad infinitum.

Economic productivity - monetary value of production.

It is my goal in this and the following section to present a thorough review of the recent literature on mating system and breed evaluation experiments in sheep in which some economic criterion has been used. The studies are presented more or less chronologically within the order of increasing complexity. Results are summarized in table 1 (for studies in which genetic groups have been compared for an economic criterion) and table 2 (for studies in which heterosis for an economic trait has been quantified or in which genetic groups have been compared in more than one environment or for more than one economic trait). These summaries involve, in many cases, computation of statistics from data originally reported in other forms. I do not, therefore, advocate direct quotation of the statistics but rather encourage readers interested in specific comparisons to consult the original sources.

In a number of studies, the historic price relationship per kilogram between lamb and wool has been used to approximate in an index fashion the total income generated by genetic groups under comparison. Carter and Kirton (1975) reported that, leading up to the time of their experiment, one kilogram of lamb's wool historically was equal in commercial value to 2.5 kilograms of lamb carcass weight in New Zealand. Sires of 14 potential terminal sire breeds were mated to Romney ewes, and lamb carcass weight and lamb fleece weights were measured. Based on the index 2.5 x lamb fleece weight plus lamb carcass weight, Dorset rams were highest in rank and Romneys were lowest. (Since all ewes were Romneys, it was only this group that received no benefit from individual lamb heterosis.) Breeds creating higher index values than using Southdown rams (a common practice in New Zealand up to the time of the report) included Dorset, Border Leicester, Suffolk, South Suffolk and Dorset Down. Breeds with a lower
Subsequent work from New Zealand used an index of lamb live weight plus 4% wool weight as a reflection of gross revenue. From a four breed diallel crossing experiment involving the Romney, Border Leicester, Cheviot and Merino (Clarke and Meyer, 1982), heterosis for the index was 20%. When the index was divided by average ewe body weight per group, heterosis dropped to 10%; and there were important changes in the ranking of sire breeds. Border Leicester was the most productive sire breed for the index itself but was below average for the index per unit of ewe body weight. The Merino was least productive for the index, most productive for the index divided by ewe body weight. The most productive sheep overall were the Romney x Border Leicester reciprocal crosses.

Clarke et al. (1982) also used the relationship of one to four for the values per kilogram of lamb and wool to evaluate overall productivity of Romney, Corriedale and Dorset sheep in a diallel crossing design. Of straightbred groups, Romneys were high in wool and low in lamb production, Dorsets the opposite, with Corriedales roughly equal to Romneys for wool but surpassing them for lamb production. With reciprocal crosses pooled, all the crosses were above average in total productivity, with Corriedale x Dorset and Romney x Dorset groups essentially equal.

Clarke and Rattray (1983) reviewed other New Zealand work in which breeds and breed crosses were compared for the productivity index. In one experiment, Border Leicester x Romney ewes exceeded Romneys by 23% for the index but by only 6% for the index per unit of ewe weight at mating. In a second experiment, relative values for the productivity index were Coopworth (122), high fertility Romney (109), Perendale (107) and control Romney (100). When productivity was expressed per unit of weight or per unit of pasture intake, the Coopworths and high fertility Romneys were essentially equal to each other (107 to 108), and Perendales were essentially equal (100 to 102) to the control Romneys (100). Thus, the relative merit of the breeds and crosses was dependent upon the economic basis for the comparison.

Minnesota, USA workers (Oltenacu and Boylan, 1981) used similar procedures except that a wool to lamb value ratio of 3:1 was adopted. Also in their experiment, ewes were given credit for lambs they bore but which were artificially reared. Various breeds and crosses were evaluated. Among only the straightbred ewes, Finnsheep surpassed Targhees and Suffolks, which were approximately equal for the index but which surpassed a synthetic strain composed of Rambouillet, Border Leicester and Cheviot inheritance. First-cross ewes had higher productivity than their straightbred mothers, whereas F₁ ewes were intermediate in productivity between their F₁ mothers and straightbred granddams. When the productivity index was expressed per unit of ewe body weight, the synthetic strain ewes and crosses increased in relative merit, while the Suffolk ewes and crosses decreased.

In an early study Bradford et al. (1960) compared Southdowns to Suffolks as terminal sires when mated to Corriedale-type ewes on California, USA ranges. Since the season of high quality forage is variable but short in that environment, they reasoned that a sufficiently higher proportion of Southdown cross than Suffolk cross lambs might be ready for slaughter directly at weaning (at a higher per kilogram value than store or feeder lambs) to compensate for the expected lower weight of lamb weaned per ewe. Although a higher proportion of Southdown cross lambs was slaughtered at weaning, using Suffolks as terminal sires resulted in 16% more net return per ewe than using Southdown rams.
In another early study (Vesely et al., 1966), relative annual gross revenues from lamb and wool from straightbred Suffolk, Targhee Columbia, Rambouillet and Willamette ewes in southeastern Alberta, Canada were 105, 103, 103, 101 and 100, respectively. Most of the differences per ewe were attributable to differences among the breeds in wool quantity and value per kilogram rather than in lamb production. Coarser grades were more valuable than finer grades of wool at the time of the study, counter to recent trends.

In an Oregon, USA study, Hohenboken (1976) mated Hampshire, Suffolk and Willamette sheep (a synthetic strain with 50% Columbia, 25% Dorset and 25% Cotswold ancestry) in a diallel design replicated in dryland hill pasture and irrigated pasture environments. The economic criterion was gross revenue per ewe, made up of wool, feeder lamb and slaughter lamb production, each assigned an appropriate market value. Average heterosis for gross revenue was 12%, but the system interacted strongly with grazing environment. On hill pastures, ewe income per ewe was greater and stressful factors such as endoparasites, parasitism and respiratory diseases presumably were less, heterosis was only 2%. On irrigated pastures, heterosis was 26%. On hill pastures Willamette ewes surpassed Suffolks which surpassed Hampshires in gross revenue. On irrigated pastures, Suffolk and Willamette ewes were approximately equal, and both generated more revenue than Hampshire ewes.

Geenty and Clarke (1977) computed gross returns from carcass weight plus fleece produced by the slaughter lamb. Rams of four potential terminal sire breeds (Southdown, Suffolk, Border Leicester and Dorset Down) were mated to Romney, Corriedale and Dorset ewes and to ewes that were F₁ crosses among those three breeds. Dorset Down, Suffolk and Border Leicester sires generated gross income per lamb 6%, 6% and 3% above that of Southdowns. Among straightbred ewe groups, breeds ranked Dorset (111), Romney (102), Corriedale (100) for gross return per lamb. Crossbred ewes generated only 1% higher returns per lamb than straightbred ewes, but differences among crossbred groups ranged from relative values of 104 for Corriedale x Dorset ewes to 96 for Corriedale x Romneys. Since returns were reported on a per lamb basis, differences among ewe groups in fertility, prolificacy, lamb survival and longevity were not considered.

Cochran et al. (1984) computed gross income per 100 Dorset, ⅔ Finnsh Sheep or ⅔ Finnsh Sheep ewes lambing per year. Since a common age distribution was assumed for each breed group, differences in attrition were not accounted for, nor were differences in fertility. From lamb and wool production combined, the gross income totals were 115 and 126 for ⅔ and ⅔ Finnsh Sheep ewes, respectively, relative to 100 for Dorsets. In related work, Ercanbrack and Knight (1985) compared straightbred Columbia, Targhee and Rambouillet ewes to ⅔ and ⅔ Finnish Landrace ewes whose remaining inheritance was from the three whitefaced breeds. Ewes were recognised for either donating or accepting a foster lamb by crediting them with half of the weight weaned from the foster lamb. Differences in attrition were accounted for by examining cumulative production through seven years of age. For the total monetary value of lifetime production, the ⅔ and ⅔ Finnsh Sheep ewes surpassed straightbreds by 18 and 29%, respectively.

Economic efficiency - revenue minus cost. As stated previously, crossbreeding experiments in which costs as well as revenues have been considered are infrequent. Sorrenson and Scott (1978) estimated gross margins per ewe (the difference between gross revenue and variable costs) for exotic crossbreds compared to straightbred New Zealand Romney ewes and to crosses commercially available in New Zealand at the time. When the Romneys were assigned a gross margin per ewe of 100, the exotic crosses ranged from 121 for German Whitehead Mutton to 148 for East Friesian to 155 for Finnish Landrace.
revenue of 131 on the same scale. The authors estimated that about 20% of the advantage of the Finnish Landrace crosses would be lost if additional labor were budgeted to handle the larger sized litters. Hanrahan (1982) also used gross margin per ewe as the economic criterion to evaluate 1/4 Finnish Landrace, 3/4 Galway ewes in comparison to straightbred Galways. In his study, the Finnish Landrace crossbred ewe advantage was 41%.

Economic merits of Romney, Coopworth and Perendale ewes, the three breeds accounting for some 80% of dual purpose commercial sheep in New Zealand, were examined by Smeaton et al. (1985). They combined data from four experiment stations, with from three to fourteen years of records per station and incorporated the debatable assumption that "costs associated with running each breed were the same". For gross revenue generated per ewe mated, Coopworth, Perendale and Romney ewes rated 100, 95 and 88, respectively; whereas for gross margin per ewe (revenue minus variable costs), the three breeds rated 100, 92 and 82. When gross revenue was expressed per 55 kg ewe, Coopworths, Perendales and Romneys were rated 100, 97 and 92, respectively. The lighter Romney ewes did relatively better when compared on a per unit of body weight basis. The overall economic ranking of Coopworth over Perendale over Romney was remarkably consistent across years and experimental sites.

Cameron et al. (1984) used gross returns and gross returns divided by an index incorporating the dam's metabolic weight and the metabolic midweights and slaughter ages of her lambs to evaluate crossbred ewes from Scottish Blackface dams and sired by Border Leicester, Bluefaced Leicester or Animal Breeding Research Organization Dam Line rams. Returns per ewe were lowest for Border Leicester sired ewes and approximately equal for the other two groups. For returns per unit of the ewe and lamb weight index, the Dam Line cross females were highest (108), Bluefaced Leicester crosses were intermediate (104) and Border Leicester crosses were poorest (100). When differences in ewe fertility were accounted for, the advantages of the Dam Line and Bluefaced Leicester crosses increased to 15% and 6%, respectively.

Saoud and Hohenboken (1984) attempted to account for differences among genetic groups in survival and longevity by including in net revenue a ewe ownership cost. Each ewe in the experiment was assigned a constant assumed purchase cost. Annual feed costs were then estimated according to the number of lambs gestated and nursed by the ewe, taking also into account her wt and wt change for the year. Income was from store or feeder lambs, orphan lambs (sold at birth) and ewe salvage value (if the ewe survived the entire duration of the experiment). The economic criterion was lifetime net revenue, the gross revenue minus estimated feed and ewe purchase costs. Eight crossbred ewe types, from mating Dorset, Finnish Landrace, North Country Cheviot and Romney rams to Columbia and Suffolk ewes, were evaluated in two grazing environments. Crossbred groups differed significantly for lifetime net revenue and interacted significantly with grazing environment. For example, Suffolk crossbred ewes were much more productive than Columbia crossbreds on irrigated pastures, while on dryland hill pastures, the opposite was true. Finnish Landrace crossbred ewes generated high levels, while Romney and Cheviot crossbreds generated low levels of net revenue in both environments. Dorset crossbred ewes generated high levels of income on irrigated pasture but were roughly equivalent to Cheviot and Romney crossbreds on hill pastures. On hill pastures, Cheviot crosses surpassed Romney crosses; whereas on irrigated pastures, Romney crosses surpassed Cheviot crosses.

Levine et al. (1978) also examined net returns as revenue minus variable costs, but they expressed annual net returns both on a per ewe and per hectare basis. Feed costs were estimated using a modified grazing simulation model written originally for Australian conditions. Feed intakes from pasture, hay and grain were valued at their estimated costs of production or purchase.
Straightbred Suffolk and Columbia ewes mated to rams of four breeds were involved in the experiment. Averaged over two years and using prices relevant to those years, the gross margin per Suffolk ewe was 143% of the gross margin per Columbia ewe exposed to mating. Net returns above variable costs per hectare, though, favoured the Suffolk ewes by only 22% because fewer of the heavier Suffolk ewes than of the lighter Columbia ewes could be stocked per hectare.

Breed introduction impacts on national economies.

An economic analysis of a different sort was reported by Sorrenson and Scott (1978). They estimated the benefit to the New Zealand national economy of the importation, evaluation and utilization of exotic sheep breeds. Based upon a number of simplifying assumptions, the internal rate of return to public investment in the exotic sheep importation scheme was calculated to equal 27%, from which they concluded that there were "sound economic grounds for the continuation of the exotic sheep research and development program". Bushnell and Hutton (1982) also projected benefits to the New Zealand economy of the importation and release of exotic sheep genotypes, particularly the Finnish Landrace. Based upon what they considered to be conservative estimates of adoption of half and quarter Finn ewes by farmers, they estimated a net present value for the scheme of NZ190 million, an increase in annual export earnings per annum of NZ260 million (beginning in 2006) and an internal rate of return on public investment of over 80%.

RECOMMENDATIONS FOR FUTURE RESEARCH

A first recommendation is aggressively to pursue and support all technological advances that would aid in the assessment of costs incurred by individual animals. Already mentioned were controlled release devices to add indigestible markers to the rumen, thereby allowing easier assessment of individual nutrient intakes of grazing animals. When such procedures become validated and available, they should be used to ascertain the nutrient costs of maintenance, wool and body tissue growth, gestation, lactation and the physical exertion associated with grazing, as well as age and seasonal variation in those costs, both within and among genetic groups. Telemetry devices to monitor livestock behaviour and electronic data processing equipment linked to data bases in order to log labor and veterinary expenses are other possible advances. Information on costs incurred per animal is needed before accurate and realistic economic analyses routinely can be conducted.

The majority of past studies have attempted to assess economic efficiency on the basis of production per animal per year, and such analyses will continue to have value. Production should include all income sources (meat, wool, replacements, cull breeders and milk production) with each weighted according to its value. As stated earlier, deciding upon the most appropriate value can be difficult, since results and conclusions can be sensitive to the prices chosen. Life cycle as opposed strictly to annual economic efficiency would generally be more relevant to the ultimate user of the research data. This could be accomplished by comparing ewes of different genetic groups or mating systems on a lifetime basis (Saoud and Hohenboken, 1984; Ercanbrack and Knight, 1985) or by comparing flocks of the characteristic age structure for each genetic group on an annual basis (Cochran et al., 1984).

For results to be most valid, the highest possible proportion of total identifiable costs should be accounted for in the economic criterion. For example, revenue generated per ewe has some relevance, but gross margin per ewe (gross returns minus variable costs) conveys more information, while net revenue (gross returns minus variable and a proportionate share of fixed costs) conveys
even more. As, however, higher proportions of total costs are accounted for in an economic criterion, the experimental results become more region, management system and time specific. Strictly biological efficiency (calories in and retail product out, for example) is more robust over time than measures of economic efficiency.

Future economic analyses should not be restricted to defining economic efficiency on a per animal basis. For many production systems (pastoral farming in New Zealand, for example), land is the basic limiting resource and profit per hectare is more meaningful than profit per ewe. In other situations, profit per unit of financial investment or per unit of labour input might be the most meaningful. Profit per farm would, for a specific enterprise, combine aspects of profit per hectare, per labour unit and per dollar invested. Ideally, data should be collected to allow economic efficiency to be expressed with respect to any of the above resources, then analyses conducted using the most appropriate sets of criteria for each specific experiment.

Most animal breeders are keen statisticians, with a pathological urge to account for phenotypic variation. In our zeal to maximize R², we must be careful not to account for variation possibly or partly the responsibility of the genetic groups and/or mating systems under investigation. For example, the influence of body weight on ovulation and twinning rate is well known. If lamb production, as a contributor to an economic trait, is subjected to an analysis with ewe weight as a covariate, part of inherent differences among genetic groups could be eliminated. As another example, adjusting carcass weights for birth and rearing rank would give an undue bonus to more prolific groups of sheep.

Accounting for variation by expressing production on a "per unit of input" basis also may fail to account adequately for the intended effect. For example, production per unit of ewe or cow metabolic weight has been used as a measure of biological efficiency. This may or may not account for differences in maintenance energy attributable to differences in weight, but it certainly does not account for differences in energy requirement of the female attributable to differences in production (the rearing of twin compared to single lambs, for example).

Bioeconomic computer simulation models of production systems are a powerful tool with which to estimate the overall economic effects of breed and mating system choices (Wilton, 1979). Simulation models also can aid in risk assessment, because profit from a given mating system and array of breeds can be simulated across, for example, a range of years, input and output price relationships and management systems. Several models have been published for sheep (e.g. Christian et al., 1978; France et al., 1983; White et al., 1983 and McCall, 1984), but none of those cited is able readily to simulate the utilization of different breeds, breed combinations or mating systems. The structures of the various simulation models are one limitation, and the lack of appropriate inputs for breed differences and heterosis levels for, particularly, feed and other cost inputs is an equally serious limitation. The development and validation of bioeconomic simulation models appropriate for each major sheep production climatic and managerial environment, and the fuelling of such models with appropriate biological and economic inputs, should be a high priority for future research in the economic ramifications of breed choices and mating strategies in sheep.

A final recommendation is that quantitative geneticists establish close liaison with farm management and production economics specialists, ideally throughout the research process (i.e. establishment of objectives, experimental protocol and design, implementation, analysis and interpretation). The team need not, of course, be restricted to individuals of those specialties. Closer interaction and understanding among cooperating scientists would be mutually beneficial.
to all of them and, ultimately and more importantly, to consumers of search information - and of sheep and wool products as well.

LITERATURE CITED


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<tr>
<td>Coopworths, Perendale, control Romneys, high fertility Romneys</td>
<td>Same as previous study plus index per unit of pasture intake</td>
<td>No major changes of breed ranking, but the range from poorest to best was larger for the index (22%) than for index per ewe weight or forage intake (7-8%)</td>
<td>Oltenacu and Boylan (1981)</td>
</tr>
<tr>
<td>Four breeds plus various F₁ crosses, F₂ crosses and backcrosses</td>
<td>Index of lamb live weight and ewe wool value, per ewe mated and per unit of ewe weight at mating.</td>
<td>When the index was expressed per unit of ewe weight, heavier groups decreased while lighter groups gained in relative merit. Rank changes did not occur.</td>
<td>Hohenboken (1976)</td>
</tr>
<tr>
<td>Three breed diallel</td>
<td>Gross revenue, per ewe exposed, from lamb and wool</td>
<td>Heterosis was 12% overall, 2% in the more benign environment, 26% in the more stressful environment. Ewe breeds changed rank between a dryland hill pasture and irrigated pasture environment.</td>
<td>Geenty and Clarke (1977)</td>
</tr>
<tr>
<td>Ewes from a three-bred diallel mated to four terminal sire breeds</td>
<td>Gross return, per slaughter lamb, from carcass and wool</td>
<td>Heterosis (crossbred compared to straight-bred ewes all raising crossbred lambs) was 1%, but criterion did not allow for expression of differences in fertility, prolificacy or survival. Coopworths always out-ranked Perendales which always out-ranked Romneys, but the range of differences depended upon the economic criterion.</td>
<td>Smeaton et al. (1985)</td>
</tr>
<tr>
<td>Nature of experiment</td>
<td>Economic criterion</td>
<td>Results</td>
<td>Reference</td>
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<tr>
<td>Crossbred ewes sired by rams of three &quot;maternal&quot; breeds</td>
<td>Gross revenue per ewe and gross revenue per ewe plus litter metabolic weight, (both per ewe lambing). Gross revenue per 100 ewes and per 100 ewe plus litter metabolic weights (both per ewe mated)</td>
<td>Breed rankings did not change with economic criterion, but the range increased when differences in fertility were accounted for.</td>
<td>Cameron et al. (1984)</td>
</tr>
<tr>
<td>Eight crossbred ewe groups in two management environments</td>
<td>Lifetime net revenue per ewe entering the experiment</td>
<td>Important changes in breed rankings. For example, Suffolk crosses more productive than Columbias on irrigated pastures, vice versa on hill pastures.</td>
<td>Saoud and Hohenboken (1984)</td>
</tr>
<tr>
<td>Ewes of two breeds producing crossbred lambs</td>
<td>Gross margin per ewe exposed and per hectare</td>
<td>Breed ranking did not change, but the difference between breeds was much less on a per hectare compared to a per ewe basis.</td>
<td>Levine et al. (1978)</td>
</tr>
</tbody>
</table>