AN ABSTRACT OF THE THESIS OF

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Title: SHEEP SELECTION IN RETROSPECT

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A total of 399 crossbred ewes from two birth years were raised under two management systems, irrigated vs. dryland hill pastures. The crossbred ewes were sired by North Country Cheviot, Dorset, Finnsheep and Romney rams that were mated to Suffolk and Columbia-type ewes. Hampshire rams were the terminal sire breed used to mate the crossbred ewes throughout the experiment. Total feed cost and gross income from feeder and orphan lambs were estimated per ewe for either 4 or 5 potential years of production. Efficiency was defined as estimated dollars net revenue per ewe, the difference between estimated gross income and estimated feed and ewe ownership cost. Crossbred group and crossbred group x management system interaction significantly affected net revenue. The relative merit of crossbred groups was strongly dependent upon the environment in which the comparison was made.

Ten ewe lamb traits were then used (individually and in combinations) in regression analyses to determine their relationships with lifetime production efficiency (LPE). The ewe's within-year birthdate, postweaning average daily gain, age at first estrus and lambing

date during her first production year were not predictive of subsequent LPE. Ewes born as triplets had better future LPE than those born as either twins or singles ($P < .05$), but single-born ewes surpassed twins in LPE. Actual weaning weight (WWt), weaning weight adjusted for age of dam, date of birth and type of birth and rearing (AWWt), postweaning weight (PWWt) and lamb production and net revenue of ewes mated to lamb at 12 months of age were correlated to the ewe's LPE ($P < .05$).

Results of "paper selection" involving single traits, independent culling level based upon birth type and postweaning weight and backward selection showed that either of the three ewe lamb weights (WWt, AWWt, PWWt) was a good predictor of future cumulative and subsequent ewe productivity (excluding first year contribution). None of the ewe lamb early life traits was predictive of ewe longevity, i.e., the ability to survive the entire duration of the experiment. It is suggested that a selection scheme, perhaps an index, including type of birth and either of the three weights could be most efficient in predicting the maximum LPE per ewe.

Sheep Selection in Retrospect

by

Nabeel B. Saoud

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And to my wife, Hania, whose support, understanding and love helped bring us through safely and successfully. And to my daughters, Deya and Nayla.

For in Him we live and move and have our being; . . .

Acts, 17:28

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INTRODUCTION

To a commercial sheep producer, selection of replacement ewes is of utmost importance in affecting efficiency of the operating unit. It is never a simple, straightforward decision to differentiate potentially efficient ewes from those that are not. Hopefully, though, the farmer or breeder will have selected replacement ewe lambs that have a higher potential for production efficiency, on the average, than those that are culled. Unfortunately, the comparison between those culled and those retained is not possible.

In these sets of experiments, lifetime production efficiency and its components for eight groups of crossbred ewes of two birth years and two management systems is assessed. One birth year group was subjected to no artificial selection. In the other birth year, 80% of ewes of each crossbred group, based upon size and health, were retained. Comparisons of ewe efficiency are made among crossbred groups and management systems. Other objectives are to study the relationship of various ewe lamb traits with the lifetime production efficiency of the ewes. Various paper selection exercises are practiced, aiming at identifying the effects of selection in retrospect upon the ewe's lifetime production efficiency.

Chapter 2

GENETIC, ENVIRONMENTAL AND INTERACTION EFFECTS ON LIFETIME PRODUCTION EFFICIENCY OF CROSSBRED EWES[1]

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Summary

A total of 399 crossbred ewes born in two years were maintained under two pasture management systems, irrigated vs dryland hill pastures. The ewes were sired by North Country Cheviot, Dorset, Finnsheep or Romney rams mated to Suffolk or Columbia-type ewes. The crossbred ewes were mated to Hampshire rams throughout the study, and had the opportunity for either 4 or 5 yr of production. Annual feed cost was estimated based upon annual metabolizable energy (ME) maintenance requirements, plus ME for ewe growth, pregnancy and lactation. Income from weaned feeder lambs and from orphans sold shortly following birth and feed cost were also analyzed during each ewe's first production year, as well as for the entire period of the experiment. Crossbred group significantly affected income from lambs produced, feed cost and net revenue for the ewes' first production year. Crossbred group and crossbred group x management system interactions significantly influenced lifetime income from lambs produced and from orphans sold, gross income, total cost and net revenue per ewe. Finnsheep Suffolk ewes performed best on irrigated pastures but were slightly below average for lifetime net revenue on hill pastures. Finnsheep x Columbia ewes performed best on hill pastures and, with Dorset x Suffolk and Dorset x Columbia ewes, were well above average for lifetime net revenue on irrigated pastures. Ewes with Suffolk inheritance consistently performed better on irrigated pastures than on hill pastures. While most ewes with Columbia-type inheritance

were better producers on hill than on irrigated pastures, this was not always consistent.

(Key words: Crossbred sheep, genetic x environment interaction, lifetime production efficiency)

Introduction

One of the major objectives of animal genetic improvement is to increase the efficiency of production of the individual animal as well as that of the operating unit. This increase in efficiency can be achieved by increasing animal production (e.g. growth of progeny) and reproduction and(or) by decreasing the cost of production (Dickerson, 1970; Harris, 1970). Dickerson (1970) further emphasized the importance of the management system under which production occurs and the choice of breeds well adapted both to management and physical conditions.

Ewes of eight crossbred groups were maintained on irrigated or dryland hill pastures in western Oregon for 4 or 5 yr of production. Estimates were derived, in dollars, of each ewe's feeder lamb and orphan lamb income, feed plus ewe ownership cost and net revenue. Objectives of the experiment were: 1) to assess genetic, environmental and the genetic x environment interaction effects on estimated lifetime production efficiency and its components, 2) to document variability among ewes within crossbred groups in the components of production efficiency and 3) to study relationships among factors contributing to lifetime economic production efficiency.

Materials and Methods

Population and Management. A two-phase crossbreeding experiment with sheep was initiated at Oregon State University in 1972. In Phase I, approximately 200 each of Suffolk and Columbia-type ewes were mated to North Country Cheviot, Dorset, Finnsheep and Romney rams for two breeding seasons. Each year, four rams/breed were each mated to approximately 12 Suffolk and 12 Columbia-type ewes. Rams were only used for 1 yr. For further information concerning Phase I management see Cedillo et al. (1977) and Levine and Hohenboken (1978).

Phase II of the experiment dealt with the crossbred offspring of the Phase I ewes. Of the ewe lambs born in 1973, approximately 80% from each breed group were retained (a total of 194 ewes) for mating. Adjusted weaning weight and overall appearance were the bases of the within-group selection. That is, only small, unthrifty or unhealthy ewes were not retained. All 205 surviving ewe lambs born in 1974 were kept for mating. Ewe lambs were weaned in June of each birth year. They were then moved to irrigated pastures, where they were exposed at 7 mo of age to vasectomized rams and scored for age at first estrus. Ewe lambs were mated to intact Hampshire rams (4/100 ewes) during the September and October breeding season. They were then randomly divided within crossbred group into two flocks. One flock was moved to dryland hill pastures while the other was left on irrigated pastures. The flocks remained in these pasture management systems until the end of the study in 1978. There was no culling on production. Some ewes died before the termination of the experiment (Norman et al., 1979; Hohenboken and Clarke, 1981), and a few sick ewes were culled when it was predicted that their illnesses were terminal. Otherwise, all ewes entering the experiment were retained through the 1978 production year.

Hampshire rams were used throughout the study as the terminal sire breed. Multiple-sire mating was practiced, so sire identification of individual lambs was not possible. Lambing each year occurred in February through mid-March, and lambs were weaned in June of each year. Management details are reported by Klinger and Hohenboken (1978). The study was terminated after weaning of the lambs born in 1978. Thus lifetime lamb production is defined here as 5 and 4 yr of production for ewes born in 1973 and 1974, respectively. In summary, two birth years, two management systems and eight crossbred groups were involved.

Estimation of Components of Efficiency. Production efficiency in this experiment is defined as estimated net revenue per ewe (in dollars), the difference between estimated gross income and estimated feed and ewe purchase cost. Lifetime gross income was the sum of lifetime feeder lamb production, lifetime orphan lamb production and ewe salvage value, all measured in dollars. Lifetime lamb production was the sum of annual lamb productions (from 4 or 5 yr for 1974- and 1973-born ewes, respectively) times $1.016 per kg (from O.S.U. Extension Service commodity data sheets from 1974 through 1978). Annual lamb production per ewe was the total weight of lambs weaned in her litter, with individual lamb weights corrected for sex (ewe lamb weights were multiplied by 1.1) but not for type of birth and rearing or for lamb age.

The usual practice, with a few exceptions, at the Oregon State University Sheep Center was to allow any ewe bearing more than two lambs to raise only two of them, at most. Within a few days of parturition, the extra lambs were either sold or grafted onto ewes that either lost a lamb or were predicted to be capable of raising another. A ewe donating an orphan (sold as an extra lamb or grafted to another ewe) was credited $15.00 per orphan, and any ewe accepting a foster (grafted) lamb was charged $15.00 opportunity cost. Subsequently she was credited the weight weaned from the foster lamb. Foster lamb feed costs were calculated only for that period during which they might have infringed a cost upon the ewe. Foster mothers of the only four foster lambs that died before weaning were not charged opportunity or feed cost for those lambs.

Ewe salvage value was granted to those ewes that were still present at the time the study was terminated in 1978. A ewe born in 1973 was credited a salvage value of $20.00, whereas a ewe born in 1974 was credited a salvage value of $26.00.

Cost of production in this analysis was composed of one constant cost (ewe purchase cost) and one variable cost (feed cost). Other costs (e.g., taxes, depreciation on equipment, interest) were not considered since, on a per ewe basis, they would have been similar among ewes within pasture management environment (but dissimilar between environments). Based upon previous results (Hohenboken and

Clarke, 1981; Clarke and Hohenboken, 1983), it was expected that crossbred group x management system interactions would be important. Thus inferences about relative merits of crossbred groups would have to be environment specific, and differences between environments in nonfeed costs per ewe would not affect those inferences. The ewe purchase cost of $50.00 was the estimated purchase price of a ewe entering the experiment at 7 mo of age. This price did not vary among genetic groups, management systems or birth years. The inclusion of this constant cost is necessary since not all the ewes survived the entire duration of the experiment to be credited a salvage value. By assigning a purchase cost and a salvage value, ewes leaving the flock before the termination of the study were penalized and their higher ownership cost was accounted for.

No individual or group feed intake records were collected during the experiment. We therefore estimated the metabolizable energy required for each ewe based upon ewe weight when the breeding season began, the number of lambs gestated and reared by the ewe and ewe body weight change from one year to the next. For the first year of production, which began when ewes were approximately 7 mo of age, the formulas used to estimate metabolizable energy requirements in megacalories per day (ME/day) were modified from NRC (1975), based on ewe body weight at the beginning of the breeding season. These formulas ranged from ME/day = 0.258 $W^{.75}$ for a 25 kg ewe lamb, where W represents body weight in kg, to ME/day = 0.148 $W^{.75}$ for a 55 kg ewe lamb. Seven such formulas were derived at 5 kg intervals in ewe lamb body weight. Changes in live weight were accounted for by multiplying the appropriate formula by $(1 \pm .0055\ g)$ where g represents gain (or loss) of weight in grams/day (NRC, 1975). The $\pm$ sign was determined by whether the change in weight was a gain (+) or a loss (-).

For the rest of the production years, ewes were treated as mature and, hence, one formula was used for all individuals. The formula used, ME/day = $0.132\ W^{.75}\ (1 \pm .0055\ g)$, was modified from Young and Corbett (1968) and accounted for weight changes from one year to the next in the same manner as before. In all these formulas the ME/day requirements were calculated on the basis of daily maintenance requirements of a nonpregnant and nonlactating ewe. Gestation and lactation requirements were based on the stage of gestation and on the number of lambs born and reared. I. E. Coop (personal communication) suggests that the production year of the ewe on pasture (beginning of one breeding season to the beginning of the next) be divided into three stages, with different ME/day requirements for each stage. A nonpregnant, nonlactating ewe will be on a maintenance diet for 218 d, which includes the period from weaning through breeding in addition to the first 15 wk of gestation. The ewe was charged an equivalent of 1 x ME/day, as calculated by the appropriate formula, for this stage. The second stage of the production year is the last 6 wk of gestation. The ewes' ME/day during this period was computed as 1.5, 1.75 or 1.85 times the daily maintenance requirements of a nonpregnant, nonlactating ewe, depending upon whether the ewe was bearing a single lamb, twins or triplets, respectively. During lactation (105 d), which comprised the third stage of the production year, a lactating ewe with a single lamb required an equivalent of 2.75 times the daily maintenance requirements of a nonlactating ewe, whereas ewes rearing twins or triplets were charged 3.5 x ME and 4 x ME/day, respectively. All of these estimates take into consideration the amount of pasture that might have been consumed directly by the lambs. The Mcal/year for each of the 399 ewes was then computed for each of the production years.

The average cost of a Mcal was calculated based upon partitioning annual feed intake (measured in Mcal) into three parts, 89% coming from pasture, 5.6% from barley (IFN 4-00-549) and 5.4% from grass/legume hay. Barley and hay were consumed when the ewes were brought into the barn during the lambing season. The price per metric ton of barley ($106.92) and of hay ($53.77) were averaged over the five-year period (1974-1978) from the commodity data sheets of the Oregon State University Extension Service. Pasture cost was estimated based on the price of a ton of hay from which the estimated cost of hay making and handling was deducted. The Mcal/kg dry matter (DM) of each of the above ingredients was obtained from the Atlas of Nutritional Data on United States and Canadian Feeds (1971). Once the cost of one Mcal was computed, the feed cost/year and for the period of the experiment were then calculated for each ewe. When a ewe died before the end of a production year, she was charged for feed only up to the time of her death.

Total cost for the first year of production was composed only of the feed cost for that year. Cost of production for the whole experimental period was composed of the sum of annual feed costs plus the ewe purchase cost.

The net revenue for the first year of production for each ewe was estimated by the following formula: Net revenue = gross income (feeder lambs + orphan lambs - foster lambs) - feed cost. The lifetime gross income per ewe was estimated by adding all the income from lambs weaned, lambs sold as orphans and the ewe salvage value, when applicable, and then deducting the cost of foster lambs whose weaning weights were included. The lifetime net revenue was then estimated by subtracting the total lifetime cost of production from the gross income.

Statistical Analysis. Net revenue and the components contributing to that estimate of efficiency were analyzed at two different phases, production as a ewe lamb and life time production (entire period of the experiment). For each of these two stages, there were five dependent variables. For the ewe lambs, these were: income from lambs weaned, income from lambs orphaned, income from lambs weaned plus lambs orphaned, total feed cost and net revenue. For the other stage, the ewe salvage value was added to the sum of the income from weaned and orphaned lambs, and the ewe purchase price was added to the total feed cost. The rest of the variables were the same, except that they represented all the production years involved.

The mathematical model included crossbred group, management system, birth year and all possible two factor interactions as fixed sources of variation. Least-squares analyses of variance (Harvey, 1977) were then performed, and residual correlations among the dependent variables were also computed. Path coefficients were computed describing a cause and effect scheme for lifetime production efficiency (Li, 1976). The least significant difference procedure was the test criterion to analyze differences among the crossbred group means for the various dependent variables (Steel and Torrie, 1980). A random sire of ewe effect was not included in the model because the level of nesting required for determining the sire effect would have introduced computational complexities that would have greatly increased computational costs. Inclusion of sires would have allowed more accurate testing of the statistical significance of differences among crossbred groups. Exclusion of sires did not, however, affect estimates of crossbred group x management system least-squares means nor tests of differences among them, a major goal of the experiment.

Results and Discussion

As shown in Table 1, the distribution of ewes among the eight crossbred groups and the two management systems was fairly even. Least-squares analyses of variance for the first year's production are presented in Table 2, while those for lifetime production are presented in Table 3.

Crossbred group x birth year and birth year x management system interactions were not important in their effects on any of the traits studied. Furthermore, management system and the crossbred group x management system interaction were not important for any of the ewe lamb economic traits. This was to be expected since ewe lambs were not randomly divided between the two management systems until the termination of their first breeding season. Thus there was limited time that first year for management system to exert an effect. Birth year was a significant source of variation on all traits. Certain of these effects are at least partly attributable to 1973 ewes having one more potential year of production than ewes born in 1974. For this reason, and because fixed year effects are not inherently interesting to begin with, there will be no further discussion of these differences.

Income from Lamb Production. Crossbred group of ewe played a significant ($P < .01$) role in affecting the income from lambs born and weaned by ewe lambs. As shown in Table 4, ewes with 50% Finnsheep and 50% Suffolk inheritance (FxS) earned by far the most lamb income when compared to the rest of the crossbred groups. They were followed by the Finnsheep x Columbia-type (FxC) and Dorset x Suffolk (DxS) ewes. The three other crossbred groups with Columbia-type inheritance (Dorset (DxC), Cheviot (ChxC) and Romney (RxC)) were poorest in income from lambs. Hohenboken and Clarke (1981) reported that Finnsheep-sired ewes were the most prolific as ewe lambs and throughout the duration of this experiment. Cedillo et al. (1977) reported that ewes with Suffolk dams reached puberty at an earlier age than those with Columbia-type dams. This could explain part of the difference in income between the two Finnsheep crossbred groups. In the same study, Cedillo et al. (1977) did not find sire breed effects on age at puberty, contrary to the findings of Dickerson and Laster (1975) that Finnsheep crosses were earlier to reach sexual maturity than other breeds and crosses.

Income from lambs produced throughout the duration of the experiment was affected by crossbred group ($P < .01$), management system ($P < .05$), and the crossbred group x management system interaction ($P < .01$). The least-squares means of the different crossbred groups within environments are presented in Table 5. Ewes grazing on irrigated pastures earned, on the average, $13.42 more income from lambs weaned than did ewes grazing on hill pastures. As shown in Figure 1, ChxC and FxC ewes were the only groups to produce more lamb income on hill pastures than on irrigated pastures, contributing to the crossbred group x management system interaction. The relative merit of a crossbred group frequently was dependent upon the environment in which the comparison was made. In particular, FxS and DxS ewes were much more productive on irrigated than on hill pastures; for ChxC ewes, the opposite was true. Those groups with 50% Suffolk inheritance performed much better on irrigated than on hill pastures. Hohenboken and Clarke (1981) discussed this genotype x environment interaction in more detail.

Orphans. There was no significant difference in income from orphans between the two management systems nor among the crossbred groups for the first year of production. Due to a low frequency of multiple births from the ewe lambs (Cedillo et al., 1977), few orphans were produced by the ewe lambs; and orphan lamb income the first year was very low. It averaged only $.71, the equivalent of approximately one orphan/20 ewes.

For the total orphans produced throughout the duration of the experiment, only crossbred group had a significant effect on income from orphan lambs. Finnsheep-sired ewes orphaned more lambs than any of the other crossbred groups. On the average, a FxC ewe orphaned one lamb during the lifespan of the study, while a FxS ewe's income from orphans was approximately equivalent to 0.75 of an orphan. Most breed groups had a similar income from orphans (ranging from $6.42 from ChxS to $2.63 from ChxC) under either environment. Management system was not important in affecting the income from lambs orphaned.

Gross Income. Finnsheep x Suffolk ewes produced the highest gross income as ewe lambs. Finnsheep x Columbia-type and DxS crossbred groups followed, with almost equal income. The other two groups with Suffolk inheritance (ChxS and RxS) were lower but not significantly so. Romney x Columbia-type ewe lambs had the lowest ($P < .01$) income from lamb production and orphan lambs.

Lifetime gross income was affected by crossbred group and by the crossbred group x management system interaction ($P < .01$). While FxS ewes had, on the average, the highest gross income on irrigated pastures, their income on hill pastures was the lowest. On the other hand, FxC ewes had the highest gross income on hill pastures and ranked well above average on irrigated pastures as well. The superiority of the Finnsheep-sired ewes, once orphan lamb income was accounted for, was predicted by Hohenboken and Clarke (1981).

Feed and Total Costs. While the formulas used to calculate ewe energy requirements did not differ among crossbred groups, it is not surprising that crossbred groups did affect feed cost. This significant effect of crossbred group is due in part to the method of estimating the daily metabolizable energy required per ewe. Ewe weight was used as the basis for the determination of ME required per day. Breed differences in weight would therefore lead to differences among groups in ME requirements. Nevertheless, a change of 10 kg in body weight would cause a change of only 13% in Mcal of annual ME per ewe, on a nongestating, nonlactating ewe basis. The effect of differences in number of lambs born and weaned is more significant. From a base of zero lamb production, bearing and weaning one lamb required 55% more energy per year, whereas 80% and 95% more energy per year were necessary for ewes bearing and weaning twins and triplets, respectively. Since crossbred groups differed for prolificacy, it is only natural that feed cost should also be significantly affected by crossbred groups. This breed effect was highly significant for the first year of production. Finn x Suffolk ewes incurred more feed cost than ewes of other groups, consistent with their higher lamb production. The remaining groups were similar for feed cost. For lifetime production, the level of significance for crossbred group dropped ($P < .05$) while the crossbred group x management system interaction became more important ($P < .01$). While FxS and RxS ewes incurred more cost on irrigated than on hill pastures, ChxC ewes were opposite, costing more on hill pastures than on irrigated pastures. All other crossbred groups were similar in total cost of production on both environments. Estimated feed costs per ewe per year were comparable to simulated costs of feeding Suffolk and Columbia-type ewes (the dams of ewes in the current experiment) as reported by Levine et al. (1978).

Net Revenue. Only the FxS ewes had a positive estimated net return for the first year of production. Romney x Columbia ewes had the largest negative estimated net revenue, even though their feed cost for that year was estimated to be the least.

All three main effects had a significant influence on estimated lifetime net revenue per ewe. The crossbred group x management system interaction was also significant. Finn x Suffolk and FxC ewes excelled on irrigated and hill pastures, respectively, over the other crossbred groups. Finn x Columbia-type, DxS and DxC ewes had similar net revenues under irrigated pasture conditions, all generating greater than average net revenue. While ChxC ewes ranked second on hill pastures, on irrigated pastures their estimated net revenue was poorest of all groups. In Figure 2, net revenue of each crossbred group under both environments is illustrated.

The superiority of Finn-sired ewes over crosses involving other breeds examined in this study was reported by Meyer et al. (1977). They compared Finn x Romney to Dorset x Romney and Cheviot x Romney ewes (in addition to other crosses) and found that Finn crossbred ewes were superior in income/ewe to all crosses as well as to straightbred Romneys. Sorrenson and Scott (1978), in evaluating exotic breed crosses, concluded that Finn, Dorset and Cheviot importations into New Zealand could result in an internal rate of return on investment of approximately 25%. Dickerson (1977) suggested that the use of F_1 Finncross ewes (with such breeds as Dorset, Suffolk, Targhee or Rambouillet) mated to meat-type rams could reduce ewe costs per unit weight of market lamb by 20-50%, compared with Rambouillet x domestic crossbred ewes.

It was not feasible to include accurate estimates of wool income per individual ewe in these analyses. It is unlikely that this exclusion influenced our findings significantly. That is, breed rankings within environments would not likely have been altered by consideration of wool income. Thomas and Whiteman (1979a,b) and Drummond et al. (1980) found some reduction in fleece weight and quality from crosses involving Finnsheep. Nevertheless, Cedillo et al. (1977) analyzed the first year gross income (including wool income) of the ewes in the present experiment and reported that FxS ewes generated the highest income whereas the RxC group generated the least. The ranking of the other crossbred groups agreed completely with their rankings in this study for the first year of production.

Variation in Net Revenue and Its Components. To document the large variation among ewes in productivity, extremes in total production per 1973-born ewe which survived through the entire experiment are shown in Table 6. Two ewes under hill pasture management produced no lamb income at all and were credited only with salvage value of $20.00 each. One of them never lambed and probably was barren. The other lambed one time but did not raise a lamb to weaning. At the other extreme, one FxS ewe on irrigated pastures produced gross revenue of $342.70. Usually the ewe with the least gross income also had the lowest net revenue and the one with the highest gross income also had the highest net revenue. The range in total net revenue from the best to the poorest ewe on hill pastures was approximately $260.00, while on irrigated pastures this range was a little over $215.00. Within crossbred group x management system subclasses, the range in estimated net revenue from best to poorest ewe ranged from $51.00 (ChxS ewes on irrigated pastures) to $202.00 (FxS ewes on irrigated pastures). With this much individual variation, it is surprising that any main effects or interactions were significant and that R^2 values from the analyses were as large as they were.

It is also noteworthy that on hill pastures, the percentage of 1973-born Suffolk crossbred ewes that survived the course of the experiment was consistently lower than the percentage of Columbia-type crossbreds that survived. On irrigated pastures, there was no consistent difference in survival percentage of these two groups. Hohenboken and Clarke (1981) discussed this genetic x environmental interaction in greater detail.

If a ewe's genetic merit for lifetime net revenue could be predicted accurately from traits measured early in life, it would be of great benefit to production efficiency. Other papers in this series report on efforts to identify such traits (Saoud and Hohenboken, 1983b,c).

Residual Correlations. Residual correlations among the ten dependent variables were computed and are presented in Table 7. Because of the way the components of production efficiency were defined, many of the traits have a part:whole relationship, which contributes to the large magnitude of many of the correlations. Correlations between income from lambs weaned and from lambs orphaned, which does not represent a part:whole situation, were very close to zero.

In Figure 3, a path coefficient diagram showing relationships among lifetime net revenue and its components is presented. In the diagram, a zero correlation between salvage value of the ewe and both feeder lamb and orphan lamb income was assumed, which probably is not true. Ewes not surviving the entire duration of the experiment (and therefore having zero salvage value) would have, on the average, less lamb and orphan lamb income than ewes which did have a nonzero salvage value. Granting this invalid assumption, the effect of variation among ewes in lamb income was much greater than that of variation among ewes in either orphan lamb income or salvage value in explaining variation among ewes in gross income. Likewise, variation among ewes in gross income was more important in explaining differences among ewes in net revenue than was variation among ewes in estimated costs. The path coefficient between gross income and net revenue shows that by increasing gross income by approximately one phenotypic standard deviation, net revenue would increase by 1.7 phenotypic standard deviations, if feed costs were not affected. On the other hand, decreasing the feed cost by one standard deviation, while gross income remained constant, would be expected to lead to an increase in net revenue of approximately 0.9 standard deviations.

Chapter 3

PHENOTYPIC RELATIONSHIPS AMONG EARLY LIFE TRAITS AND LIFETIME EWE PRODUCTION EFFICIENCY[1]

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Summary

In least-squares analyses of variance, ten ewe lamb traits were used, singly and in various combinations, to predict lifetime production efficiency. Ewes belonged to eight crossbred groups and were raised on two management systems for either 4 or 5 yr of production. Lifetime production efficiency components were total feed and ewe ownership cost, gross income and net revenue. A ewe lamb's type of birth, date of birth, actual and adjusted weaning weight (WWt and AWWt), postweaning weight (PWWt) and first year gross income (FGROS) were significantly phenotypically related to the ewe's lifetime production efficiency. While triplets were better than either of the other two birth types, single-born ewes were better than twin-born ewes for lifetime production efficiency. Any of the three ewe-lamb weights (AWWt, WWt or PWWt) appeared to be accurate estimators of lifetime production efficiency, and actual weaning weight explained slightly more variation in future production than did adjusted weaning weight. The effect of first year productivity was largely a part:whole relationship with lifetime production since the regression coefficients of subsequent lifetime production efficiency (not including first year production) on first year productivity were near zero. Postweaning average daily gain, ewe age at first estrus and date of first lambing at 12 mo of age did not have significant relationships with lifetime production efficiency. When a ewe's type of birth, date of birth, weaning weight and first year gross income were analyzed simultaneously, weaning weight and FGROS had the greatest effect on lifetime production efficiency. When AWWt and type of birth were considered simultaneously, both had significant relationship with lifetime production efficiency.

(Key words: Ewe lamb traits, lifetime production efficiency, indicators of production efficiency, crossbred sheep)

Introduction

Genetic improvement in lifetime production efficiency is dependent upon selection for traits with which lifetime production efficiency is genetically correlated. Many early life traits have been suggested and are being used as selection criteria. Multiple-born ewes have been reported to have an advantage over those born as singles (Turner, 1969; Hanrahan, 1976; Turner, 1978). Furthermore, ewes born early in the lambing season may be preferred over those born later in the season (Thrift et al., 1971). Age at first estrus (Hulet et al., 1969) and whether a ewe did or did not lamb at 12 mo of age (Levine et al., 1978) have been reported to be predictive of the ewe's subsequent production efficiency. Selection based upon ewe lamb growth rate and weaning and postweaning weights has also been recommended (Olson et al., 1976; Scott, 1982). Basuthakur et al. (1973) and High and Jury (1976) found that yearling weight was positively correlated with all measures of lamb and wool production.

The purpose of this study was to assess the phenotypic relationship of various ewe lamb traits with lifetime production efficiency.

Materials and Methods

Eight crossbred ewe groups from two birth years were maintained on either irrigated pastures or on dryland hill pastures for 4 or 5 yr of production. Ewes were sired by North Country Cheviot, Dorset, Finnsheep and Romney rams that were mated to Suffolk and Columbia-type ewes. Hampshire sires were used as the terminal sire breed on the crossbred ewes throughout the experiment. Ewes were mated to lamb first at approximately 12 mo of age. For further information about the population and management, see Cedillo et al. (1977) and Levine and Hohenboken (1978). Annual and lifetime feed and ewe ownership cost, income from lamb production and ewe salvage value (when appropriate) and net revenue per ewe were estimated and discussed in an accompanying paper (Saoud and Hohenboken 1983a). Partial lifetime production, cost and net revenue were calculated by deducting each ewe's first year production, cost and net revenue from her lifetime values for each respective economic trait. This allowed examination of the relationships among production during a ewe's first year with subsequent production without complications from part:whole relationships among the traits.

Statistical Analysis. One discrete and nine continuous ewe lamb traits were examined as possible indicators of lifetime production efficiency. These indicators were the ewe's birth type, birth date within her lambing season, actual weaning weight, weaning weight adjusted for age of dam, birth date and type of birth and rearing, postweaning average daily gain, postweaning weight, age at first estrus, date of her first lambing at 12 mo of age (when appropriate) and first year gross income and net revenue. The adjustments made on weaning weight are similar to those recommended and practiced in the sheep industry and were described by Scott (1982).

The importance and effect of the indicator traits were assessed as follows. First, the data for gross income, cost and net revenue were analyzed (Harvey, 1977) using a model with discrete, fixed sources of variation for crossbred group-management system subclass (16 groups) and birth year (2 groups). Preliminary analyses indicated that the interaction between these effects was not important, so it was not included in subsequent analyses. The possible indicator traits were then added to the model, alone and in various combinations. Changes in R^2 attributable to the addition of an effect or effects, the level of statistical significance associated with the added variable or variables and the least-squares means or regression coefficients were then examined. For continuously distributed indicator traits, the models included pooled and within crossbred group-management system subclass linear and quadratic regressions.

Nine dependent variables representing three stages of the ewe's lifetime production period were studied. These included, for each ewe's first production year: feed cost (FCOST), income from lambs weaned and lambs sold as orphans (FGROS) and net revenue (FNTRV) which is the difference between (FGROS) and (FCOST); for the lifetime production period: Total cost (LCOST) which includes ewe ownership as well as feed cost, gross income (LGROS), which includes ewe salvage value when applicable, and net revenue (LNTRV); and for partial lifetime production: Partial cost (PCOST) = (LCOST) - (FCOST), partial gross income (PGROS) = (LGROS) - (FGROS) and partial net revenue (PNTRV) = (PGROS) - (PCOST). Estimation procedures for these traits were described in detail by Saoud and Hohenboken (1983a).

Results and Discussion

Individual Indicators

Results of the analyses involving potential indicators of first year, lifetime and partial lifetime production efficiencies are presented in Tables 8, 9, and 10, respectively.

Type of Birth. Of 399 ewes in the experiment, 117, 257 and 25 were born as singles, twins and triplets, respectively. Addition of ewe's type of birth to the basic model increased R^2 values for the various dependent variables by .05 to .09. Two-factor interactions of birth type with crossbred group-management system subclass and with birth year were not significant for any of the nine dependent variables. They were, therefore, not included in subsequent analyses. For all three production stages, cost was the major component of efficiency that was significantly affected by the ewe's birth type. Twin-born ewes had lower costs than ewes born either as triplets or as singles. Lifetime gross income was also significantly ($P < .05$) affected by birth type. Triplets surpassed both twins and singles in dollars earned and singles surprisingly performed better than twins. Several workers have reported successful selection for increased reproduction rate (Clarke, 1972; Hanrahan, 1976; Turner, 1978, for example) even though heritability of multiple births is reported to be low (Terrill, 1958; Mechling and Carter, 1969; Turner, 1969). While net revenue for the three stages of production was not significantly affected by birth type, single-born ewes were, on average, more efficient than twin-born ewes. These findings are in apparent contradiction with conclusions of Turner (1969), who summarized results from 10 studies representing several breeds and breed combinations. All except one reported an advantage of twin- or multiple-born ewes over single-born ewes in number of lambs born per ewe mated. Examination of our data revealed three reasons that could have contributed, jointly or individually, to the advantage of single-born ewes over those born as twins. First, single-born ewes were approximately 5.9 kg heavier at weaning that twin-born ewes (Levine and Hohenboken, 1978). This difference would not be expected to decrease significantly by the beginning of the ewes' first breeding season. Ewes heavier at the onset of the breeding season are more sexually mature than their lighter contemporaries (Hulet et al., 1969). This difference could have affected first year production (Table 1) but probably would not carry over to account for differences in subsequent (partial) production. Second, fertility percentages of single- and twin-born ewe lambs were 55.6% and 43.6%, respectively. Hence the average income from lambs produced the first year should be greater for the single-born than for the twin-born ewes. Again, this difference should not carry over to influence partial production. Third, twin-born ewes had a slightly higher attrition rate than single-born ewes; 86.3% vs. 79.4% of single vs. twin ewes survived the duration of the experiment. Ewes surviving the four or five production years would not only have higher income from lamb production than ewes dying before termination of the experiment, they also would benefit from ewe salvage value (Saoud and Hohenboken, 1983a). Furthermore, single-born ewes produced, on the average, 5.89 lambs and weaned 4.62 lambs whereas those born as twins produced and weaned 4.95 and 4.01 lambs, respectively. Thrift and Dutt (1976) reported that single-born ewes lambed and reared .05 and .04 more lambs than did twin-born ewes, the difference not being statistically significant. Excluding the number of lambs born and weaned during the first year from lifetime production did not affect the ranking of single-born ewes compared with the twin-born ewes for lamb production. Single-born ewes bore and weaned 5.03 and 4.11 lambs, respectively; twin-born ewes bore and weaned 4.30 and 3.41 lambs, respectively, for the same period. To further illustrate this point, lambs born to Finn-sired ewes in both environments are documented in Table 11. Single-born Finn-sired ewes were more prolific in all four groups than were their twin-born counterparts. Being the most prolific of the crossbred groups, Finn-sired ewes were selected to demonstrate this effect. However, it is not restricted to this crossbred group.

Date of Birth. Ewe's birth date was added to the basic model as a continuous independent variable, and the economic components of efficiency were regressed upon it. The regression coefficients for the first year components of production efficiency on ewe birth date were significantly negative. Ewes born early in the lambing season thus performed better during the first year than ewes born later in the lambing season. This effect was not, however, carried over in subsequent production years. Thrift et al. (1971) reported that selection for early-born lamb replacements and the culling of barren and late lambing ewes could improve overall reproductive performance of the ewe flock. They concluded, however, that changes in lamb traits (e.g., date of birth, rate of gain from birth to 120 d and 120 d weight) had not changed significantly over a 14-yr selection period.

Ewe Lamb Weaning Weight. Lambs were weaned at an average age of 115 d. Actual weaning weight (WWt) and weaning weight adjusted for age of dam, date of birth and type of birth and rearing (AWWt) were each added separately to the basic model as continuous independent variables. Pooled linear and quadratic regression coefficients of first year gross income and net revenue on actual weaning weight were significantly different from zero. However, significance for quadratic effects did not hold for either lifetime or partial lifetime components of production efficiency. Within crossbred group-management system subclass regression coefficients were not significantly different from each other for any of the nine dependent variables.

Actual and adjusted weaning weights were good indicators of lifetime and partial lifetime productivities, as evidenced by substantial increases in R^2 from their addition to the basic model. Actual weaning weight explained slightly more variation than did adjusted weaning weight. Regression coefficients of the lifetime and partial lifetime components of production efficiency on actual and adjusted weaning weight were significantly ($P < .01$) different from zero. For each 1 kg increase in actual weaning weight, a ewe was expected to earn \$3.17 more in gross income and \$1.75 more in net revenue. The regression coefficient of lifetime gross income on adjusted weaning weight was \$3.25 per kg increase. Although none of the quadratic regressions for partial or lifetime efficiency components was significant, it is noteworthy that all coefficients were positive. Thus, there is no suggestion of an intermediate optimum weaning weight for future productivity as was reported by Etienne and Martin (1979) in beef cattle. Heritabilities of preweaning growth rate and of weaning weight are estimated to be low to moderate (Olson et al., 1976 and Thrift et al., 1973 for example). Therefore selection based upon weaning weight might lead to only small improvements in lifetime production efficiency.

Postweaning Average Daily Gain (ADG). Ewe lambs were weighed 7 wk after weaning at an average age of approximately 23 wk. Postweaning ADG was then used as a continuous independent variable in regression analyses for the nine dependent variables.

Despite increases in R^2 from the basic model ranging from .06 for FNTRV to .10 for LNTRV, none of the regressions on ADG was significant; and all were close to zero. Harrington et al. (1962) estimated the heritability of postweaning ADG to be $.38 \pm .13$ which leads to the prediction that selection for this trait would cause genetic improvement in postweaning ADG of the flock. However, based on this study, selection for postweaning ADG would not improve lifetime production efficiency. This could be attributable partially to the way efficiency was estimated in this study. Weight of lambs weaned rather than lamb market weight constituted the major component of income.

Postweaning Weight. The heritability of this ewe lamb weight, at 22 wk of age as estimated by Olson et al. (1976), is in the neighborhood of .44. Any improvement in this trait should cause simultaneous improvement in those traits positively genetically correlated with it. The inclusion of the ewe lamb's postweaning weight as a continuous independent variable caused increases in R^2 values ranging from .16 to .25 for the various dependent variables. Furthermore, an increase of 1 kg in a ewe lamb's postweaning weight resulted in an increase in estimated first year gross income of about 92 cents. This was carried over throughout the ewe's lifetime to add \$1.53 and \$2.45 to PGROS and LGROS, respectively. First year, lifetime and partial lifetime net revenue increased by \$.71, \$1.43 and \$.72, respectively, per kilogram increase in postweaning weight. These results are consistent with others in the literature dealing with the relationship of postweaning weights and yearling weights to subsequent production in sheep (e.g., Terrill and Stoehr, 1942; Purser and Roberts, 1959; Shelton and Menzies, 1968; Hight and Jury, 1976; Elliott et al., 1979).

Age at First Estrus. Meyer (1981) found that ewe lamb age at first estrus tended to be phenotypically associated with live weight and that a small phenotypic relationship existed between age at first estrus and subsequent mature reproductive performance. The inclusion of ewe age at first estrus raised R^2 by about .08 for the first year components of production efficiency and from .05 to .07 for subsequent production efficiency. Nevertheless, the regression coefficients of all nine dependent variables on age at first estrus were not significantly different from zero. These findings are in disagreement with those of Hulet et al. (1969) and Meyer (1981). Meyer (1981), however, suggested that the genetic correlation between hogget estrus and later reproduction levels was near zero.

Date of First Lambing. This ewe lamb trait could be related to age at first estrus. Ewe lambs cycling at an earlier age are expected to lamb earlier during the subsequent lambing season. Measurements of age at first estrus (Cedillo et al., 1977) were error prone, since they depended upon raddle marks on ewes mounted by vasectomized rams. Date of first lambing could be a more accurate indicator of the ewe lamb's postweaning estrus activity. In addition a ewe lambing early in the season would likely wean heavier lambs and therefore produce higher gross income. A possible disadvantage of early lambing, though, is that ovulation rate (and subsequent twinning rate) tends to increase, then decrease, as the breeding season progresses (Lamberson and Thomas, 1982).

The basic model here was the same as for the rest of the indicators, but the population included only those ewe lambs that lambed during the first year of production. This constituted about 50% of the total population. When date of first lambing was added to this basic model, R^2 values increased by .11, .16 and .16 for first year feed cost, FGROS and FNTRV, respectively. For lifetime performance,

R^2 increased from .23 to .38 for LCOST, .28 to .38 for LGROS and from .30 to .38 for LNTRV. For partial lifetime components of production efficiency, the increases in R^2 were greater than those for the comparable components of lifetime production efficiency (Table 3). Nevertheless, the regression coefficients of FCOST, FGROS and FNTRV on date of first lambing were close to and not significantly different from zero. For lifetime and partial lifetime components of production efficiency, the regression coefficients also were not significantly different from zero. They were, however, of substantial magnitude and suggested, if anything, that lambing later in the season the first production year led to an increase in subsequent production, a surprising result.

First Year Productivity. Levine et al. (1978) reported that ewes lambing as ewe lambs were more productive in subsequent years (excluding their first year's production) as well as cumulatively (including the first year production) than were ewes who did not lamb though given the opportunity to do so. They reported, however, some differences among breeds for the effect of first year production on subsequent ewe productivity. In this study, ewe lamb's FNTRV and FGROS were used separately as independent continuous variables added to the basic model. The increase in R^2 from FGROS was greater than the increase in R^2 from FNTRV for each of the six dependent variables. The pooled linear regression coefficients of PCOST, PGROS, PNTRV and LCOST on FGROS and FNTRV were not significantly different from zero. LGROS and LNTRV, however, had a positive relationship with first year production efficiency. A ewe having a $1.00 increase in FGROS and FNTRV was predicted to have $1.18 and $1.07 more in LGROS and $0.98 and $0.89 more in LNTRV, respectively. These regression coefficients are close to $1.00, so the increase in lifetime income largely was a carryover of the first year productivity. First year gross income and FNTRV were not accurate indicators of subsequent productivity excluding the first year production. There was much variation among crossbred group-management system subclasses in the effect of FGROS on subsequent productivity of the ewes. Within crossbred group-management system regression coefficients of LGROS, LNTRV, PGROS and PNTRV on FGROS are presented in Table 12. With such heterogeneity among within crossbred group-management system regressions, it is not surprising that the pooled regressions did not differ from zero. These findings are in conflict with those of Levine et al. (1978).

Individual indicators that were significantly related to components of production efficiency as defined in this study included ewe lamb's birth type, birth date, weaning and postweaning weights and ewe lamb production efficiency (FGROS and FNTRV). Postweaning average daily gain, age at first estrus and date of first lambing did not influence components of production efficiency.

Combinations of Indicator Traits

Several combinations of the indicator traits that were significantly related to the components of production efficiency were analyzed. Results of five of these models are presented in Tables 13 and 14 for lifetime and partial lifetime components of efficiency, respectively. First year production efficiency was not analyzed by multiple regression analysis since one of its components (FGROS) was used as an indicator.

Model I. When type of birth, the ewe's own date of birth, actual weaning weight and FGROS were used in combination, R^2 for LGROS increased from .19 (from the basic model) to .41 (Table 6), while R^2 for LNTRV increased from .21 to .46. The changes in R^2 for partial lifetime production efficiency components were not as large as they were for lifetime productivity. For partial lifetime efficiency components, only actual weaning weight had a significant effect. For lifetime productivity, FGROS was also significantly related to LGROS and LNTRV. This is understandable since when testing cumulative lifetime production efficiency, FGROS shares a part:whole relationship with LGROS and LNTRV. It is interesting that when these indicator traits were considered in this combination, the effect of type of birth on partial or lifetime efficiency was no longer significant. Also, least-squares constant estimates from model I, though not significant, showed the expected superiority of triplets over twins and of twins over singles for the traits. Thus, the previously discussed superiority of single-born over twin-born ewes was associated with some combination of birth date, actual weaning weight and first year lamb production.

Model II. A common industry recommendation (Scott, 1982) is to select ewe lamb replacements from among multiple-born ewes with the highest adjusted weaning weights. These two traits were therefore examined in combination. Both indicators were significantly related to lifetime productivity whereas only AWWt was significantly ($P < .05$) related to PGROS under the same model. Including type of birth in addition to AWWt resulted in a very small increase in R^2 for PGROS (from .25 to .26) and for LGROS (from .26 to .28) as compared to having AWWt as the only indicator trait in the model. Based on these data, birth type in addition to AWWt did little to improve accuracy of predicting subsequent ewe productivity.

Models III, IV and V. The purpose of these models was to compare the three weights when used alone to when used in combination with first year gross income (FGROS) and to compare the three models with each other. As shown in Tables 2 and 6, R^2 for each of the three models increased substantially for each of the lifetime production efficiency components over the corresponding R^2 of the three weights used as individual indicators. Comparing R^2's of these three combination models to those R^2's obtained when using FGROS as a single indicator shows that the change was smaller. In all three cases, when FGROS was added to the model, the change in lifetime gross income corresponded to the first year contribution to the cumulative income. Therefore the significance associated with the addition of FGROS as an indicator in combination with any of the ewe-lamb weights was merely a part:whole relationship and added little to the accuracy of prediction. This is verified by examination of effects of FGROS in combination models III through V on the partial lifetime production efficiency components. The regression coefficients on

FGROS are very close to zero for all three components (Table 14).

Comparing models III and IV, it is evident that adjusting weaning weights for age of dam, date of birth and type of birth and rearing did not, in these data, add any improvement to the accuracy of the multiple regression model. All three models, for both lifetime stages and for each of the production efficiency components, were approximately equivalent in the amount of variability explained by the indicator traits.

Conclusions

Uncorrected weaning weight seemed to be as accurate as adjusted weaning weight in predicting lifetime efficiency of ewes of the different crossbred group-management system subclasses. Since lamb production was the major component of gross income, it might have been predicted that ewe lamb weaning weight would be a good predictor of lifetime production ability. It was reasonably highly and positively related to production efficiency. Postweaning weight also was a good predictor of lifetime gross income and net revenue. These data indicate that selecting twin- over single-born ewes as the sole criterion would not be expected to improve the productive merit of the flock. Other factors would need to be considered when choosing between a twin- or a single-born replacement.

We emphasize that relationships reported in this experiment are phenotypic and may or may not reflect genetic correlations among the indicator and lifetime efficiency traits. In the final paper of this series (Saoud and Hohenboken, 1983c) we conduct "paper selections" to determine what the effect on flock productivity would have been, if selection of 30% of the ewes of each crossbred group-management system - birth year subclass had been selected according to various criteria. We also report how the elite ewes, based upon lifetime productivity, compared to the overall population averages for early life traits as well as to the averages of the less productive ewes.

Chapter 4

THE EFFECT OF SELECTION IN RETROSPECT ON LIFETIME PRODUCTION EFFICIENCY IN SHEEP[1]

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Summary

Within crossbred group paper selection based upon several ewe-lamb traits, singly or in combination, was analyzed; and the change in ewe lifetime production efficiency of the selected populations compared to the overall population was assessed. Ewes were from two birth years, eight crossbred groups and two management systems. Ewe's type of birth, date of birth, actual and adjusted weaning weight (WWt and AWWt), postweaning weight (PWWt) and first year gross income (FGROS) were the ewe lamb traits involved in the single trait paper selection schemes. Only the ewe lamb weights (WWt, AWWt and PWWt) caused a significant increase in the production efficiency of selected populations over those of the corresponding unselected populations. When postweaning weight was used jointly with the ewe's type of birth in an independent culling level selection scheme, both the group composed of heavier multiple-born ewes and the group composed primarily of single-born ewes were more productive than the group composed of lighter multiple-born ewes. Backward selection of the elite ewes having the best production efficiency also showed that the heavier the ewe lamb, the more efficient it was expected to be. Examination of ewes surviving the entire duration of the experiment failed to identify any early life trait that predicted longevity. Furthermore, surviving ewes were equally variable in their early life traits to the populations at large.

(Key words: Sheep, selection in retrospect, lifetime production efficiency)

Introduction

In commercial sheep production, farmers generally choose as replacements only a portion of those ewe lambs available each year. Unselected females are usually either sold as feeder lambs or are fattened on the farm and then sold for slaughter. Either way, unselected ewe lambs are prevented from proving their potential and hence, the breeder cannot ensure that selection was optimal. In most situations, selection is according to accepted, 'traditional' criteria. It would be desirable that each selected ewe be fertile and productive and that it survive throughout the expected life span of ewes in the flock. This is far from being the situation in practice. In surveying the literature, few reports dealing with unselected populations of farm animals were found. The cost of maintaining an unselected population for conducting long term studies of that sort is often prohibitive.

In an accompanying paper, Saoud and Hohenboken (1983a) defined lifetime production efficiency (LPE) in a mildly selected and an unselected sheep population and computed per ewe estimates of LPE and its components. The relationships of several ewe lamb traits to LPE also were assessed (Saoud and Hohenboken, 1983b). The objectives of this study were, within ewe birth year group, 1) to conduct "paper selection" of replacement ewe lambs based upon various individual selection criteria and to compare average LPE of the selected groups to that of the total unselected populations, 2) to divide the entire populations into upper, middle and lower thirds based upon independent culling level selection on multiple births and postweaning weight and to compare LPE of the groups, 3) to divide the entire populations into upper, middle and lower thirds (based upon estimated LPE) and to compare early life traits of the groups to the population at large and 4) to determine whether ewes which survived throughout the duration of the experiment differed in early life traits from the unselected population averages.

Materials and Methods

The population was composed of eight crossbred groups, from Suffolk and Columbia-type ewes mated to North Country Cheviot, Dorset, Finnsheep and Romney rams during two years. Crossbred ewe lambs born in 1973 were subjected to mild selection, with approximately 80% of each crossbred group being retained. Selection criteria were thriftiness, body size and overall health. All surviving lambs born in 1974 were retained without any artificial selection. The 399 ewes were divided randomly within crossbred group and year into two populations, one maintained on dryland hill pastures and the other on irrigated pastures. Hampshire rams were used as terminal sires throughout the study. The experiment was terminated after weaning of the lambs born in 1978, so 1973 and 1974 ewes had the opportunity for 5 and 4 years of production, respectively. For each ewe, estimated annual feed cost, gross income and net revenue and lifetime and partial lifetime production efficiency (LPE) and its components were then computed and analyzed (Saoud and Hohenboken, 1983a). Partial lifetime traits were computed as total lifetime production (gross income or net revenue) minus production during the ewe's first year (when mated to lamb at approximately 1 yr of age). The population and management systems were described in greater detail by Cedillo et al. (1977) and Levine and Hohenboken (1978).

Single Trait "Paper Selection". Six ewe lamb traits were evaluated as selection criteria. These traits were found, by analysis of variance, to be related to LPE and its components by Saoud and Hohenboken (1983b). For each birth year group, approximately 30% of the ewes within each crossbred group-management system subclass were selected based upon phenotype for each of the indicator traits. The selection intensity of 30% was considered to be realistic considering average prolificacy, lamb survival and ewe lifespan in the experimental populations (Hohenboken and Clarke, 1981).

For type of birth, all triplet-born ewe lambs first were selected; then replacements to equal 30% of each groups were chosen randomly from the twin-born ewes. No single-born ewes were selected in any group. For date of birth as a selection criterion, the earliest born ewes in each group were selected. For actual and adjusted weaning weights (WWt and AWWt) and postweaning weight (PWWt), the heaviest ewes per group were retained. For first year gross income (FGROS; that is, production of ewes mated to lamb at approximately 1 yr of age), the ewes in each group earning the most or losing the least money were selected.

The effect of single trait, paper selection according to each of the six criteria was assessed as follows. First, for each birth year separately, a least-squares analysis (Harvey, 1977) was performed on data from the entire unselected populations. The LPE components were dependent variables and crossbred group-management system subclass was the independent variable. Overall least-squares means and standard errors were noted from these analyses. After paper selection, comparable least-squares analyses were conducted on data from the ewes retained by selection for each trait. These least-squares means for LPE were compared to those of the unselected groups, to assess what the impact on productivity of the selection would have been.

Independent Culling Level Paper Selection. Separately for each birth year, the populations were divided into three approximately equal groups based upon two lamb traits (type of birth and postweaning weight) by independent culling level selection. The three groups will henceforth be called thirtiles. Type of birth was considered to be of two categories, multiple or single birth. For each birth year and within crossbred group-management system subclass, multiple-born ewes with the heaviest postweaning weight were selected to make the first thirtile. The middle thirtile was also composed of multiple-born ewes but these had lighter postweaning weights. The last thirtile was comprised mainly of single-born ewes but included the remaining multiple-born ewes not previously selected. This selection scheme was chosen because it would be a practical means for commercial growers to practice sequential selection, on birth type at weaning and on weight at the start of the breeding season.

To assess the effectiveness of the independent culling level selection, arithmetic means of the three groups within each birth year were compared, for LPE and its components (including those for partial lifetime production) and for early life traits as well. Coefficients of variation also were computed, to allow examination of effects of the selection on variability of early life or LPE traits.

Backward Selection. For each birth year group, ewes were ranked within crossbred group-management system subclass based upon lifetime gross income (LGROS), partial lifetime gross income (PGROS), lifetime net revenue (LNTRV) and partial lifetime net revenue (PNTRV). The populations were then divided into three approximately equal thirtiles. The arithmetic means, standard errors and coefficients of variation of LPE and the ewe lamb traits of each of the thirtiles were then computed and compared to identify any differences among the elite ewes for LPE and their mediocre and inferior contemporaries.

Early Life Traits and LPE of Surviving Ewes. The last analysis involved those ewes surviving the entire duration of the experiment. For each birth year, the means, standard errors and coefficients of variation for early life traits as well as the components of LPE of the surviving ewes were compared to those of the populations at large.

Results and Discussion

Single Trait Selection

The least-squares means of lifetime and partial lifetime gross income and net revenue for the two unselected and the various selected populations are presented in Table 15.

Type of Birth. Selection of all the triplets in addition to random selection among twin-born ewes had little impact on production efficiency in either birth year group (Table 15). The effect on LNTRV of the "paper selection" was only $1.38 for 1973 ewes and $-3.73 for 1974 ewes, neither difference being significant. Differences in the other LPE traits from the paper selection also were not significant. Saoud and Hohenboken (1983b) discussed possible reasons that ewe birth type in the experiment was not predictive of subsequent productivity.

Ewe's Date of Birth. The use of this ewe lamb trait as a selection criterion resulted in insignificant increases in means of LGROS, LNTRV, PGROS and PNTRV of the 1973 selected groups as compared to the unselected population. This was not consistent with 1974, however, where the effect of paper selection for date of birth on all four production efficiency traits was negative but close to zero.

Weaning Weights. Both actual and adjusted weaning weights (WWt and AWWt, respectively) were consistent over the two birth years in increasing the lifetime and partial lifetime production of the selected ewes above those of the unselected populations. While WWt and AWWt caused similar increases in the least-squares means of the four production efficiency components for the first birth year, WWt caused consistently though not significantly greater increases than AWWt for LPE in the second birth year. The increases in LPE of the selected populations over those of the unselected groups support the conclusions of Saoud and Hohenboken (1983b) that actual or adjusted weaning weights would be accurate predictors of lifetime production efficiency as defined in these experiments.

Postweaning Weight. Paper selection for PWWt consistently increased LPE estimates, compared to values in the unselected populations, for both birth year groups. In most cases, there was a modest but not significant advantage of PWWt selection over selection for WWt or AWWt. This trait, however, requires a delay in the selection process beyond weaning, as well as an additional handling of the ewe lambs before they enter the first breeding season at 7 mo of age. The advantages, however, could be rewarding, especially if the genetic relationship between postweaning weight and lifetime production efficiency were higher than that of weaning weights with subsequent production.

First Year Gross Income. The effect of this ewe lamb trait was not consistent between years. Its part:whole relationship to LGROS and LNTRV did result in improvement in these two lifetime production efficiency traits from paper selection for FGROS. For 1973-born ewes, it also resulted in a modest, nonsignificant improvement in PGROS and PNTRV, with which it does not have a part:whole relationship. This was not true for the 1974 group.

Of early life traits examined in this experiment, ewe lamb weaning or postweaning weight appears to be the best single criterion upon which selection should be based to increase lifetime production efficiency.

Independent Culling Level Selection

For each birth year, arithmetic means and standard errors for early life and LPE traits of unselected populations and the three selected groups are presented in Table 16; coefficients of variation are presented in Table 17. Differences in average birth date of ewes from the different thirtiles were not significant but there was a tendency in both years for ewes in the top group to have been born early in the season. Coefficients of variation among groups within years also were similar.

Thirtiles differed significantly and systematically each year for type of birth, which was expected since this was one of the two criteria employed in the selection exercise. For 1973, the ratio of twins to single lambs in the bottom group was approximately one to six; for 1974, this ratio was approximately one to three. This could influence differences in results between the two years involving the bottom groups of ewes. The coefficients of variation for type of birth indicate that the upper two thirtiles were more uniform than were the respective populations at large and the lowest groups.

Again, this difference was imposed by the method of selection employed. Thirtiles also differed for PWWt's but, in both years, the top and bottom groups had the heavier weights. Ewes in the first group were heavy because of the selection method imposed. Ewes in the bottom group were heavy because they were predominantly of single- as opposed to multiple-birth type. We believe that this bimodal distribution for PWWt (and for WWt and AWWt to a similar extent) imposed by the method of selection is responsible for some of the apparently anomalous results for LPE.

For the 1973 birth year, the highest and lowest groups had similar total numbers of lambs born and weaned, while the number of lambs produced and weaned by the middle group was significantly less. This same tendency existed for 1974, but the differences were not as large. Though middle groups produced fewer lambs, they had moderately larger coefficients of variation than upper and lower groups.

For the 1973 birth year, selected groups were markedly different from each other for all four LPE traits presented in Table 16. The upper group ranked highest for all efficiency traits, by a substantial margin; but the lowest thirtile was substantially higher than the middle group for all LPE estimates. These rankings were consistent (except for LNTRV) in 1974, but differences among groups were not nearly as large. The data suggest that single-born ewes (the lower thirtile) are more productive than multiple-born ewes that are light in body weight at the start of their first breeding season (the middle thirtile).

Based upon findings from both birth years, the first thirtile, with the heaviest multiple-born ewes, would be more productive than either of the other two groups. Therefore, the selection system applied here would successfully have identified the most efficient of the three groups. It would not, however, have identified the most efficient third of all ewes available for selection. From data to be presented, the top 33% of 1973-born ewes for LNTRV averaged $65.05, compared to $30.91 for the top 33% of ewes from the independent level selection. Comparable averages for 1974-born ewes were $37.15 and $9.12. Culling all the single-born ewes at weaning based on their type of birth resulted in less than maximum improvement in LPE. It appears that a scheme allowing selection of some single-born ewes would be appropriate, possibly an index combining birth type of the individual and information from relatives with weaning or postweaning weight.

Backward Selection

The four backward selection criteria (LGROS, LNTRV, PGROS, PNTRV) produced similar results and hence only results for LNTRV will be presented and discussed. For both birth years, birth date averages of each thirtile were not significantly different (Table 18), nor did the within-group variation differ among groups (Table 19). Birth type averages for the elite, mediocre and inferior groups also were not significantly different in either birth year. Nevertheless, the mediocre group had the lowest birth type average for both years, suggesting that some multiple-born ewes became elite producers while others were inferior. Multiple births are not synonymous with subsequent productivity; not all triplet- and twin-born ewes are created equal. Having more single lambs, it is not surprising that the mediocre group had the highest ewe lamb weights for the 1973 birth year, while being nearly equal to ewes of the elite group for 1974 birth year. For all three ewe lamb weights (WWt, AWWt and PWWt), elite ewes were heavier than inferior ewes for both birth years, though the differences for 1973 were small. Here again, the association of the ewe lamb weights with LPE is evident.

For both birth year groups, as expected, the elite group was more prolific and weaned more lambs than did the mediocre and inferior groups, and mediocre ewes surpassed their inferior contemporaries. The same ranking also applied to the uniformity of lamb production among the ewes of each thirtile, the elite group being the most uniform and the inferior groups the least.

First year production also differed among the three thirtiles within birth years. The elite group had higher gross income and net revenue during their first year of production than did either of the other two thirtiles. This superiority also existed for PNTRV, suggesting some predictive relationship between a ewe's first year production efficiency and her subsequent productivity (excluding the first year contribution). Levine et al. (1978) reported that ewes lambing as ewe lambs were more productive in future years than ewes not lambing as ewe lambs when given the opportunity to do so.

Results of the backward selection showed that some single-born ewes had higher LPE than many twins, and that ewe lamb weights (WWt, AWWt, PWWt) tended to be predictive of future ewe LPE. Furthermore, prolificacy and number of lambs born and weaned were highly related to LPE. Ewes lambing during the first year tended to be more productive throughout their lifetime as well as in subsequent years excluding the first year of production.

Early Life Traits and LPE of Surviving Ewes

In Table 20, arithmetic means for early life traits and for production efficiency of ewes surviving the entire duration of the experiment are presented, in comparison with means in birth year groups at large. Not only was there no instance in which survivors differed significantly from their entire group for early life traits, for birth date, type of birth, actual and adjusted weaning weight and postweaning weight, and for both birth year groups, survivors were nearly identical to population averages. We were not successful, therefore, in identifying potential indicator traits for longevity. In addition, coefficients of variation for early life traits of survivors were very similar to those from populations at large. Thus there was no evidence that ewe mortality took the form of stabilizing natural selection, as this would have resulted in reduced variation in survivors. Longevity is, however, shown to affect lifetime production efficiency significantly. Total number of lambs born and weaned and all four components of LPE are considerably higher for ewes surviving until the end of the experiment.

SUMMARY

Based upon results of these studies, the following conclusions have been reached:

1) There exist important genotype x environment interaction effects on production efficiency, and hence not all breeds are expected to perform equally under all management systems. This should be realized when choosing the breeds that are to be raised on certain management systems. Specifically, Finnsheep x Suffolk crossbred ewes were the most efficient when on irrigated pastures, yet they were among the least efficient when raised on dryland hill pastures. The reverse was true for Cheviot x Columbia-type crossbred ewes, who performed well on hill pastures and very poorly on irrigated pastures.

2) Selection based solely on type of birth is not likely to lead to improved lifetime production efficiency. Selecting multiple-born ewes that are heavier at either weaning or prior to breeding would lead to increased production efficiency but would not identify successfully the group with maximum potential efficiency.

3) The most effective criterion among those investigated for single-trait selection to improve lifetime production efficiency appears to be ewe lamb weights. No other ewe lamb trait assessed was as consistent or as efficient.

4) Uncorrected weaning weight seems to be as accurate as adjusted weaning weight in predicting lifetime efficiency of ewes of

the different crossbred group-management system subclasses.

5) Prolificacy and number of lambs born and weaned were highly related to lifetime production efficiency.

6) None of the ewe lamb traits was predictive of longevity. Ewes surviving throughout the duration of the experiment had similar means for ewe lamb traits to those of the populations at large. Furthermore, coefficients of variation for early life traits of survivors were very similar to those from the overall populations.

7) Longevity was found to affect lifetime production efficiency significantly. Total number of lambs born and weaned and all four components of lifetime production efficiency were considerably higher for ewes surviving until the end of the experiment.

TABLE 1. DISTRIBUTION OF EWES AMONG CROSSBRED GROUPS WITHIN ENVIRONMENT AND BETWEEN THE TWO YEARS

Breed group	No. of ewes/management system				
	Hill		Irrigated		
	1973	1974	1973	1974	Overall
Cheviot x Columbia	12	13	11	14	50
Cheviot x Suffolk	14	16	14	13	57
Dorset x Columbia	9	12	9	13	43
Dorset x Suffolk	12	12	15	15	54
Finnsheep x Columbia	14	10	13	11	48
Finnsheep x Suffolk	14	10	11	10	45
Romney x Columbia	11	12	9	12	44
Romney x Suffolk	13	14	13	18	58
Total	99	99	95	106	399

TABLE 2. LEAST-SQUARES ANALYSES OF VARIANCE FOR LAMB, ORPHAN AND LAMB PLUS ORPHAN INCOME, FEED COST AND NET REVENUE DURING THE FIRST YEAR OF PRODUCTION

		Mean squares ($\$^2$)				
Source	d.f.	Lamb income	Orphan and(or) foster lamb income	Lamb and orphan lamb income	Feed cost	First year net revenue
Crossbred group (G)	7	2,740.9**	13.9	2,728.3**	70.0**	1,966.1**
Birth year (Y)	1	3,453.3**	77.4*	2,496.9**	47.9	1,852.8**
Management system (M)	1	40.4	0.8	29.8	18.3	1.4
G x Y	7	127.7	22.5	200.2	10.1	194.7
G x M	7	398.4	13.9	338.0	35.0	178.6
Y x M	1	517.8	3.4	436.7	24.9	252.9
Residual	374	311.5	15.2	317.3	17.5	227.6
R^2		0.18	0.07	0.17	0.12	0.17

*P<.05.

**P<.01.

TABLE 3. LEAST-SQUARES ANALYSES OF VARIANCE FOR LAMB INCOME, ORPHAN INCOME, GROSS INCOME, TOTAL COST AND NET REVENUE OF THE LIFETIME PRODUCTION OF THE EWES

		Mean squares ($\$^2$)				
Source	d.f.	Lamb income	Orphan and(or) foster lamb income	Gross income[a]	Total cost of production[b]	Net revenue[c]
Crossbred group (G)	7	12,436.8**	1,037.3**	18,976.5**	1,460.6*	12,294.2**
Birth year (Y)	1	82,782.2**	567.8	59,518.0**	18,743.0**	11,461.5**
Management system (M)	1	17,628.8*	206.4	13,969.8	397.0	9,656.7*
G x Y	7	1,872.6	202.5	2,986.6	578.1	1,152.2
G x M	7	13,784.9**	294.1	18,802.3**	2,389.4**	8,321.9**
Y x M	1	1,403.8	38.4	678.3	4.1	576.8
Residual	374	2,899.9	156.2	3,814.9	698.6	1,636.6
R^2		0.22	0.18	0.20	0.16	0.23

[a]Includes value of lamb produced, value of orphans and(or) fosters and salvage value of the ewe.

[b]Includes total feed cost and $50 purchase price per ewe.

[c]Difference between gross income and total cost of production.

*P<.05.

**P<.01.

TABLE 4. LEAST-SQUARES MEANS FOR THE BREED EFFECTS ON FIRST YEAR LAMB INCOME, ORPHAN AND(OR) FOSTER LAMB INCOME, TOTAL LAMB INCOME, FEED COST AND NET REVENUE ($)

Breed	No.	Lamb income	Orphan and(or) foster lamb income	Lamb + orphan lamb income	Feed cost	Net revenue
Overall mean	399	13.91 ± 0.90	0.71 ± 0.20	14.62 ± 0.90	20.46 ± 0.21	-5.84 ± 0.77
Cheviot-Columbia	50	8.64 ± 2.50[cd]	0.01 ± 0.55	8.64 ± 2.53[cd]	18.96 ± 0.59[c]	-10.31 ± 2.14[bc]
Cheviot-Suffolk	57	13.97 ± 2.34[bc]	0.99 ± 0.52	14.96 ± 2.36[bc]	20.42 ± 0.56[abc]	-5.46 ± 2.00[b]
Dorset-Columbia	43	8.78 ± 2.73[cd]	1.67 ± 0.60	10.42 ± 2.75[bc]	19.94 ± 0.65[bc]	-9.52 ± 2.33[bc]
Dorset-Suffolk	54	17.04 ± 2.42[b]	0.25 ± 0.53	17.29 ± 2.44[b]	21.16 ± 0.57[ab]	-3.87 ± 2.06[b]
Finnsheep-Columbia	48	17.14 ± 2.57[b]	1.11 ± 0.57	18.26 ± 2.59[b]	21.54 ± 0.61[ab]	-3.29 ± 2.20[b]
Finnsheep-Suffolk	45	29.30 ± 2.65[a]	0.64 ± 0.59	29.94 ± 2.68[a]	22.38 ± 0.63[a]	7.56 ± 2.27[a]
Romney-Columbia	44	3.01 ± 2.68[d]	0.76 ± 0.59	3.76 ± 2.70[d]	18.79 ± 0.63[c]	-15.03 ± 2.29[c]
Romney-Suffolk	58	13.43 ± 2.34[b]	0.28 ± 0.52	13.71 ± 2.36[bc]	20.49 ± 0.55[abc]	-6.80 ± 2.00[b]

[a,b,c,d]Means in the same column with unlike superscripts differ at $P<.01$.

TABLE 5. LEAST-SQUARES MEANS FOR MANAGEMENT EFFECTS AND FOR THE CROSSBRED X MANAGEMENT INTERACTION ON LIFETIME ECONOMIC PRODUCTION, COST AND NET REVENUE ($)

Management Breed	Lamb Income	Orphan and(or) foster lamb income	Gross Income	Total cost	Net revenue
Hill pastures	114.71 ± 3.86	6.70 ± 0.90	138.73 ± 4.42	132.42 ± 1.89	6.31 ± 2.90
Cheviot x Columbia	126.78 ± 10.78^{ab}	2.98 ± 2.50^{b}	150.05 ± 12.36^{ab}	139.09 ± 5.29^{a}	10.96 ± 8.09^{b}
Cheviot x Suffolk	103.39 ± 9.84^{b}	9.48 ± 2.28^{b}	128.40 ± 11.29^{b}	129.15 ± 4.83^{ab}	-0.75 ± 7.40^{b}
Dorset x Columbia	123.36 ± 11.82^{ab}	3.93 ± 2.74^{b}	146.72 ± 13.55^{b}	142.28 ± 5.80^{a}	4.45 ± 8.88^{b}
Dorset x Suffolk	112.12 ± 10.99^{b}	3.75 ± 2.55^{b}	133.12 ± 12.61^{b}	133.22 ± 5.40^{ab}	-0.11 ± 8.26^{b}
Finnsheep x Columbia	148.01 ± 11.08^{a}	19.77 ± 2.57^{a}	187.32 ± 12.71^{a}	142.68 ± 5.44^{a}	44.64 ± 8.32^{a}
Finnsheep x Suffolk	99.90 ± 11.08^{b}	7.56 ± 2.57^{b}	119.58 ± 12.71^{b}	116.01 ± 5.44^{b}	3.57 ± 8.33^{b}
Romney x Columbia	99.06 ± 11.23^{b}	2.69 ± 2.61^{b}	119.73 ± 12.89^{b}	128.24 ± 5.51^{ab}	-8.50 ± 8.44^{b}
Romney x Suffolk	105.09 ± 10.37^{b}	3.45 ± 2.41^{b}	124.91 ± 11.89	128.66 ± 5.09^{ab}	-3.75 ± 7.79^{b}
Irrigated pastures	128.13 ± 3.85	5.25 ± 0.90	150.67 ± 4.42	134.43 ± 1.89	16.24 ± 2.90
Cheviot x Columbia	76.05 ± 10.81^{d}	2.28 ± 2.51^{bc}	92.32 ± 12.40^{d}	115.10 ± 5.31	-22.76 ± 8.12^{e}
Cheviot x Suffolk	111.82 ± 10.37^{bcd}	3.36 ± 2.41^{bc}	130.65 ± 11.89^{cd}	130.05 ± 5.09^{ab}	0.60 ± 7.79^{cde}
Dorset x Columbia	144.47 ± 11.59^{ab}	1.70 ± 2.69^{c}	166.18 ± 13.29^{abc}	140.16 ± 5.69^{a}	26.02 ± 8.71^{bc}
Dorset x Suffolk	153.89 ± 9.83^{a}	3.00 ± 2.28^{bc}	172.89 ± 11.28^{ab}	140.73 ± 4.83^{a}	32.16 ± 7.39^{ab}
Finnsheep x Columbia	139.89 ± 11.01^{abc}	10.25 ± 2.56^{ab}	169.66 ± 12.63^{abc}	138.56 ± 5.41^{a}	31.10 ± 8.27^{ab}
Finnsheep x Suffolk	161.77 ± 11.76^{a}	15.05 ± 2.73^{a}	195.78 ± 13.49^{a}	141.62 ± 5.77^{a}	54.16 ± 8.83^{a}
Romney x Columbia	108.31 ± 11.82^{cd}	3.04 ± 2.74^{bc}	128.73 ± 13.55^{cd}	130.08 ± 5.80^{ab}	-1.35 ± 8.88^{de}
Romney x Suffolk	128.84 ± 9.75^{abc}	3.33 ± 2.26^{bc}	149.16 ± 11.18^{bc}	139.15 ± 4.78^{a}	10.02 ± 7.32^{bcd}

^{a,b,c,d,e}Means in the same column with unlike superscripts differ at $P < .01$.

TABLE 6. EXTREMES IN TOTAL PRODUCTION PER EWE FOR 1973 EWES WHICH SURVIVED THROUGH THE ENTIRE EXPERIMENT AND THEREFORE HAD FIVE OPPORTUNITIES TO LAMB

Environment Breed group	Survival %[a]	Total lambs produced Min.	Total lambs produced Max.	Total lambs weaned Min.	Total lambs weaned Max.	Orphan lambs Max.[b]	Orphan lambs No.[c]	Gross revenue Min.	Gross revenue Max.	Net revenue Min.	Net revenue Max.
Hill pastures	69.7	0	14	0	9	6	52	20.00	321.25	-109.92	149.12
Cheviot x Columbia	83.33	4	9	4	8	2	3	136.23	261.93	-18.95	95.15
Cheviot x Suffolk	57.14	4	8	3	7	2	7	127.94	240.26	-18.78	84.07
Dorset x Columbia	88.89	0	10	0	7	2	3	20.00	225.74	-106.07	68.81
Dorset x Suffolk	75.00	1	10	0	7	3	4	20.00	246.94	-109.92	77.88
Finnsheep x Columbia	78.57	6	14	2	9	6	24	143.61	321.25	-5.89	149.12
Finnsheep x Suffolk	42.86	5	9	3	9	5	5	167.87	269.99	10.63	103.65
Romney x Columbia	81.82	4	7	4	6	1	2	133.00	206.35	-5.38	49.95
Romney x Suffolk	61.54	4	7	4	6	2	4	126.33	213.27	-26.09	47.58
Irrigated pastures	67.4	3	15	2	10	5	33	91.03	342.70	-51.72	164.10
Cheviot x Columbia	36.36	3	6	3	5	1	1	99.33	185.83	-33.61	35.80
Cheviot x Suffolk	64.29	4	8	3	6	2	3	144.78	219.27	-1.48	49.34
Dorset x Columbia	66.67	4	10	4	9	0	0	135.32	301.37	-23.78	135.65
Dorset x Suffolk	73.33	3	10	3	9	1	2	118.71	310.14	-29.29	131.65
Finnsheep x Columbia	76.92	3	14	2	8	2	8	91.03	269.33	-51.72	111.59
Finnsheep x Suffolk	72.73	5	15	3	10	5	10	112.03	342.70	-38.08	164.10
Romney x Columbia	88.89	4	8	3	7	3	4	125.15	213.26	-21.27	55.45
Romney x Suffolk	61.54	3	9	3	8	2	5	126.55	238.65	-15.96	72.52

[a]Percentages of ewes per group that survived through the entire five production years.

[b]The minimum number of orphans/ewe is always zero.

[c]Total number of orphans by all the ewes of each breed group for the five production years.

TABLE 7. RESIDUAL CORRELATIONS AMONG THE COMPONENTS OF PRODUCTION EFFICIENCY

Trait	2[a]	3	4	5	6	7	8	9	10
1) First year lamb production	-.07	.74[b]	.98	.95	.38	.02	.14	.33	.42
2) First year orphan income		-.06	.15	.20	-.06	.35	-.08	.02	.08
3) First year feed cost			.72	.57	.54	.08	.50	.52	.47
4) First year gross income				.98	.36	.09	.12	.33	.43
5) First year net revenue					.28	.09	.00	.25	.38
6) Lifetime lamb production						.025	.83	.97	.93
7) Lifetime orphan income							.18	.24	.26
8) Lifetime total cost								.88	.69
9) Lifetime gross income									.95

[a] Numbers in column headings correspond to like-numbered traits in rows. Trait 10 is lifetime net revenue.

[b] Correlations greater than .10 and greater than .14 in absolute value are different from zero at $P<.05$ and $P<.01$, respectively.

TABLE 8. LEAST-SQUARES CONSTANTS AND REGRESSION COEFFICIENTS AND R^2 VALUES FOR EFFECTS OF EWE LAMB TRAITS ON FIRST YEAR PRODUCTION EFFICIENCY ($)

Model[a]	Feed cost		Gross income		Net revenue	
	R^2	b ± SE[d]	R^2	b ± SE[d]	R^2	b ± SE[d]
Basic	.10	20.46 ± 0.21	.16	14.52 ± 0.90	.16	-5.94 ± 0.76
Birth type	.17		.24		.25	
Single		0.20 ± 0.44[ef]		-0.08 ± 1.87		-0.27 ± 1.58
Twin		-0.92 ± 0.41[f]		-2.98 ± 1.70		-2.06 ± 1.44
Triplet		-0.73 ± 0.70[e]		3.06 ± 2.93		2.33 ± 2.45
Birth date	.14	-0.50 ± 0.03*	.21	-0.33 ± 0.11**	.21	-0.28 ± 0.09**
WWt	.22		.27		.26	
Linear		0.24 ± 0.07**		1.03 ± 0.30**		0.79 ± 0.25**
Quadratic		-0.02 ± 0.01		-0.10 ± 0.04**		-0.08 ± 0.04**
AWWt	.23		.26		.25	
Linear		0.27 ± 0.08**		0.99 ± 0.36**		0.72 ± 0.31*
Quadratic		-0.01 ± 0.01		-0.07 ± 0.06		-0.06 ± 0.05
ADG[b]	.21	0.00 ± 0.01	.23	0.03 ± 0.01	.22	0.02 ± 0.02
PWWt[b]	.18	0.21 ± 0.04**	.25	0.92 ± 0.18**	.25	0.71 ± 0.15**
Estrus[b]	.18	0.05 ± 0.05	.24	-0.01 ± 0.22	.23	-0.06 ± 0.19
First lambing[b]						
Basic[c]	.10		.16		.16	
Linear	.21	-0.04 ± 0.10	.32	-0.01 ± 0.40	.33	0.03 ± 0.35

[a]"Birth date" is the ewe's own date of birth within her lambing season. Row abbreviations are WWt = actual weaning weight, AWWt = adjusted weaning weight, ADG = postweaning average daily gain and PWWt = postweaning weight. "Estrus" means age of the ewe at her first recorded estrus. "First lambing" is her age at first lambing.

[b]Quadratic regression coefficients were very close to zero for these traits.

[c]Basic model included only ewe lambs that lambed during the first year.

[d]For the basic model, these represent the overall means; for type of birth, they represent constant estimates.

[e,f]Constant estimates in the same column with unlike superscripts differ at $P < .05$.

*$P < .05$, **$P < .01$.

TABLE 9. LEAST-SQUARES CONSTANTS AND REGRESSION COEFFICIENTS AND R^2 VALUES FOR EFFECTS OF EWE LAMB TRAITS ON LIFETIME PRODUCTION EFFICIENCY ($)

Model[a]	Feed cost		Gross income		Net revenue	
	R^2	b ± SE[d]	R^2	b ± SE[d]	R^2	b ± SE[d]
Basic	.15	133.36 ± 1.33	.19	144.63 ± 3.11	.21	11.27 ± 2.03
Birth type	.22		.25		.27	
Single		2.32 ± 2.79[ef]		-1.38 ± 6.56[ef]		-3.70 ± 4.29[ef]
Twin		-6.59 ± 2.54[f]		-15.71 ± 5.98[e]		-9.12 ± 3.91[f]
Triplet		4.28 ± 4.38[e]		17.10 ± 10.30[e]		12.82 ± 6.73[e]
Birth date	.16	0.00 ± 0.17	.21	-0.22 ± 0.39	.23	-0.22 ± 0.25
WWt	.29		.31		.31	
Linear		1.42 ± 0.44**		3.17 ± 1.03**		1.75 ± 0.68**
Quadratic		0.07 ± 0.06		0.15 ± 0.15		0.08 ± 0.10
AWWt	.28		.29		.29	
Linear		1.55 ± 0.52**		3.25 ± 1.25**		1.70 ± 0.83*
Quadratic		0.12 ± 0.08		0.24 ± 0.20		0.11 ± 0.13
ADG[b]	.22	-0.02 ± 0.03	.28	-0.00 ± 0.08	.31	0.02 ± 0.05
PWWt[b]	.23	1.02 ± 0.26*	.27	2.45 ± 0.61*	.28	1.43 ± 0.40
Estrus[b]	.22	0.39 ± 0.33	.25	0.75 ± 0.77	.26	0.36 ± 0.50
First lambing[b]						
Basic[c]	.23		.28		.30	
Linear	.38	0.20 ± 0.68	.38	1.29 ± 1.61	.38	1.09 ± 1.05
First year[b]						
Net revenue	.24	0.20 ± 0.16	.32	1.18 ± 0.37**	.39	0.98 ± 0.23**
Gross income	.22	0.18 ± 0.09*	.34	1.07 ± 0.20**	.41	0.89 ± 0.12**

[a]For row abbreviations, see footnote a to Table 8.

[b]Quadratic regression coefficients were very close to zero for these traits.

[c]Basic model included only ewe lambs that lambed during the first year.

[d]For the basic model, these represent the overall means; for type of birth, they represent constant estimates.

[e,f]Constant estimates in the same column with unlike superscripts differ at $P < .05$.

*$P < .05$, **$P < .01$.

TABLE 10. LEAST-SQUARES CONSTANTS AND REGRESSION COEFFICIENTS AND R^2 VALUES FOR EFFECTS OF EWE LAMB TRAITS ON PARTIAL LIFETIME PRODUCTION EFFICIENCY ($)

	Feed cost		Gross income		Net revenue	
Model[a]	R^2	b ± SE[d]	R^2	b ± SE[d]	R^2	b ± SE[d]
Basic	.16	112.90 ± 1.24	.19	130.11 ± 2.93	.20	17.21 ± 1.88
Birth type	.22		.24		.25	
Single		2.12 ± 2.60[ef]		-1.30 ± 6.22		-3.42 ± 4.00
Twin		-5.67 ± 2.37[f]		-12.73 ± 5.67		-7.06 ± 3.64
Triplet		3.55 ± 4.08[e]		14.04 ± 9.77		10.49 ± 6.27
Birth date	.18	0.05 ± 0.15	.21	0.10 ± 0.37	.22	0.05 ± 0.24
WWt	.29		.29		.29	
Linear		1.18 ± 0.41**		2.14 ± 0.98*		0.96 ± 0.64
Quadratic		0.09 ± 0.06		0.25 ± 0.14		0.16 ± 0.09
AWWt	.29		.28		.28	
Linear		1.28 ± 0.49**		2.26 ± 1.19*		0.98 ± 0.77
Quadratic		0.14 ± 0.08		0.31 ± 0.19		0.17 ± 0.12
ADG[b]	.23	-0.02 ± 0.03	.26	-0.03 ± 0.08	.28	-0.01 ± 0.05
PWWt[b]	.24	0.81 ± 0.24**	.25	1.53 ± 0.59**	.24	0.72 ± 0.38
Estrus[b]	.24	0.34 ± 0.30	.26	0.76 ± 0.72	.26	0.42 ± 0.46
First lambing[b]						
Basic[c]	.23		.27		.29	
Linear	.39	0.25 ± 0.63	.39	1.30 ± 1.53	.39	1.05 ± 0.99
First year[b]						
Net revenue	.24	-0.05 ± 0.15	.27	-0.07 ± 0.36	.27	-0.02 ± 0.23
Gross income	.26	0.08 ± 0.11	.28	0.17 ± 0.27	.29	0.09 ± 0.17

[a]For row abbreviations, see footnote a to Table 8.

[b]Quadratic regression coefficients were very close to zero for these traits.

[c]Basic model included only ewe lambs that lambed during the first year.

[d]For the basic model, these represent the overall means; for birth type, they represent constant estimates.

[e,f]Constant estimates in the same column with unlike superscripts differ at $P < .05$.

*$P < .05$, **$P < .01$.

TABLE 11. LIFETIME AND PARTIAL LIFETIME NUMBER OF LAMBS BORN TO SINGLE- AND TWIN-BORN FINN-SIRED EWES ON THE TWO MANAGEMENT SYSTEMS

Crossbred group	Birthtype	No. of lambs born on					
		Hill			Irrigated		
		No. of ewes	Lifetime	Partial[a]	No. of ewes	Lifetime	Partial[a]
Finnsheep	Single	7	6.14	4.57	6	8.00	7.33
x Suffolk	Twin	12	4.42	3.25	11	7.64	6.64
Finnsheep	Single	5	10.00	8.40	5	8.60	7.20
x Columbia	Twin	17	7.77	6.71	18	6.89	5.83

[a]Lifetime number of lambs born excluding the lambs born during the first year of production.

TABLE 12. WITHIN CROSSBRED GROUP-MANAGEMENT SYSTEM SUBCLASS REGRESSION COEFFICIENTS OF LIFETIME GROSS INCOME AND NET REVENUE AND PARTIAL LIFETIME GROSS INCOME AND NET REVENUE ON FIRST YEAR GROSS INCOME ($)

		Lifetime		Partial lifetime	
Breed-management[a]		Gross	Net revenue	Gross	Net revenue
Chev x Col	(H)	0.50 ± 0.66	0.65 ± 0.41	-0.49 ± 0.66	-0.17 ± 0.42
Chev x Col	(I)	2.29 ± 1.15	1.40 ± 0.72	1.29 ± 1.15	0.69 ± 0.74
Chev x Suf	(H)	1.32 ± 0.64	1.17 ± 0.40	0.32 ± 0.64	0.32 ± 0.41
Chev x Suf	(I)	0.72 ± 0.52	0.59 ± 0.33	-0.28 ± 0.52	-0.22 ± 0.33
Dors x Col	(H)	1.62 ± 0.86	1.29 ± 0.54	0.62 ± 0.86	0.46 ± 0.55
Dors x Col	(I)	0.66 ± 0.75	0.81 ± 0.47	-0.34 ± 0.75	-0.06 ± 0.48
Dors x Suf	(H)	2.57 ± 0.65	1.68 ± 0.41	1.58 ± 0.65	0.90 ± 0.42
Dors x Suf	(I)	1.52 ± 0.52	1.08 ± 0.32	0.52 ± 0.52	0.23 ± 0.33
Finn x Col	(H)	1.32 ± 0.64	1.18 ± 0.40	0.32 ± 0.64	0.36 ± 0.41
Finn x Col	(I)	0.26 ± 0.67	0.06 ± 0.42	-0.74 ± 0.67	-0.70 ± 0.43
Finn x Suf	(H)	-0.61 ± 0.52	0.14 ± 0.33	-1.61 ± 0.52	-0.81 ± 0.33
Finn x Suf	(I)	1.96 ± 0.46	1.60 ± 0.29	0.96 ± 0.46	0.71 ± 0.30
Rom x Col	(H)	-0.40 ± 1.09	-0.16 ± 0.69	-1.40 ± 1.09	-0.93 ± 0.70
Rom x Col	(I)	-0.41 ± 1.44	-0.10 ± 0.90	-1.41 ± 1.44	-0.86 ± 0.92
Rom x Suf	(H)	1.91 ± 0.72	1.36 ± 0.45	0.91 ± 0.72	0.60 ± 0.46
Rom x Suf	(I)	1.84 ± 0.57	1.51 ± 0.35	0.84 ± 0.57	0.70 ± 0.36

[a]Chev = North Country Cheviot, Col = Columbia-type, Suf = Suffolk, Dors = Dorset, Finn = Finnsheep, Rom = Romney, H = Hill pastures and I = Irrigated pastures.

TABLE 13. LEAST-SQUARES CONSTANTS, REGRESSION COEFFICIENTS AND R^2 VALUES FOR EFFECTS OF COMBINATIONS OF EWE LAMB TRAITS ON LIFETIME PRODUCTION ($)

Model[a]	Feed cost		Gross income		Net revenue	
	R^2	b ± SE[b]	R^2	b ± SE[b]	R^2	b ± SE[b]
Basic	.15		.19		.21	
I.	.33		.41		.46	
Birth type						
Single		0.91 ± 3.15		-4.46 ± 7.10		-5.37 ± 4.51
Twin		-2.19 ± 2.46		-3.89 ± 5.55		-1.70 ± 3.53
Triplet		1.28 ± 4.22		8.34 ± 9.53		7.06 ± 6.05
Birth date		0.12 ± 0.18		0.26 ± 0.40		0.14 ± 0.25
WWt		1.20 ± 0.42**		2.48 ± 0.94**		1.28 ± 0.60*
FGROS		0.10 ± 0.10		0.95 ± 0.23**		0.85 ± 0.15**
II.	.27		.28		.28	
Birth type						
Single		0.37 ± 2.67[d]		-6.77 ± 6.35[cd]		-7.14 ± 4.22[d]
Twin		-6.17 ± 2.28[d]		-14.65 ± 5.43[d]		-8.48 ± 3.61[d]
Triplet		5.80 ± 3.92[c]		21.42 ± 9.34[c]		15.62 ± 6.20[c]
AWWt		1.09 ± 0.36**		2.82 ± 0.86**		1.73 ± 0.57**
III.	.32		.40		.45	
WWt		1.25 ± 0.32**		2.14 ± 0.73**		0.89 ± 0.46*
FGROS		0.09 ± 0.09		0.93 ± 0.21**		0.84 ± 0.13**
IV.	.32		.39		.44	
AWWt		1.20 ± 0.36**		2.01 ± 0.81*		0.81 ± 0.52
FGROS		0.12 ± 0.09		0.99 ± 0.21**		0.87 ± 0.13**
V.	.29		.39		.44	
PWWt		1.02 ± 0.27**		1.81 ± 0.61*		0.79 ± 0.39*
FGROS		0.11 ± 0.09		0.97 ± 0.21*		0.86 ± 0.13**

[a]"Birth date" is the ewe's own date of birth within her lambing season. Row abbreviations are WWt = actual weaning weight, FGROS = first year gross income, AWWt = adjusted weaning weight and PWWt = postweaning weight.

[b]For type of birth, these represent constant estimates.

[c,d]Constant estimates in the same column with unlike superscripts differ at $P < .05$.

*$P < .05$, **$P < .01$.

TABLE 14. LEAST-SQUARES CONSTANTS, REGRESSION COEFFICIENTS AND R^2 VALUES FOR EFFECTS OF COMBINATIONS OF EWE LAMB TRAITS ON PARTIAL LIFETIME PRODUCTION ($)

	Feed cost		Gross income		Net revenue	
Model[a]	R^2	b ± SE[b]	R^2	b ± SE[b]	R^2	b ± SE[b]
Basic	.16		.19		.20	
I.	.33		.33		.33	
Birth type						
Single		0.55 ± 2.95		-4.46 ± 7.10		-5.01 ± 4.61
Twin		-1.82 ± 2.31		-3.88 ± 5.54		-2.06 ± 3.60
Triplet		1.27 ± 3.96		8.34 ± 9.53		7.07 ± 6.19
Birth date		0.11 ± 0.16		0.26 ± 0.40		0.15 ± 0.26
WWt		1.20 ± 0.39**		2.48 ± 0.94**		1.28 ± 0.61*
FGROS		-0.08 ± 0.10		-0.05 ± 0.23		0.03 ± 0.15
II.	.26		.26		.25	
Birth type						
Single		0.33 ± 2.50^{cd}		-4.94 ± 6.05^{cd}		-5.27 ± 3.94^{d}
Twin		-5.30 ± 2.14^{d}		-11.56 ± 5.18^{d}		-6.25 ± 3.37^{d}
Triplet		4.97 ± 3.68^{c}		16.49 ± 8.90^{c}		11.52 ± 5.79^{c}
AWWt		0.86 ± 0.34**		1.72 ± 0.82*		0.84 ± 0.54
III.	.32		.32		.31	
WWt		1.22 ± 0.30**		2.14 ± 0.73*		0.92 ± 0.47*
FGROS		-0.09 ± 0.09		-0.07 ± 0.21		0.02 ± 0.14
IV.	.32		.32		.31	
AWWt		1.17 ± 0.34**		2.02 ± 0.81*		0.85 ± 0.53
FGROS		-0.07 ± 0.09		-0.01 ± 0.21		0.06 ± 0.14
V.	.29		.31		.30	
PWWt		0.97 ± 0.26**		1.81 ± 0.61**		0.84 ± 0.40*
FGROS		-0.07 ± 0.09		-0.03 ± 0.21		0.04 ± 0.13

[a]For row abbreviations, see footnote a to Table 13.

[b]For type of birth, these represent constant estimates.

[c,d]Constant estimates in the same column with unlike superscripts differ at $P < .05$.

*$P < .05$, **$P < .01$.

TABLE 15. LEAST-SQUARES MEANS AND STANDARD ERRORS OF LIFETIME AND PARTIAL LIFETIME GROSS INCOME AND NET REVENUE OF THE TWO BIRTH YEAR GROUPS AND OF THE POPULATIONS COMPOSED OF EWES SELECTED ACCORDING TO SIX INDIVIDUAL CRITERIA ($)

Criterion[a]	LGROS[b] ± SE		LNTRV[b] ± SE		PGROS[b] ± SE		PNTRV[b] ± SE	
	1973	1974	1973	1974	1973	1974	1973	1974
Unselected	157.08 ± 5.31	131.82 ± 3.55	16.72 ± 3.44	5.02 ± 2.37	144.94 ± 4.97	115.00 ± 3.39	24.69 ± 3.18	9.05 ± 2.20
TB	156.85 ± 10.44	124.40 ± 7.06	18.10 ± 6.78	1.29 ± 4.62	142.71 ± 9.91	108.10 ± 6.85	24.36 ± 6.45	5.50 ± 4.41
DB	169.22 ± 9.12	130.48 ± 6.44	24.61 ± 6.03	3.91 ± 4.38	150.89 ± 8.63	112.68 ± 6.30	27.68 ± 5.63	7.16 ± 4.09
WWt	172.28 ± 7.33	148.32 ± 5.20	22.27 ± 5.17	13.58 ± 4.09	158.17 ± 7.03	129.42 ± 4.97	29.20 ± 4.87	16.35 ± 3.66
AWWt	172.61 ± 7.42	140.31 ± 6.08	24.00 ± 5.11	8.83 ± 4.40	158.70 ± 6.67	121.46 ± 5.94	30.83 ± 4.39	11.61 ± 4.01
PWWt	177.28 ± 7.92	146.97 ± 6.17	26.83 ± 5.58	13.86 ± 4.56	161.18 ± 7.23	127.01 ± 5.87	31.80 ± 4.98	15.61 ± 4.15
FGROS	190.96 ± 8.49	146.06 ± 7.05	41.46 ± 5.46	20.95 ± 4.46	158.11 ± 8.60	110.05 ± 2.81	32.72 ± 5.57	8.36 ± 7.00

[a]TB = selection based upon type of birth; DB = date of birth; WWt = actual weaning weight; AWWt = adjusted weaning weight; PWWT = postweaning weight and FGROS = first year gross income.

[b]LGROS = lifetime gross income; LNTRV = lifetime net revenue, PGROS = partial lifetime gross income and PNTRV = partial lifetime net revenue.

TABLE 16. MEANS AND STANDARD ERRORS OF EWE-LAMB TRAITS AND LIFETIME AND PARTIAL LIFETIME GROSS INCOME AND NET REVENUE AS AFFECTED BY THE INDEPENDENT CULLING LEVEL TYPE OF SELECTION, IN COMPARISON WITH THE UNSELECTED POPULATIONS FOR BOTH BIRTH YEARS

Type of Selection	Birth date (d)	Birth type	Weaning weight (kg)	Adjusted weaning weight (kg)	Post-weaning weight (kg)	No. of lambs born	No. of lambs weaned	Lifetime gross income ($)	Lifetime net revenue ($)	Partial lifetime gross income ($)	Partial lifetime net revenue ($)
1973 Birth year											
No selection	48.04[a]	1.76	29.45	31.91	32.59	5.75	4.52	157.06	16.98	144.50	24.64
	(.55)	(.04)	(.33)	(.32)	(.38)	(.21)	(.17)	(5.55)	(3.66)	(5.19)	(3.37)
Upper	46.17	2.11	29.64	32.85	34.17	6.35	4.95	174.76	30.91	157.68	34.89
	(.76)	(.04)	(.38)	(.45)	(.38)	(.39)	(.31)	(9.96)	(6.38)	(9.35)	(5.99)
Middle	49.49	2.00	26.71	29.98	29.17	4.94	3.88	135.35	3.39	127.30	14.44
	(.96)	(.05)	(.52)	(.53)	(.57)	(.37)	(.30)	(10.13)	(6.37)	(9.62)	(6.03)
Lower	48.22	1.13	32.31	33.14	34.78	6.08	4.73	160.83	16.09	147.72	23.57
	(1.03)	(.05)	(.61)	(.58)	(.75)	(.32)	(.24)	(7.98)	(5.82)	(7.40)	(5.21)
1974 Birth year											
No selection	49.31	1.78	27.24	29.57	32.36	4.69	3.88	131.88	4.85	115.22	9.01
	(.67)	(.04)	(.39)	(.38)	(.47)	(.15)	(.12)	(3.71)	(2.57)	(3.42)	(2.26)
Upper	46.05	2.06	28.60	31.54	34.95	4.74	3.91	137.17	9.12	114.11	3.15
	(1.06)	(.03)	(.52)	(.55)	(.67)	(.25)	(.21)	(6.83)	(4.59)	(6.50)	(4.31)
Middle	50.20	1.95	25.57	28.28	30.10	4.50	3.78	126.73	2.96	103.55	7.23
	(1.20)	(.07)	(.71)	(.67)	(.79)	(.29)	(.22)	(6.84)	(4.63)	(6.22)	(3.93)
Lower	51.65	1.33	27.52	28.87	32.00	4.82	3.95	131.66	2.47	116.60	8.36
	(1.13)	(.07)	(.74)	(.67)	(.87)	(.25)	(.18)	(5.62)	(4.17)	(3.54)	(3.54)

[a]Standard error of each mean is enclosed by parentheses under the corresponding mean.

TABLE 17. COEFFICIENTS OF VARIATION OF EWE-LAMB TRAITS AND LIFETIME AND PARTIAL LIFETIME GROSS INCOME AND NET REVENUE FOR BOTH BIRTH YEARS AND THEIR RESPECTIVE THIRTILES THAT WERE CREATED BY SELECTING FOR EWE'S POSTWEANING WEIGHT AND TYPE OF BIRTH IN AN INDEPENDENT CULLING LEVEL SCHEME

Trait[a]	Type of selection							
	1973				1974			
	No selection	Upper	Middle	Lower	No selection	Upper	Middle	Lower
BD (d)	15.84	13.42	15.68	16.94	19.04	18.52	19.10	17.89
TB	32.39	14.69	19.50	33.78	30.34	11.65	23.14	42.29
WWt (kg)	15.82	10.43	15.81	14.88	20.19	14.69	22.35	21.94
AWWt (kg)	13.79	11.20	14.38	13.90	17.82	13.98	19.09	18.79
PWWt (kg)	16.14	8.96	15.74	17.17	20.36	15.36	21.06	22.16
No. of lambs born	51.48	50.25	60.53	41.29	44.99	42.82	51.33	41.33
No. of lambs weaned	51.99	50.98	62.11	41.11	42.53	44.25	46.53	37.49
LGROS ($)	49.22	46.27	60.33	39.39	39.32	40.15	43.17	34.69
LNTRV ($)	300.12	102.88	1514.45	286.94	740.82	402.50	1250.68	1371.01
PGROS ($)	50.04	48.22	60.90	39.77	41.49	44.35	44.94	35.20
PNTRV ($)	190.67	139.38	336.57	175.51	350.83	304.82	434.58	343.86

[a]BD = ewe's birth date in days, TB = ewe's type of birth, WWt = actual weaning weight, AWWt = adjusted weaning weight, PWWt = postweaning weight, LGROS = lifetime gross income, LNTRV = lifetime net revenue, PGROS = partial lifetime gross income and PNTRV = partial lifetime net revenue.

TABLE 18. COMPARISONS AMONG THE ELITE, MEDIOCRE AND INFERIOR EWES (FOR LIFETIME NET REVENUE) IN EARLY LIFE TRAITS AND PRODUCTION EFFICIENCY COMPONENTS

Selection	Birth date (d)	Birth type	Weaning weight (kg)	Adjusted weaning weight (kg)	Post-weaning weight (kg)	No. of lambs born	No. of lambs weaned	First year gross income ($)	First year net revenue ($)	Lifetime net revenue ($)	Partial lifetime net revenue ($)
1973 Birth year											
No selection	48.04	1.76	29.45	31.91	32.59	5.75	4.52	12.55	-7.66	16.98	24.64
	(.55)	(.04)	(.33)	(.32)	(.38)	(.21)	(.17)	(1.31)	(1.08)	(3.66)	(3.37)
Elite	47.47	1.85	29.38	31.88	32.72	7.73	6.50	22.84	.28	65.05	64.77
	(.92)	(.07)	(.56)	(.53)	(.61)	(.30)	(.21)	(2.64)	(2.20)	(5.04)	(4.26)
Mediocre	48.88	1.67	30.26	32.53	33.49	6.22	4.78	8.56	-11.73	18.84	30.56
	(.95)	(.07)	(.58)	(.52)	(.64)	(.29)	(.18)	(1.74)	(1.41)	(3.49)	(3.62)
Inferior	47.67	1.76	28.63	31.27	31.48	3.38	2.30	6.80	-11.03	-32.35	-21.33
	(.96)	(.06)	(.59)	(.58)	(.69)	(.30)	(.22)	(1.80)	(1.64)	(3.62)	(3.94)
1974 Birth year											
No selection	49.31	1.78	27.24	29.57	32.36	4.69	3.88	16.66	-4.16	4.85	9.01
	(.67)	(.04)	(.39)	(.38)	(.47)	(.15)	(.12)	(1.38)	(1.18)	(2.57)	(2.26)
Elite	48.13	1.78	28.05	30.15	33.64	5.94	5.16	23.65	1.40	37.15	35.75
	(1.11)	(.07)	(.70)	(.66)	(.89)	(.19)	(.13)	(2.35)	(1.98)	(2.95)	(2.47)
Mediocre	49.23	1.71	28.01	30.34	32.88	4.83	4.04	15.72	-5.36	4.49	9.85
	(1.15)	(.06)	(.68)	(.63)	(.77)	(.24)	(.14)	(2.20)	(1.89)	(2.52)	(2.58)
Inferior	50.60	1.85	25.54	28.10	30.47	3.26	2.40	10.63	-8.45	-27.57	-19.12
	(1.13)	(.08)	(.62)	(.65)	(.77)	(.24)	(.18)	(2.40)	(2.13)	(3.80)	(3.40)

TABLE 19. COEFFICIENTS OF VARIATION OF EWE LAMB TRAITS AND LIFETIME PRODUCTION EFFICIENCY FOR BOTH BIRTH YEAR GROUPS AND THEIR RESPECTIVE THIRTILES WHICH WERE CREATED BASED UPON EWE LIFETIME NET REVENUE

Trait[a]	Type of selection							
	1973				1974			
	No selection	Elite	Mediocre	Inferior	No selection	Elite	Mediocre	Inferior
BD (d)	15.84	15.29	16.18	16.07	19.04	18.28	19.50	19.19
TB	32.39	30.81	36.53	28.41	30.34	30.89	28.65	32.43
WWt (kg)	15.82	15.01	15.86	16.35	20.19	19.93	20.17	19.11
AWWt (kg)	13.79	13.11	13.37	14.81	17.82	17.35	17.34	18.15
PWWt (kg)	16.14	14.73	15.95	17.38	20.36	20.90	19.31	19.86
No. of lambs born	51.48	30.40	38.91	69.23	44.99	24.75	41.25	59.20
No. of lambs weaned	51.99	25.69	31.80	74.78	42.53	20.74	28.47	60.42
FGROS	145.34	91.24	168.57	219.71	115.73	78.98	117.11	177.61
FNTRV	297.13	6192.85	100.00	118.22	397.11	1120.00	295.33	198.70
LNTRV	300.12	61.11	153.98	88.72	740.12	63.01	471.49	108.63
PNTRV	190.67	51.78	98.43	146.51	190.67	54.88	219.39	139.85

[a]See footnote a to Table 17 for definition of abbreviations; FGROS = first year gross income and FNTRV = first year net revenue.

TABLE 20. MEANS, STANDARD ERRORS AND COEFFICIENTS OF VARIATION (C.V.) FOR THE WHOLE POPULATION AND THE SURVIVING EWES FOR EARLY LIFE TRAITS, LIFETIME AND PARTIAL LIFETIME GROSS INCOME AND NET REVENUE

Population	No.	Birth date (d)	Birth type	Weaning weight (kg)	Adjusted weaning weight (kg)	Post-weaning weight (kg)	No. of lambs born	No. of lambs weaned	Lifetime gross income ($)	Lifetime net revenue ($)	Partial lifetime gross income ($)	Partial lifetime net revenue ($)
1973												
All ewes	194	48.04[a]	1.76	29.45	31.91	32.59	5.75	4.52	157.06	16.98	144.50	24.64
		(.55)	(.04)	(.33)	(.32)	(.38)	(.21)	(.17)	(5.55)	(3.66)	(5.19)	(3.37)
C.V.		15.84	32.39	15.82	13.79	16.14	51.48	51.99	49.22	300.12	50.04	190.67
Survivals	133	48.47	1.74	29.63	32.07	32.61	6.86	5.50	192.85	35.62	179.39	43.09
		(.70)	(.05)	(.42)	(.40)	(.45)	(.22)	(.16)	(4.73)	(3.96)	(3.95)	(3.36)
C.V.		16.67	32.75	16.20	14.25	15.93	36.30	33.45	28.23	128.35	25.37	90.04
1974												
All ewes	195	49.31	1.78	27.24	29.57	32.36	4.69	3.88	131.88	4.85	115.22	9.01
		(.67)	(.04)	(.39)	(.38)	(.47)	(.15)	(.12)	(3.71)	(2.57)	(3.42)	(2.26)
C.V.		19.04	30.34	20.19	17.82	20.36	44.99	42.53	39.32	740.82	41.49	350.83
Survivals	156	49.18	1.75	27.48	29.70	32.56	5.19	4.31	148.87	13.64	133.06	19.03
		(.74)	(.04)	(.45)	(.42)	(.52)	(.15)	(.11)	(3.03)	(2.57)	(2.34)	(1.99)
C.V.		18.79	30.86	20.34	17.71	19.90	36.42	30.63	25.43	235.12	21.98	130.27

[a]Standard errors are in brackets.

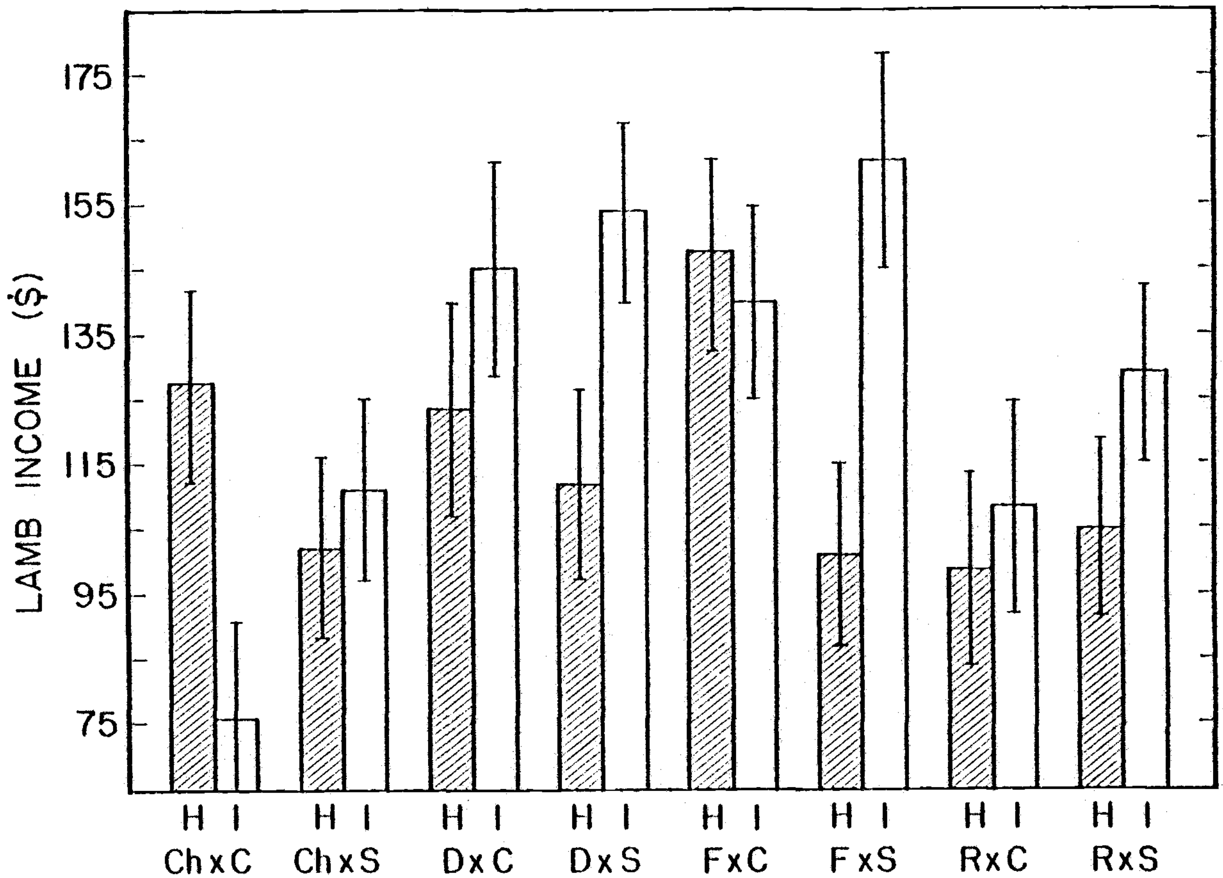

Figure 1. Income from total lamb production per ewe for each of the eight crossbred groups under the two management systems, where C = Columbia-type, S = Suffolk, Ch = Cheviot, D = Dorset, F = Finnsheep, R = Romney, H = hill pastures and I = irrigated pastures.

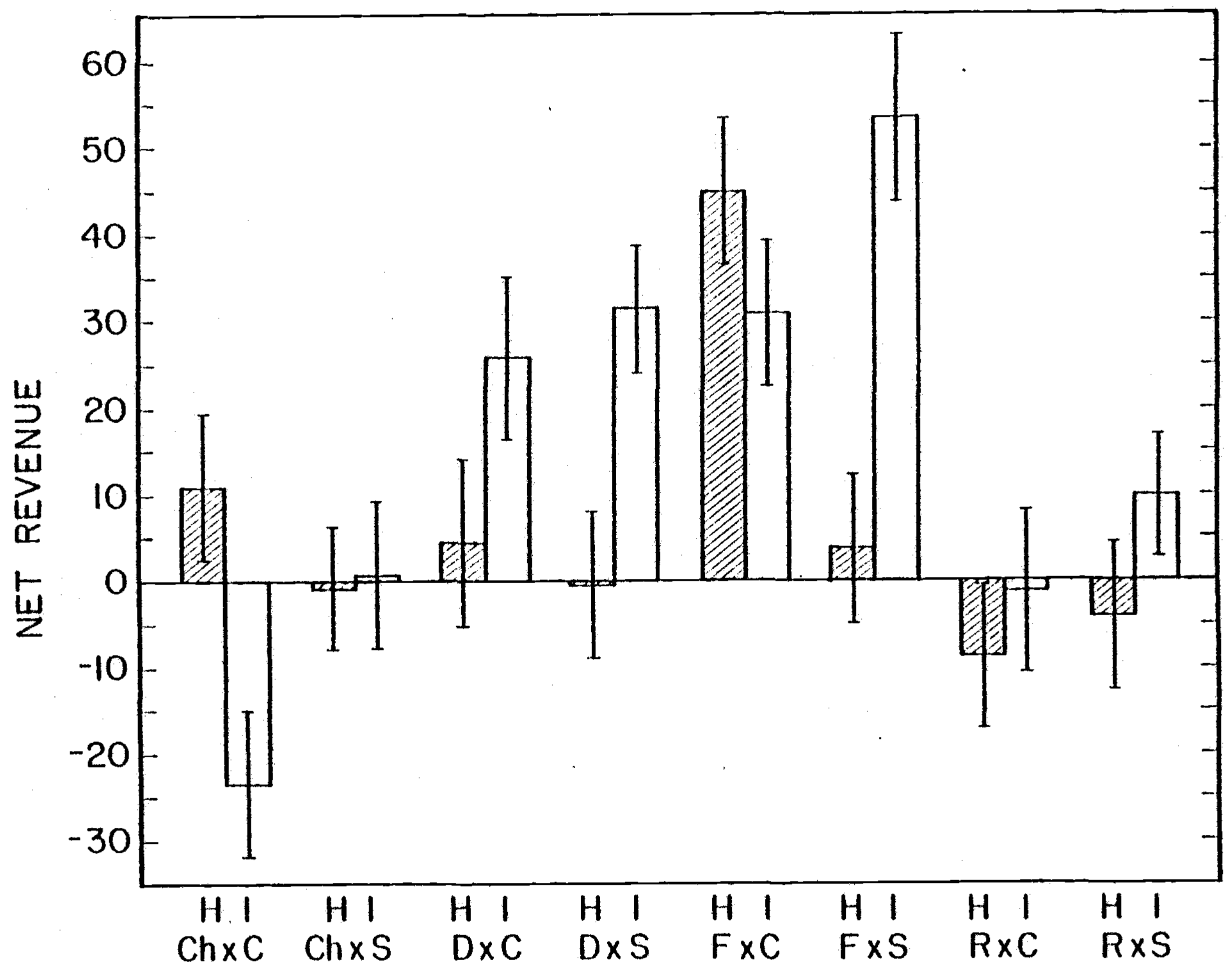

Figure 2. Net revenue per ewe for each of the eight crossbred groups on the two management systems, where C = Columbia-type, S = Suffolk, Ch = Cheviot, D = Dorset, F = Finnsheep, R = Romney, H = hill-pastures and I = irrigated pastures.

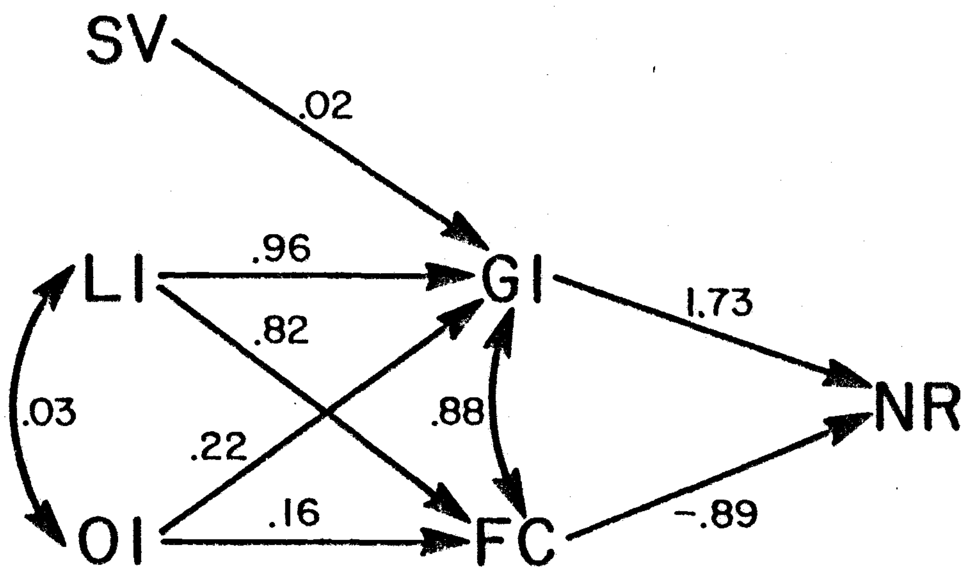

Figure 3. Path coefficient diagram relating the components of lifetime production efficiency, where SV = salvage value, LI = income from lambs weaned, OI = income from orphan lambs, GI = gross income, FC = total cost and NR = net revenue.

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