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Title: Breed and Heterosis Effects on Wool and Lamb Production of Rotationally Crossed Ewes

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One thousand twenty-three lambing records of 351 ewes bred in a rotational crossbreeding system involving Columbia or Targhee, Hampshire and Finnish Landrace breeds were examined. A regression approach was used to determine the effects of breeds and heterosis on wool grade, greasy fleece weight, ewe weight at lambing, lambing date, number of lambs born and weaned and litter weight at birth and weaning. Relationships among these ewe production traits were examined by means of residual correlations, and repeatabilities were calculated. A ewe production index equal to the weight of lamb weaned by a ewe plus three times her greasy fleece weight was computed for various purebred and crossbred matings. It was concluded that heterosis of the dam was the most important factor influencing ewe productivity.

BREED AND HETEROSIS EFFECTS ON WOOL AND LAMB PRODUCTION OF ROTATIONALLY CROSSED EWES

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INTRODUCTION

Because of the wide variety of uses of sheep and of environments in which they are kept, many diverse types of sheep, each adapted to a particular function and habitat, are required. While this end might be accomplished by long term selection, many of the traits of economic importance, including most traits involved in reproductive fitness, have low heritabilities and consequently will respond slowly to selection (Rae, 1982).

Crossbreeding has been, and continues to be, an important method of developing different types of sheep to meet the varied demands of the commercial sheep industry. As well as producing an animal which combines desirable attributes of two or more pure breeds, for some traits crossbreeding will lead to increased performance over the expected intermediate or midparent level. This increased performance of the crossbred offspring over the average of the parental breeds, or heterosis, is dependent upon the degree of genetic differences between the breeds being crossed and the extent to which the trait is controlled by non-additive or dominance genetic effects. Heterosis tends to be greatest for traits of low heritability (Clarke, 1982).

In order to predict which breed combinations will be the most effective in a given environment, it is necessary to know the genetic merit of the breeds for the traits concerned and the level of heterosis which can be expected, both from the individual and from the dam in the form of an improved maternal environment.

As described by Fraser and Stamp (1961), the Columbia and the Targhee breeds both originated from a program begun in 1912 by the USDA in an effort to produce a range ewe which would combine the fine wool and herding instinct of the Rambouillet and the long wool and carcass merits of the English Longwool breeds. The Columbia is based upon a crossbred foundation of Lincoln rams mated to Rambouillet ewes, and the Targhee resulted from backcrosses to Rambouillet. Both breeds are whitefaced and distinguished from the Rambouillet by their open-faced condition and the absence of horns.

The Hampshire breed originated in the county of Hampshire in south-central England. It is one of the largest of the medium-woolled breeds, with brown face, ears and legs. It is noted for growth rate and carcass quality which make it a popular terminal sire for use on whitefaced crossbred ewes (Fraser and

Stamp, 1961). The heavy shoulders and large head of the Hampshire are a cause for concern at lambing time as they may result in an increase in dystocia.

The Finnish Landrace originated in Finland. The first Finnish Landrace in America were imported into Canada in 1966. It is a whitefaced sheep with a low density fleece, fine bone structure and relatively poor carcass quality. The Finnish Landrace have a large litter size, up to seven per lambing. They are used in the United States and Canada to produce crossbred ewes of higher prolificacy than that of other available breeds (Scott, 1982).

Efforts to develop the Montadale breed were initiated in 1914 in the United States, but the foundation was not established until 1939. The foundation cross was a Columbia ram mated to North Country Cheviot ewes. The Montadale is a polled sheep of good mutton type. It possesses a white face and legs that are free from wool (Mattingly, 1945).

Rotational crossbreeding involves the alternate use, in a regular sequence, of sires of two or more breeds. Sheridan (1981) made several conclusions regarding the advantages of rotational crossbreeding. He stated that rotational crossbreeding could be economically advantageous if the level of heterosis at least approximated the proportion of heterozygosity and if there were little additional economic advantage in using specific sire or dam lines. As crossbred female progeny from one generation are used as dams for the next generation, a rotational crossbreeding system substantially reduces the proportion of the population being held as purebred parental stock. The lower than maximum level of heterozygosity in the progeny from a rotational crossbreeding system may be more than offset by the increased proportion of the population which is crossbred and thus exhibits some heterosis. A two breed rotational cross retains 66.7% and a three breed rotational cross 85.7% of the maximum potential heterozygosity for both the dam and the offspring.

Clarke (1982) described the disadvantages of a rotational crossbreeding system. Since each breed contributes on average to the same extent on both the sire and the dam side, the breeds used in the cross must be selected for both ewe and lamb performance traits, as opposed to specific crosses involving dam breeds and sire breeds. Furthermore, since the genotypes of the progeny are determined in excess of 50% by the breed of the sire last used, with overlapping generations the population is less uniform and hence less adaptable to a specific environment.

From 1973 to 1981, a sheep crossbreeding experiment was conducted under farm flock conditions at the Eastern Oregon Agricultural Experiment Station, Union, Oregon. Columbia and Targhee ewes were mated to Hampshire and Finnish Landrace rams in early years of the experiment. Thereafter replacement females were mated in a three breed rotational cross (Columbia or Targhee, Hampshire and Finnish Landrace).

The first objective of this experiment was to determine the effect of Hampshire and Finnish Landrace breeding (relative to Columbia or Targhee breeding) and the effect of ewe and lamb heterosis on several ewe production traits (wool grade, greasy fleece weight, ewe weight, date of lambing, number of lambs born, number of lambs weaned, birth weight of the litter and 120 d adjusted weaning weight of the litter). The second objective was to examine, through correlations, the relationships among these traits. The third objective was to calculate repeatabilities of all of the traits (with the exception of wool grade). The fourth objective was to compare the predicted performances of several possible purebred and crossbred matings among the three breeds.

MATERIALS AND METHODS

Population

This experiment was conducted at the Eastern Oregon Agricultural Research Station, Union, Oregon (location 45°13'N latitude, 117°52'W longitude, elevation 853 m, annual rainfall 330 mm, average growing season 120 d). The initial population was composed of straightbred Columbia and Targhee ewes born in the spring of 1973. For the remainder of the experiment and analysis, Columbia and Targhee ewes were considered together as "whiteface range" ewes (WFR) due to their common ancestry of Rambouillet and Lincoln breeding. Sharma (1982) found phenotypic differences between these purebred types to be small. These ewes were bred to Hampshire (H), Finnish Landrace (FL) and WFR rams, in a three-way rotational crossbreeding system, from 1973 until 1980. Eight different breed types composed of varying levels of WFR, H and FL breeding were created. The Hampshire is a popular carcass sire breed. The Finnish Landrace were chosen to provide information about the performance of this recently imported breed under western farm flock conditions. The breeds were combined in a three-way rotational crossbreeding system because it is a system more easily managed than a three-way terminal crossbreeding system involving the maintenance of purebred as well as crossbred ewes.

Ewes were managed as a typical western intermountain area farm flock. Throughout most of the year, ewes and lambs were run on fescue/Ladino clover or orchardgrass/alfalfa pastures or hay stubble. Supplemental feeding of hay or hay and grain was necessary during late gestation and early lactation. Replacement ewe lambs were selected on sex and age adjusted weaning weight, type of birth and conformation traits.

Ewes were bred at approximately seven months of age to Montadale rams (M), which were used in the interest of limiting dystocia in the ewes lambing for the first time. No replacements were kept from these first matings, and ewes that failed to lamb in their first year were culled.

Measurements of wool grade were made on all ewes during their first production year; and measurements of greasy fleece weight, ewe weight, date of lambing, number of lambs born, number of lambs weaned, birth weight of the litter and 120 d adjusted weaning weight of the litter were made for all production years. Ewes giving birth to more than two lambs were allowed to raise no more than two of them and were credited only for the lambs which they themselves raised. The remaining lambs were fostered onto other ewes or raised artificially.

The experiment terminated in 1981. Ewes born in 1973 had eight potential years of production. Each later birth year group of ewes (1974-1979) had one less year of potential production. None of the 1980 birth year ewes were kept as replacements.

Statistical Procedures

Weaning weights were adjusted for sex (Scott, 1982) and to a common 120 d weaning age according to the formula:

Age adjusted weaning weight =

$$\frac{\text{(Actual weaning weight-Birth weight)}}{\text{Actual weaning age}} \times 120 + \text{Birth weight.}$$

To evaluate maternal and direct effects of the breeds in the experiment and of heterosis on the ewe production traits, a regression approach (Dickerson, 1969) was used. Each production record was coded for percentage of inheritance from each breed in both the ewe and the lamb or lambs and for the percentage of maximum heterozygosity retained in both the ewe and the lamb or lambs.

To remove dependencies among variables, the percentage WFR inheritance in each ewe was subtracted from each ewe's percentage of WFR, H, and FL inheritance. Likewise, percentage of WFR inheritance of each litter was subtracted from WFR, H, FL and M inheritance of the same litter. This resulted in the values for

$\%H_E$, $\%FL_E$, $\%H_L$, $\%FL_L$, and $\%M_L$ being expressed as deviations from the percentage of WFR breeding, where E and L subscripts represent ewe and litter, respectively.

Heterosis, measured as the percentage of maximum heterozygosity retained, was calculated for ewes (EH) and lambs (LH) by the following formula:

$$EH \text{ or } LH = 100 - (\%WFR_s \times \%WFR_d) - (\%H_s \times \%H_d) - (\%FL_s \times \%FL_d)$$

where s = sire and d = dam of the ewe for EH and of the lamb or lambs for LH

The data were subjected to least-squares analysis of variance procedures to compute least-squares means, regression coefficients, residual correlations and significance levels for effects in the models (Harvey, 1977). The model for examining wool grade included the fixed main effect of birth year as well as regressions for the effects of $\%H_E$, $\%FL_E$ and EH. The model for the analysis of greasy fleece weight, ewe weight, date of lambing, number of lambs born, number of lambs weaned, birth weight of the litter and 120 d adjusted weaning weight of the litter included the fixed main effect of birth year-production year subclass as well as regressions for the effects of $\%H_E$, $\%FL_E$, $\%H_L$, $\%FL_L$, $\%M_L$, EH and LH. Since age is completely determined by birth year and production year, it could not be included in the model, but the effect of age was held constant statistically by including the birth year-production year subclasses as a main effect. Residual correlations from the analysis of variance were used to examine relationships among the traits.

The model for determining the repeatabilities included the main fixed effects of birth year, ewe age and breed type nested within birth year plus the random effect of ewe identification nested within breed type nested within birth year.

One thousand twenty-three lambing records of 351 ewes were used in the analysis.

In order to compare the predicted performances of breed combinations, some of which did not exist in the study, production indices were calculated, using the regression coefficients, for all possible purebred matings, two- and three-way crosses and backcrosses and crosses which would take place when a three way rotational cross reached equilibrium. The index was calculated as the sum of the weight of lamb weaned by a ewe plus three times her greasy fleece weight, based on the assumption that the dollar value of a pound of wool is equal to that of three pounds of weaned lamb.

RESULTS AND DISCUSSION

Effects of Breeds and Heterosis on Ewe Production

The effects of breed and heterosis on the ewe production traits are presented in Table 1 in the form of regression coefficients. Since the values of $\%H_E$ and $\%FL_E$ and of $\%H_L$, $\%FL_L$ and $\%M_L$ are expressed as deviations from $\%WFR_E$ and $\%WFR_L$, respectively, the regression coefficients for these effects are equal to the effect on the trait of replacing a purebred WFR ewe or lamb with a purebred H or FL ewe or a purebred H, FL or M lamb. The use of these regression coefficients to predict the performance of breed classes which did not actually exist in the population (eg., a purebred H or FL ewe) is subject to error from extrapolation. The regression coefficients for EH and LH are equal to the effect of replacing a purebred ewe (EH = 0%) with a ewe for whom EH = 100% or a purebred lamb (LH = 0%) with one for whom LH = 100%.

The fixed main effect of birth year-production year subclass significantly affected the greasy fleece weights, ewe lambing weights and number of lambs weaned (all $P<.01$).

Because ewes were bred to Montadale rams for only their first lambing, the effects of $\%M_L$ cannot accurately be compared to the effects of $\%H_L$ and $\%FL_L$. For this reason, the regression coefficients for $\%M_L$ are presented but not discussed.

Wool Grade. The positive but non-significant effect of $\%H_E$ and $\%FL_E$ on wool grade is surprising, considering reported wool grades of 50-60 for Columbias, 60-62 for Targhees, 54-58 for H and 50-60 for FL (Scott, 1982). Drummond et al. (1980) reported that F_1 crosses of FL with Columbias, Targhees and Rambouillets had lower spinning counts than did the standard breeds. Sidwell et al. (1971) showed that F_1 H X Targhee crosses had an average fiber diameter of 28.12μ compared to 24.60μ for purebred Targhees. The H and FL rams used in this study may not have been representative of their breeds with respect to wool grade.

The significant ($P<.01$) effect of EH in decreasing wool grade is in agreement with Sidwell et al. (1971), who found increased fibre diameter in five of seven two-way crosses and one of two three-way crosses.

Greasy Fleece Weights. The effects of replacing WFR breeding in the ewe with H breeding and with FL breeding were both negative ($P<.05$ and $P<.01$ respectively), with FL breeding having a greater adverse effect on greasy fleece weight than H breeding. These reductions in the greasy fleece weights are consistent with the findings of Oltenacu and Boylan (1981) who found that F_1 FL X Targhee ewes produced an average of 1.0 kg less wool than did purebred Targhees in their first three years of production. Also, Sidwell et al. (1971) found F_1 H X Targhee ewes to have an average greasy fleece weight of 4.35±.31 kg compared to 4.82±.20 kg for purebred Targhees.

The regression coefficient for EH indicates that the ewes for whom EH = 100% did not produce greasy fleece weights which were significantly different from the estimated means of the three pure breeds. The percentage of heterosis was computed from the regression coefficients as the difference between the estimated means of all possible two-way crosses of the three breeds and the mean of the three pure breeds, expressed as a percentage of the purebred mean. For greasy fleece weight, this was equal to only 1.3%. This degree of heterosis is markedly less than that found by Oltenacu and Boylan (1981). They found F_1 crosses of FL with Minnesota 100, Suffolk and Targhee ewes to exceed the greasy fleece weights of their respective parental means by 10.0%, 12.5% and 3.6% averaged over the first three years of production. Sidwell et al. (1971) examined two-way crosses of Targhee, Suffolk, Hampshire, Dorset and a strain composed of Columbia, Southdown and Corriedale breeding. Crossbreeding produced an increase in the greasy fleece weights of all two way crosses with the exception of the Suffolk X Targhee. The Hampshire X Columbia, Southdown and Corriedale strain F_1 ewes produced 27% more than the parental mean.

There seems to be a tendency for crosses involving breeds with higher greasy fleece weights not to exhibit as much heterosis as do crosses involving other breeds. It may be that these breeds are already homozygous for the dominant (favorable) alleles at most loci affecting greasy fleece weight and that crossbreeding, resulting in a heterozygous condition at many of these loci, therefore has little phenotypic effect.

Ewe Weight at Lambing. The effects of $\%H_E$ and $\%FL_E$ on ewe lambing weight (weighed within 24 hr after lambing) were both negative, although only the effect of $\%FL_E$ was significant ($P<.05$). Scott (1982) reported mature ewe weights of 68-102 kg for WFR, 79-102 kg for H and 55-86 kg for FL. The significant ($P<.01$) effect of $\%FL_L$ on ewe weight at lambing is not surprising in view of the significantly ($P<.05$) negative effect of $\%FL_L$ on the birth weight of the litter.

Lambing Date. The only significant effect on date of lambing was that of $\%H_L$ ($P<.05$). Hafez (1952) concluded that natural selection had resulted in the length of the breeding season in sheep being in proportion to the proximity of the geographic origin of the breed to the equator, and that breeds with extended breeding seasons began cycling earlier than other breeds rather than continuing to cycle later. Christenson (1983) found highest estrous activity in Rambouillets, Targhees, and Dorsets from Aug. 18 - Sept. 7 and in Hampshires, Suffolks and Finnish Landrace crosses from Sept. 7-28. The positive but non-significant regression coefficients on $\%H_E$ and $\%FL_E$ in this study are in agreement with the work of Christenson.

However, Lindsay and Ellsmore (1968) have shown that the extended breeding seasons of such breeds as the Merino and the Dorset Horn also apply to the rams. Ewes in this study mated to H or FL rams lambed earlier than ewes mated to WFR rams. This is in contrast to the effect of $\%H_E$.

Differences in lambing date could also be due to breed differences in gestation length. Ewes mated to fine and medium wool whitefaced rams may have a slightly longer gestation than those bred to blackfaced rams (Scott, 1982).

The effect of EH on date of lambing was positive but not significant (equivalent to 21.0%). The breeding season of crossbred ewes has been shown to be intermediate in length between those of the two parents in the cross (Hafez, 1952), and to be heritable ($h^2 = .5$) and to respond to selection (Walrave, 1970).

Number and Weight of Lambs Born and Weaned. The effects of $\%H_E$ on number and weight of lambs born and weaned were negative but only significant for the number of lambs born ($P<.01$). The effects of $\%FL_E$ were positive and significant ($P<.01$) for number of lambs born and negative and non-significant for the other traits. These effects on the number of lambs born are in agreement with Meyer and Bradford (1973) who found mean litter sizes of 2.22 for FL X Targhee ewes compared to 1.50 for purebred Targhees (an increase in litter size of 48%), and Dickerson and Glimp (1975) who found the age-adjusted prolificacy of Targhee ewes to be 152% vs 144-148% for H. Neither the effect of EH nor LH on number of lambs born was significant, although both were positive (equivalent to 19.5% for EH). Sidwell and Miller (1971a) found positive heterosis for prolificacy in 14 of the 20 possible two-way crosses of H, Targhee, Suffolk, Dorset and a strain composed of Columbia, Southdown and Corriedale breeding. In a review, Nitter (1978) concluded that estimates of heterosis for prolificacy averaged about 2.8% and were non-significant.

The superior prolificacy of the FL cross ewes in this study was not expressed in the birth weight of their litters. Bradford (1972) stated that breeds of sheep tend to rank similarly for birth weight and mature weight. Since the FL produced more lambs and yet had a lower litter birth weight, the weights of individual lambs must have been much lower than those of lambs from the WFR ewes. Donald and Russell (1970) suggested that birth weights of FL singles and twins were small relative to ewe body weight.

Hunter (1956) and Dickinson et al. (1962) concluded that breed of lamb has a greater influence on birth weight than do maternal effects. This is in agreement with the fact that the only significant effect on birth weight of the litter was the negative ($P<.05$) effect of $\%FL_L$.

The effects of EH and LH on the birth weight of the litter were positive but not significant (18.4% for EH and 1.1% for LH).

Rastogi et al. (1982) reported an average maternal heterosis for individual birth weight of .7% and a significant individual heterosis for birth weight of 4.6%.

The number and weight of lambs weaned in this study are not expected to reflect the number of lambs born since lambs in excess of two born to a ewe were reared artificially or fostered onto another ewe. This common management practice has the effect of masking, to a certain extent, the effects of breed and heterosis of the ewe and lambs on these traits. Dickerson et al. (1975) reported that FL X domestic breed crosses had better viability than did Rambouillet crosses or H crosses. Sidwell and Miller (1971a) reported fewer purebred Targhee lambs born dead than purebred H, Suffolk, Dorset or Columbia, Southdown Corriedale strain lambs, but found the H X Targhee cross to be the best of the 20 two-way crosses in the study for % of lambs weaned per ewe bred. These results are in line with the ranking of the three breeds in this study (WFR,FL,H) for number of lambs weaned.

The effects of EH and LH on number of lambs weaned were both positive but non-significant. Sidwell et al. (1962) established that there was an increase in survivability of lambs of three- or four-way crosses, suggesting an improved maternal environment provided by crossbred dams.

The kg of lamb weaned is the ultimate measure of reproductive efficiency of the ewe and is influenced not only by the number of lambs born and surviving and by birth weight, but also by the milk production and mothering ability of the ewe and by the growth rate of the lamb. None of the effects of breeds or heterosis of ewes or lambs were significant for this trait in this study, although the effect of EH was equivalent to 37.5%. Researchers (Barker, 1975; Thomas and Whiteman, 1979) have found FL cross ewes to have superior total weaning weights as yearlings but not as mature ewes, indicating that the major advantage of FL breeding is a decrease in infertility of ewe lambs, a trait not addressed in this study. Hohenboken and Clarke (1981) found FL cross ewes to be superior at all ages on irrigated pastures. Katsigianis (1980) examined the lamb production of FL and Suffolk cross ewes mated to Polled Dorset rams. As in the present study, ewes were allowed to raise no more than two of the lambs they produced. The FL cross ewes weaned more kg of lamb per lambing at one year of age. After three lamb crops, the weight of lamb weaned per ewe was similar for the two groups, but the FL crosses had a greater weight ($P<.01$) of artificially reared lambs.

Heterosis effects on the weight of lamb weaned per ewe were examined by Fahmy (1982), who reported an effect of ewe heterosis of 18%, and by Vesely and Peters (1974) who reported two- and three-breed crosses of Romnelet, Suffolk, North Country Cheviot and Columbia to have 116.6% and 132.5%, respectively, of the pure breed averages.

Relationships Among Ewe Production Traits

The residual correlations from the analysis of variance are presented in Table 2. The correlation between ewe weight at lambing and greasy fleece weight is unreasonably high. Guicgas et al. (1982) also found positive and significant correlations between body weight and fleece weight, but the largest was .49. Basuthakur et al. (1973) reported correlations of average annual greasy fleece weight and yearling weight of Columbia and Targhee ewes of .10 and .30 respectively, and .14 and .15, respectively for lifetime production of greasy fleece weight and yearling weight. It may be that weight at lambing is more highly correlated with greasy fleece weight because they are both affected by the level of nutrition during the winter, the period the most likely to be limiting. Other correlations are consistent with expectations, e.g., the negative correlations between greasy fleece weight and lamb production traits. The decrease in the lamb production traits with increased (i.e., later) lambing date might be an indication that ewes which conceived earlier in the breeding season were somewhat outside the normal limits of their mating season and therefore ovulated at a lower rate than did ewes conceiving later in the season.

Repeatabilities of Ewe Production Traits

Repeatabilities and standard errors were calculated from variance components from the analyses of variance (Becker, 1984) and are presented in Table 3.

The repeatability of greasy fleece weight is in good agreement with the estimate of .62 reported by Lewer et al. (1983) for Perendale ewes. Clarke and Hohenboken (1983) reported a repeatability of body weight at mating of .61, which is consistent with our estimate of .62 for weight at lambing. The repeatability of lambing date of .16 is less than the estimate reported by Hanrahan (1983) of repeatability of date of first estrus of .22 for Suffolk and Texel ewes and .37 for Galway and Cheviot ewes. Clarke and Hohenboken (1983) found a higher positive repeatability (.19) of number of lambs born per ewe lambing, but their estimates of .08, .07 and .09 for number of lambs weaned, birth weight of the litter and weaning weight of the litter, respectively, are in good agreement with this study.

Production Indices

Production indices are presented in Tables 4 and 5 and the mean production indices of the various mating schemes are shown in Table 6.

The results clearly indicate that EH is the most important factor in determining the economic productivity of a mating. The increase in production index from increased LH is slight. The reduction in EH and LH at equilibrium to 85.7% did not have a large effect on production index.

Within mating schemes, ewes with a high $\%WFR_E$ were generally the most productive, probably due to their superior wool production and the fact that the FL cross ewes were not allowed to express their superior prolificacy by weaning more lambs. Crosses involving H on the sire side had higher average production indices than crosses with H on the dam side.

Sidwell and Miller (1971b) computed two indices based on weight of lamb weaned and wool production, one on a per ewe basis and one on a per unit of body weight basis, for H, Targhee, Suffolk, Dorset and a Columbia, Southdown and Corriedale strain purebred matings and all possible two way crosses. For the first index, Targhees had the highest value (51.24) followed by the Suffolk (43.78). The Columbia, Southdown and Corriedale strain had the highest index per unit of body weight followed by the Targhee and the Suffolk, suggesting that smaller ewes might be more cost-effective.

TABLE 1. REGRESSION COEFFICIENTS AND STANDARD ERRORS OF BREED AND HETEROSIS EFFECTS ON EWE PRODUCTION TRAITS

Effect	Wool grade	Greasy fleece weight (kg)	Ewe weight (kg)	Date of lambing
Mean	53.3 ± .2	4.26 ± .03	42.6 ± .3	34.2 ± .4
$\%H_E$	2.2 ± 1.2	-.52 ± .25*	-4.8 ± 2.5	3.8 ± 3.1
$\%FL_E$	.3 ± 1.1	-1.15 ± .24**	-11.6 ± 2.4*	4.6 ± 3.1
$\%H_L$		.59 ± .39	6.1 ± 3.9	-9.9 ± 5.0*
$\%FL_L$		.99 ± .39	10.3 ± 3.9**	-4.5 ± 5.0
$\%M_L$		-2.36 ± 1.18*	-24.6 ± 11.9*	10.6 ± 15.1
EH	-4.9 ± 1.7**	.05 ± .51	.3 ± 5.1	-7.8 ± 6.5
LH		.23 ± .33	2.5 ± 3.3	7.4 ± 4.2

Effect	Number of lambs born	Number of lambs weaned	Birth weight of the litter (kg)	Weaning weight of the litter (kg)
Mean	1.84 ± .02	1.50 ± .02	8.09 ± .08	51.3 ± .7
$\%H_E$	-.48 ± .18**	-.25 ± .17	-.18 ± .64	-4.5 ± 5.4
$\%FL_E$	.47 ± .18**	-.06 ± .17	-.81 ± .63	-2.3 ± 5.4
$\%H_L$	-.36 ± .29	-.30 ± .28	-.21 ± 1.03	-2.4 ± 8.7
$\%FL_L$	-.37 ± .29	-.26 ± .28	-2.34 ± 1.03*	-7.5 ± 8.7
$\%M_L$	1.08 ± .87	.76 ± .83	3.85 ± 3.10	15.3 ± 26.3
EH	.36 ± .38	.62 ± .36	1.43 ± 1.33	18.4 ± 11.3
LH	.12 ± .24	.03 ± .23	.08 ± .87	0.0 ± 7.3

* $P < 0.05$
** $P < 0.01$

TABLE 2. RESIDUAL CORRELATIONS AMONG EWE PRODUCTION TRAITS[a]

Ewe Production Traits	2	3	4	5	6	7.
1 Greasy fleece weight	1.0	.18	-.24	-.17	-.12	-.19
2 Ewe weight at lambing		.18	-.24	-.17	-.12	-.19
3 Date of lambing			-.33	-.34	-.47	-.39
4 Number of lambs born				.62	.79	.56
5 Number of lambs weaned					.63	.91
6 Birth weight of the litter						.65
7 Weaning weight of the litter						

[a] All correlations significant (P<.01).

TABLE 3. REPEATABILITIES OF EWE PRODUCTION TRAITS.

Ewe Production Trait	Repeatability	Standard Error
Greasy fleece weight	.60	.03
Ewe weight at lambing	.62	.03
Lambing date	.16	.04
Number of lambs born	-.01	.03
Number of lambs weaned	.08	.04
Birth weight of the litter	.06	.04
Weaning weight of the litter	.04	.04

TABLE 4. PRODUCTION INDICES OF PUREBRED AND CROSSBRED EWES MATED TO RAMS OF DIFFERENT BREEDS

Ram	Ewe	EH %	LH %	120 d adjusted weaning wt (kg)	Greasy fleece wt (kg)	P.I.[a]
WFR	WFR	0	0	51.34	4.26	64.12
H	H	0	0	44.51	4.33	57.50
FL	FL	0	0	41.57	4.10	53.87
WFH	H	0	100	45.65	4.27	58.45
WFR	FL	0	100	45.26	3.84	56.77
H	WFR	0	100	50.12	4.79	64.48
H	FL	0	100	44.08	4.13	56.47
FL	WFR	0	100	47.57	4.99	62.53
FL	H	0	100	41.92	4.76	56.20
WFR	H-FL	100	100	63.86	4.10	76.16
H	WFR-FL	100	100	63.86	4.10	79.02
FL	WFR-H	100	100	63.15	4.91	77.92
WFR	WFR-H	100	50	66.90	4.31	79.84
WFR	WFR-FL	100	50	66.70	4.10	78.99
H	WFR-H	100	50	65.72	4.61	79.54
H	WFR-FL	100	50	65.50	4.51	79.02
FL	WFR-FL	100	50	62.97	4.59	76.75
FL	H-FL	100	50	60.15	4.48	73.59

[a] PI = [120 d Adj. Weaning Wt. + (3 x Greasy Fleece Wt.)]

TABLE 5. PRODUCTION INDICES OF ROTATIONALLY CROSSED EWES AT EQUILIBRIUM

Sire	Ewe			120 d adjusted weaning wt (kg)	Greasy fleece wt (kg)	P.I.
	4/7	2/7	1/7			
FL	WFR	H	FL	61.20	4.84	75.73
H	FL	WFR	H	61.97	4.39	75.15
WFR	H	FL	WFR	62.45	4.19	75.02
H	WFR	FL	H	63.69	4.58	77.43
FL	H	WFR	FL	59.58	4.78	73.91
WFR	FL	H	WFR	62.34	4.07	74.54

TABLE 6. MEAN PRODUCTION INDICES OF DIFFERENT MATING SCHEMES

Mating Schemes	mean
Pure breeding	58.50
Two-Way Crosses	59.15
Three-Way Crosses	77.70
Backcrosses	77.96
Crosses at Equilibrium	75.30

CONCLUSION

The results of this study clearly indicate that the best production in a management system such as this one is to be gained from mating schemes involving crossbred ewes, with heterosis of the lamb being of secondary importance.

FL breeding in the ewes would probably lead to greater increases in production than illustrated here in systems where such ewes were allowed to raise more than two of their lambs, or were credited with having produced them. H breeding will be more effective if restricted to the sire side of the mating.

The reduction seen in production indices at equilibrium, due to decreased heterosis of the ewe, is small and would probably be more than compensated for by the extra cost of maintaining all the breed classes (including purebreds) necessary for the operation of a three-way terminal cross. However, if good two-way cross ewe lambs were available for purchase on a regular basis and at a reasonable cost, a three-way terminal cross could be practiced much more easily as there would only be one type of cross to be made at mating time, and highly specialized dam and sire breeds could be utilized much more effectively.

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