GENETIC AND ENVIRONMENTAL VARIATION AND GENOTYPE X ENVIRONMENT INTERACTIONS IN NEW ZEALAND ROMNEY SHEEP

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SHERYL-ANNE NGAIRE NEWMAN
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ABSTRACT

Performance records were kept on New Zealand Romney ewes from birth to 5 years of age. These ewes were maintained in two subflocks at different stocking rates. A proportion of the ewes were eliminated at random at about 16 months of age. From this stage until 5 years all ewes were retained unless they died of natural causes. The data represented 1944 hoggets and 919 older ewes, the progeny of 49 sires. Each of these sires were used for two consecutive years. The records were calculated between 1966 and 1983 and represented seven sire periods.

The significance of genotype x environment interactions (GEI) were investigated for a range of hogget and adult traits, including liveweight (LW), greasy fleece weight (GFW), clean fleece weight (CFW), yield (Y), quality number (QN), mean fibre diameter (MFD), staple length (SL), total crimp number (TCN), crimp frequency (CF), staple strength (SST), character (CHG), lustre (LUS), tippiness (TIP), cotting (COT), cotted area (CAG), soundness (SOU), handle (HND), greasy midside colour (GCM), scoured midside colour (SCM), greasy fleece colour (GCF), number of lambs born per ewe mated (NLB), number of lambs weaned per ewe mated (NLW), weight of lamb weaned (WLW), weight per lamb weaned (WPL) and lamb survival percentage (LSP).

The effects of the environmental factors of birth year, age, number of lambs born and weaned, stocking rate and rearing rank and all interactions among them were assessed for ewe liveweight and wool traits. A similar model was developed for hogget traits but included age at weaning rather than reproductive status. Reproductive trait models included ewe liveweight and did not include rearing rank and reproductive status.

Sire x stocking rate and sire x birth year interactions were the only genotype x environment interactions that were statistically significant.

Intra-trait genetic correlations, the correlation of the record of a trait at one stocking rate with the same trait at the other stocking rate, was used as a measure of the practical importance of sire x stocking rate interactions in selection. Intra-trait genetic correlations for hogget liveweight (0.51) and yield (0.57), and for ewe liveweight (-0.24), greasy fleece weight (0.65), yield (0.42), quality number (0.58), staple length (0.56), total crimp number (0.52) and crimp frequency (0.63) were significantly less than unity. Intra-trait genetic correlations of ewe staple strength and ewe assessed traits were also less than 1.0, but this was more a reflection of the extremely low sire variances rather than significant sire x stocking rate interactions.

Genetic parameters were calculated by different methods, including daughter-dam regression and paternal half-sib correlation techniques. Paternal half-sib estimates were calculated where the genetic variance excluded GxE interactions (EI) and where the genetic variance included GxE interactions (II). In traits where GEI were significant exclusion of the interaction terms from the numerator caused a dramatic reduction in the heritability estimates. Hence, use of the II estimates in selection programs would overestimate the amount of genetic progress likely to be achieved where GxE interactions exist.

Between-trait genetic correlations within age classes and across ages were evaluated in relation to selection policies of New Zealand Romney sheep.

Implications of the results in practical sheep breeding programs are discussed. The connotations of the significant genotype x environment interactions are that selection of rams should occur at the 'commercial' stocking rate. The environment of the stud should be taken into account when selecting rams.

Significant GEI will also have important implications in relation to breeding systems used to assist genetic improvement of the sheep population. Group breeding schemes and sire reference programs will be affected. If the GBS nucleus is in a different environment from the base flocks, both closed and open schemes can suffer a considerable loss in overall selection response when GEI exist.

Comparison of sires across flocks using sire referencing is currently receiving much attention. If sire x environment interactions are important, inconsistencies are likely to occur in the ranking of sires.

Genotype x year interactions appear likely to be a major cause of inconsistencies in the estimation of breeding values and research to identify the causes of these interactions should be carried out.

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CHAPTER ONE

INTRODUCTION

Efficient genetic improvement of animals depends greatly on the selector's ability to rank animals in an order which closely approximates to their genetic ranking. A major factor limiting the accuracy of this ranking is variation due to environmental causes. To simplify genetic concepts it is often assumed that the observed performance (phenotype) is the simple summation of the genotypic and environmental effects. However in practise it also depends on the way in which these two factors interact or combine. If the relative performance of one genotype compared with another changes as the environment changes then a genotype x environment interaction (GEI) is said to occur.

Heritabilities and other genetic parameters are normally calculated within specific environments. If genotype x environment interactions exist and sheep are selected in one environment and then their progeny have to perform in another, the selection becomes less accurate than the heritability would suggest. As Webb and Curran (1986) pointed out, selection environments have generally been chosen to maximise individual animal performance and accuracy of measurement, whereas production environments have been chosen to maximise profit. The low correlations between performance in selection and production environments reported for other species are disturbing.

In studies designed to identify whether a genotype x environment interaction (GEI) exists attempts are often made to overcome the problem of small numbers by enlarging the effects of genotype and environment, by using different breeds or widely differing environmental conditions, such as tropical versus temperate. However, care needs to be taken when interpolating from data obtained well outside the normal range likely to occur on-farm. Few studies have been carried out to investigate GEI and fewer on sheep. The majority of recent reports have been for beef and dairy cattle (Barlow, 1987).

In the sheep industry stud breeders almost invariably apply high levels of nutrition and disease control to their stock in order to enhance their appearance and marketability. Thus most of the effective selection is based on performance under favourable conditions. Progeny of rams selected under these conditions are expected to perform under less favourable commercial conditions. In this study, set up to investigate whether GEI exist and the practical significance of these, progeny of sires were run at two stocking rates which are likely to occur in practical on-farm situations. In a farming system which relies on pasture feeding, changing the stocking rate is the major method by which the level of nutrition supplied to the sheep can be varied. Clearly, if nutritional levels fluctuate widely, as they do, from low stocking rates to high stocking rates and if there are important genotype of sires x stocking rate interactions, the effectiveness of selection may be severely prejudiced (Chopra, 1978).

Estimates of genetic and phenotypic parameters are required for the prediction of genetic gain from selection and for planning selection procedures. However most published estimates are from immature ewes (Elliott *et al.*, 1979). When using these estimates to predict gain from selection in mature sheep, it is usually assumed that the same values apply and the same genes affect performance at all ages but this assumption may not be valid (Lewer *et al.*, 1983). Another factor is that no information is available from hogget records pertaining to reproductive performance.

In order to investigate the significance of genotype x environment interactions in this study it was necessary to estimate environmental effects and genetic parameters at a number of age levels including hoggets and mature ewes. A wider range of traits than is available in most other studies are presented including hogget and ewe liveweight, greasy fleece weight, clean fleece weight, clean scoured yield, quality number, mean fibre diameter, staple length, total crimp number, crimp frequency, staple strength, character, tippiness, cotting, cotted area, soundness, handle, greasy midside colour, clean midside colour and greasy fleece colour and for ewes only number of lambs born, number of lambs weaned, weight of lamb weaned and lamb survival.

CHAPTER TWO

REVIEW OF LITERATURE

GENOTYPE X NUTRITION INTERACTIONS IN LIVESTOCK AND LABORATORY SPECIES

2.1 INTRODUCTION

Different methods for classifying genotype x environment interactions (GEI) have been proposed by several authors (Haldane, 1946; McBride, 1958; Mather and Jones, 1958; Dunlop, 1962; Pani, 1971; Bowman, 1972; Wilson, 1974; Mather, 1975) and reviewed by others, including Pani and Lasley (1972) and Chopra (1978). The study of GEI is based on the theory developed by Falconer (1952) and further developed by Dickerson (1962). In general, there have been two alternative approaches - dynamic and static.

In the dynamic approach to GEI, the possible accumulations of differential responses are measured when selection is practised in different environments. It is possible to contrast the behaviour of the genotypes in various environments when they are evaluated not only in their environment of selection but also in other situations. Since the estimation of parameters with precision requires a large number of individuals in each of the alternative environments and because of the number of generations required, experiments by this method are seldom practical in livestock and have been restricted almost exclusively in mammals to growth rate on *ad lib.* and restricted feeding regimes for rats and mice. The experiment of Fowler and Ensminger (1960) is the only early report of the procedure being applied to larger animals and its conclusions have been questioned by King (1971) because of the large sampling errors attached to the original observations.

A more recent approach, reported by Lasslo, Bradford, Torell and Kennedy (1985), selected for weaning weight in Targhee sheep in two environments.

In the static approach the relative performances of different genotypes are measured under different environments and the possible presence of an interaction examined. Ideally, one would wish to compare the performance of the same genotype over different environments, but this is usually not possible with domestic animals. Hence groups of related individuals, i.e. paternal half-sibs, breeds or strains are commonly chosen for study. Considerably less resources are required for the static approach and a number of workers have applied it to farm animals.

Two types of GEI can occur. Firstly, the variation between animals can be greater in one environment than another but the animals rank in the same order. Secondly the ranking of the animals may change between environments. This type of interaction can be measured by the correlation between breeding values in the two environments. If this genetic correlation is 1.0 then the animals rank in the same order in both environments. If the genetic correlation is less than 1.0 then the genotype which is best for one environment may not be best in the other (Goddard, 1985).

The different genotypes may be represented by breeds, strains, progeny groups (paternal half-sibs) or litters (twins in the case of cattle). By comparing various breeds a large genetic variation is usually secured, which increases the chance of obtaining a significant interaction. On the other hand, the results might be of limited practical importance, as selection usually takes place within rather than between breeds. Progeny groups exhibit much less variation among genetic groups, but this can to some extent be outweighed by a larger number of groups.

McDonald (1985) concluded there is little evidence that genotype x environment interactions are of sufficiently large size to represent an area of concern for the pig and poultry industries. Unless stock are grown under conditions greatly different from those under which the breeding animals were selected, it is unlikely that problems will develop.

Syrstad (1976) commented that nutrition (level of feeding, composition of ration and feed quality) is the most important factor of environment. Interactions between genotype and location and genotype and herd have been studied more often than between genotype and nutrition in cattle and sheep. A multitude of other factors, such as management effects, climate including temperature, humidity and rainfall, herd or flock breeding values as well as nutrition are included in the environment differences in most situations. Thus it would seem very difficult to attribute environmental differences to nutrition or even a large proportion to this cause. Hence only experiments where environmental differences can clearly be attributed to nutritional sources will be reviewed.

2.2 LABORATORY SPECIES

2.2.1 *DROSOPHILA*

Frahm and Kojima (1966) compared responses to selection on body weight under divergent larval density conditions. Response to selection for light or heavy weight at two larval densities was very similar and one environmental condition served as well as the other from an overall point of view.

Robertson (1959, cited by Wilson, 1974), working with *Drosophila* , reported that lines selected for large and small body size both showed relatively larger declines when grown on sub-optimal diets than did individuals from the unselected population. However, highly inbred lines did not show reduction in excess of the parent population. The relatively large reduction in body size when subjected to sub-optimal conditions was peculiarly characteristic of the selected lines.

Sang (1964) reported on the nutritional requirements of inbred lines and crosses of *Drosophila*. He found that the hybrids were only superior to inbreds in near optimal conditions. Each line and each cross was found to have its own optimal nutritional environment and among-line rankings changed between environments.

Caligari and Mather (1975) carried out two experiments, the first a diallel experiment at three temperatures and the second an experiment in which eight lines were raised in nine environments, comprising combinations of three temperatures and three types of culture. The difference between environments in the types of culture produced differences in mean chaeta number, but there was no evidence that the genotypes differed in their reactions.

Bileva, Zimina and Malinovsky (1978) investigating longevity of females and males of inbred stocks of *Drosophila melanogaster* on normal, poor and sugar-rich nutrient media showed that the differences in longevity between these stocks depended mainly on differences in the longevity of males. In general, differences between the stocks were retained on all the variants of nutrient medium, although there was some indication of possible genotype x environment interactions as females of the third stock exceeded the longevity of females of the fifth stock except on the normal nutrient medium.

Taylor and Condra (1978) grew 12 strains of *Drosophila pseudoobscura* on ten different feeds at two temperatures. Five components of fitness were measured. The strain x temperature interaction was significant for all five traits, and the strain x food interaction was significant for three of the traits (male development time, female development time and female wing length).

MacKay (1981) subjected a large natural population of *Drosophila melanogaster*, replicated as eight subpopulations, to four different patterns of environment variation. MacKay (1981) concluded that specific genotype x environment interactions were not present, therefore adaption to heterogeneous environments was possible by selection of heterozygo sity *per se*, rather than by differential survival of genotypes in the alternative niches.

2.2.2 *TRIBOLIUM*

Tribolium castaneum, the rust-red flour beetle, is frequently utilized as a biological model in quantitative genetics. These beetles have a life expectancy of approximately six months which is equivalent to six or more generation intervals. They have ten pairs of known chromosomes and are easily cultured under laboratory conditions (Yamada, 1974).

Bray, Bell and King (1962) investigated the importance of genotype x environment interactions with reference to genetic control populations. They noted that a control which is to be used to determine the genetic progress of a selected line must accurately measure changes in the environment as they affect the selected population of interest. When definable environmental changes differentially affect a selected line and a control then comparisons between them are biased to the extent of the genotype x environment interactions. Bray *et al.* (1962) demonstrated 15 methods of maintaining control populations over eight generations.

Hardin and Bell (1967) reported results from an eight generation experiment in which selection was for high and low larval weight of *Tribolium* under good and poor nutritional conditions. Results were consistent over the four replications in that maximum performance in a single environment resulted from selection in that environment, and maximum average performance resulted from selection in the poor environment.

Yamada and Bell (1963, 1969) included the same selected lines of the previous study, plus populations selected each generation on average performance under good and poor nutrition and on performance under each level of nutrition in alternating generations, to evaluate the effectiveness of various selection methods and the importance of genotype x environment interactions under two levels of nutrition. Selection was also carried out for large and small 13-day larval weight. Direct selection responses exceeded correlated responses under both levels of nutrition, and average performance of lines selected for large size under poor nutrition exceeded average performance of lines selected for large size under good nutrition. However, contrary to theoretical expectations, those populations selected for average performance on the two rations were not superior for this trait. Asymmetrical responses were observed to be dependent on the environment of selection. When selection was based on performance in the optimal environment, response for small size was greater. The situation in the sub-optimal environment was reversed.

Wilson (1974) discussed the importance of genotype x environment interaction studies in gaining understanding of the constitution of an integrated biological system. He reviewed previous work with *Tribolium* and suggested possible areas for future research.

Hardin, Rogler and Bell (1967) found there were significant interactions in larval weight of strain with two levels of humidity and three nutritional regimes.

Benyi and Gall (1978) found the response of three lines to a good (yeast-supplemented) and a poor (yeast-free) diet indicated that large, fast-growing lines were more susceptible to poor environmental conditions than small slow-growing stocks. The F1 progeny were superior to the parental average regardless of diet and had a more rapid developmental time, particularly on the poor diet. Significant interactions were also observed between diet and both sires and dams within lines for larval weight and between diet and dams within lines for rate of development and pupal weight of female progeny. They concluded that the findings supported the notion that general-purpose stocks should be developed for production systems when environmental changes are not predictable but special-purpose stocks would hold an advantage when the environmental changes are predictable.

Rich and Bell (1980) attempted to identify genotype x environment interaction effects in long-term selected populations of *Tribolium* and their crosses kept on two nutritional diets similar to those used by Benyi and Gall (1978). Evidence of a genotype x environment interaction for 13-day larval weight was obtained from the significant interaction of crosses with progeny environment. The genotype x environment interaction effect was nonsignificant for percent heterosis indicating the near parallel response when changing from the good to the poor environment.

Murthy and Taneja (1982) designed a single generation experiment to estimate the level of GEI and genetic parameters for two strains on normal and stress mediums. The differences due to genotypes and genotype x environment interactions were highly significant for all traits. The genetic correlations between means in normal and stress mediums were 0.66 and 0.55 for larval weight, 0.82 and 0.57 for days to pupation and 0.14 and 0.37 for pupal weight in Purdue and Consejo strains respectively. These correlation coefficients differed significantly from unity indicating that genotype x environment interactions were of biological importance for the environments and genotypes studied.

High heritability estimates (0.47 to 0.53) suggested that these traits were under genetic control. Murthy and Taneja (1982) concluded it should, therefore, be possible to design an appropriate breeding programme to select for any desired level of interaction, overcoming the problem, frequently recurring in animal breeding, of carrying out selection in the presence of interaction between genotype and environment.

2.2.3 RATS AND MICE

In a classic experiment, the effect of the plane of nutrition on the improvement in body weight achieved by selection was studied in mice by Falconer and Latyszewski (1952). Two strains derived from a single foundation population were selected in exactly the same manner for weight at six weeks of age; one strain was fed *ad lib.* and the other was restricted to 75% of the normal feed intake during the period of three to six weeks of age. The results of this experiment are shown in figure 2.1.

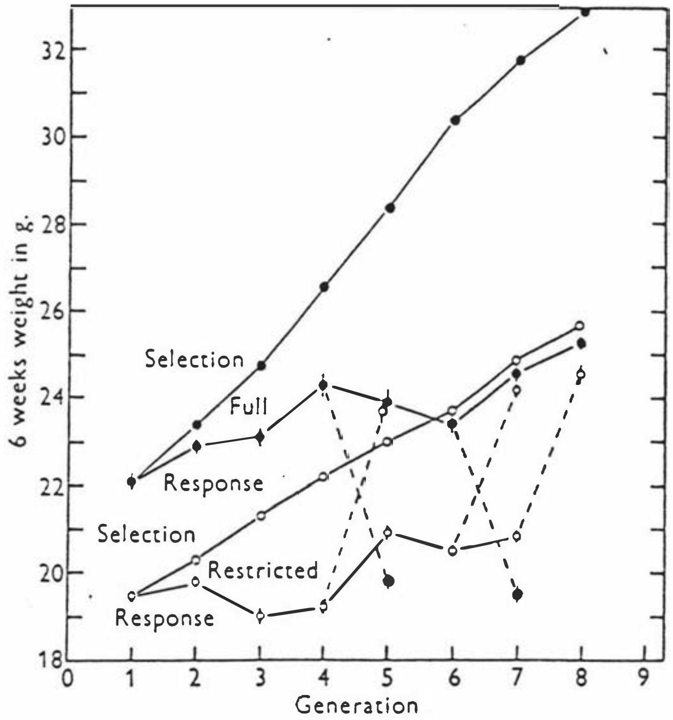

Figure 2.1: Responses to selection for 6-week weight in mice on full and restricted diets. Points connected by broken lines are means of mice raised on exchanged diets (Falconer and Latyszewski, 1952).

Weight increased under selection in both strains; the increase per generation was 0.33 g, or 1.5% of the unselected weight in the full diet line, and 0.26 g, or 1.3% in the restricted diet line. Heritability was higher in the restricted diet line (but not significantly so), being 0.29 on the restricted diet and 0.20 on the full diet.

Exchanges of nutritional level were made between the lines after five, seven and eight generations of selection. When reared on the restricted diet, the restricted diet line was superior in six-week weight; the full diet line showed no improvement over the unselected level. When reared on full diet, mice from the full diet line were larger than mice selected on the restricted diet. However, this difference was small, and mice from the restricted line showed a marked improvement over the unselected level on full diet. Thus, improvement of the genotype for rapid growth on the high plane of nutrition gave no improvement in growth on the low plane. However, selection on the low plane produced a considerable improvement for growth on the high plane.

Falconer (1960) selected for high and low body weight gain from three to six weeks of age. The diets were normal and high fibre. The latter reduced growth from three to six weeks by about 20%. Results of this experiment (figure 2.2) showed that three to six week weight, when measured in the optimal diet, was increased almost as much by selection on suboptimal as on the optimal diet, but growth on suboptimal was not increased at all by selection on optimal. Results of this and the previous experiment (Falconer and Latyszewski, 1952) indicate that it may be better to select under the worst rather than the best environmental conditions if the selected population is expected to perform over a range of environments.

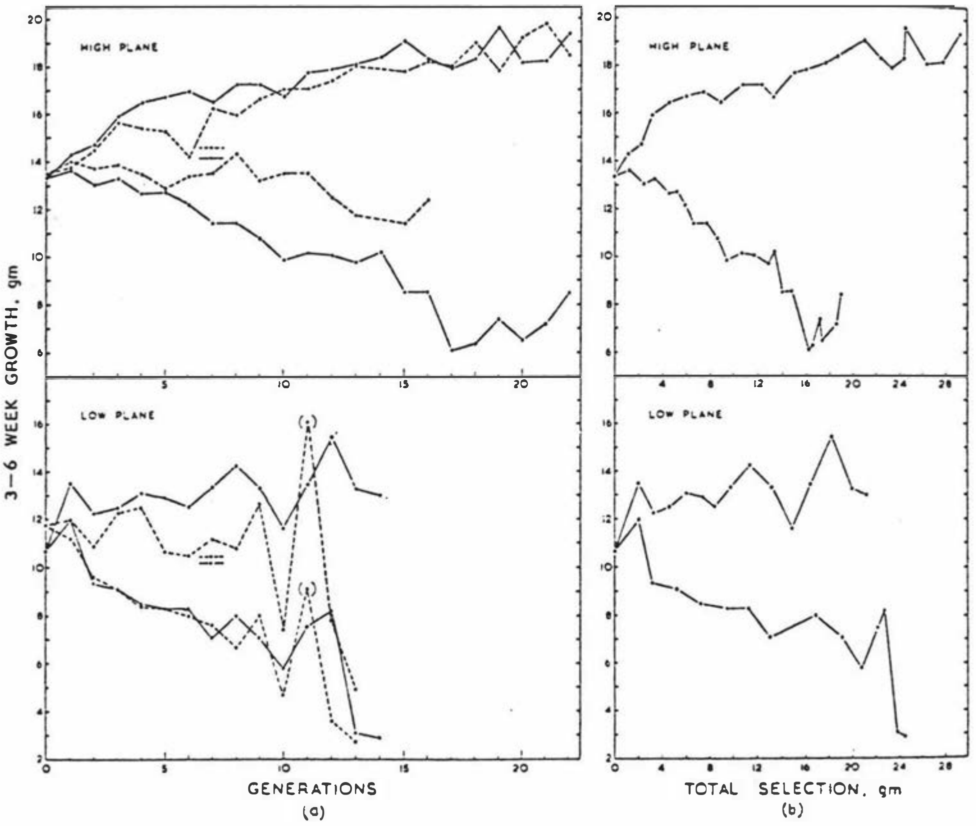

Figure 2.2: Responses to selection in mice for body weight gain from 21 to 42 days of age on high and low planes of nutrition (Falconer, 1960).

However, Falconer (1977) noted that both the experiments showed the same anomalous asymmetrical carry-over of the improvement made by selection from one diet to the other, which did not make sense genetically. He considered the most likely explanation was random genetic drift due to the small numbers of parents used. This random genetic drift can cause quite large differences between different lines selected in exactly the same way.

Young (1953) investigated genotype x environment interactions affecting the growth rate and reproductive phenomena of three strains of mice when kept in two feed (cake *vs* crushed oats) and two temperature environments. Evidence of interaction was found in both characters between nutrition and genotype. The slower growth rate of the C57 strain than the CBA strain on crushed oats suggested the presence of a strain x diet interaction. Young (1953) observed a differential response of different strains to the type of diet in litter size. The RIII strain with the smallest litter size showed no change for this trait on switching from cake to oats, whereas the other two strains showed considerable reduction. In total fertility (number of offspring produced by each female under 20 weeks of age), the C57 strain produced relatively fewer offspring when fed oats compared with cake than the other two strains.

A further experiment on selection for size in mice in different nutritional environments was conducted by Korkman (1961) with two strains of mice and two planes of nutrition. Results were considerably different from those obtained by Falconer and Latyszewski (1952); however the difference between the planes of nutrition was much greater in Korkman's experiment. The lower plane was extraordinarily low, the weight of the young in many cases decreased during the period between 30 and 40 days of age. This difference between the experiments probably caused some of the difference between the results. Korkman (1961) found the heritability to be lower in selection on the low plane (0.066) than selection on the high plane (0.218), the reverse to those found by Falconer and Latyszewski (1952). There was no significant response to the selection on weight on the low plane of nutrition.

Dalton and Bywater (1963) reported a similar experiment but they selected on total litter weight at weaning rather than individual weights. After switching diets they found no significant selection response in either of the dietary regimes, nor any correlated response. The results were expected, however, because of the low heritability of the trait and the strong maternal influence, including milk production.

In his investigations on daughters of male albino mice in two feeding groups (14 and 20% protein) Bakels (1963) also found no sire group x diet interactions for litter size. However the number and size of significant differences in liveweight between sire groups were not the same in the protein groups.

The selection of two strains of rats, one on a standard and another on a roughage diet by Kidwell, Weeth *et al.* (1960) showed significant strain x nutritional regime effects for 70-day body weight and several body measurements among the females; but except for the proportion of small intestine to body weight, none of them were significant in the male.

Bailey, Hammack, Harvey and Probert (1970) compared the effectiveness of selection on two diets with two inbred lines of rats. After selection for six generations, top gaining, select line sires were mated with control dams on both diets. There was evidence of a genotype x environment interaction within sire lines. In each of the four lines the rank of sire varied according to the nutritional regimen under which progeny were evaluated.

However, the sire line x diet interactions were not important. These results represent a situation where the interactions involving intra-population genotypes and macro-environments (Type B of McBride, 1958) were more important than those with inter-population (different inbred lines) genotypes and macro-environments (Type D of McBride, 1958) (Pani and Lasley, 1972).

Park, Hansen, Chung and Chapman (1966) investigated the extent of interaction on the effectiveness of selection for postweaning gain, from three to nine weeks of age, with three different feeding regimes in a population of laboratory rats. Selection for postweaning gain under the full-feeding regime was effective in changing postweaning gain on each feeding regime. Under the low-protein-feeding regime, selection was effective for that trait but did not lead to effective change in growth under the other regimes. These results concur with those found by Korkman (1961) with the performance improved by selection on the plane of nutrition on which the performance was subsequently selected and with the full feeding regime better than the third regime when exchanged. The interaction between line and feeding regime was significant over all generations in two cases but failed to reach statistical significance in the majority of individual generations, where numbers of animals tested were small.

Dalton (1967) repeated Falconer's (1960) experiment with slight modification to widen the dietary treatment. Conclusions from his experiment closely agreed with those of Park *et al.* (1966). Contrary to the results of Falconer (1960), Dalton (1967) found that indirect responses on either plane of nutrition were equal to the direct responses on the same plane. Hence, he concluded, selection for growth could be as efficient in the environment in which the animal was to perform or in any other environment. However, Chopra (1978) noted Dalton's findings do not so much contradict Falconer's recommendations as remove their limitations.

Bateman (1971) studied the effects of constant and of changing diets on responses to selection. Family x diet interactions were smaller than consistent family differences. Heritability of growth for forward and back selected lines was highest on good diets (0.49 on 76% maize) and lower on poor diets (0.20 on 16% maize and 0.28 on 100% maize). It was concluded that genotypic improvements may be effective over a wide range of maize-milk diets.

Kownacki and Gebler (1972) selected within litters of three mouse populations for weight gain between three and six weeks of age in one experiment and for weight of five week old mice in a second. Selection was carried out within two diets - low (10%) and high (20%) protein and within a third population where females and their offspring were fed with the low protein diet and mated with males from the high protein population, to simulate the typical livestock breeding situation where breeding females are often underfed and kept in unsuitable conditions, while the sires are raised and selected while subjected to good feeding and very good husbandry conditions. The experiment clearly indicated a genotype x environment interaction, especially in the size of litters at six weeks of age and in the liveweight gains of the progeny. No data were given on the more important question of line performance when diets are switched. Therefore, no conclusions could be drawn concerning the importance of line x dietary protein interaction (Eisen, 1974).

Roberts (1981) reported on the changes in food consumption and in efficiency found in the lines of mice selected for growth described by Falconer (1973). In the final study, involving feed restriction, the large mice gained less weight than the controls on the same amount of food. The amount fed to the large mice was the voluntary intake of the controls. Thus, at this level of feeding, the large mice were less efficient than the controls, unlike the situation under *ad lib.*

The results above differ from that reported by Stanier and Mount (1972). In a similar study, the large mice still grew better than the controls, though the differences between the two on *ad lib.* feeding was not fully realized under restriction. However, the restriction imposed by Stanier and Mount (1972) was less severe for the large mice than the one used by Falconer (1973).

Bateman (1974) fed six lines of mice distinctive fixed or shifting diets while being selected for fast growth in the first two weeks after weaning. After 10 generations of selection the lines, hybrids and unselected controls were compared on these and intermediate diets. Realized genetic correlations between growth on optimal and suboptimal diets depended on the feeding regimes in which selection was practised. They were significantly higher in lines that were selected on suboptimal diets. When the selected lines were tested on unfamiliar suboptimal diets they were hardly better than controls, but on their own diets and also on the optimum diet they were heavier. With one exception, the hybrids grew on each test diet about as well as did the best selected line.

Three lines of mice differing in body weight and ovulation rate were compared under three levels of feed intake to study the importance of genotype x environment interactions for reproductive traits and body composition by Meyer and Bradford (1974). Line x treatment interactions were significant for days to mating and percent body fat, primarily due to the differential performance of the line previously selected for rapid growth. No significant interaction was found for ovulation rate, mating performance or food intake and utilization.

Gebler and Jezierski (1975) studied pre- and postnatal litter size of mice selected for high weight gains at different levels of feeding. Their findings suggested that an unfavourable genotype x environment interaction had already occurred by the stage of embryonic development.

Radomska, Michalska and Korwin-Kossakowski (1975) conducted experiments with three lines of mice selected for body weight (high, control and unselected) at 21 days which received four diets differing in protein content and quality of fodder used. They measured body weight, degree of fatness at 56 days, body weight gains, fodder and total protein consumption. Apart from weekly weight gains at some periods of life, no genotype x environment interactions were found.

Radomska, Szynkiewicz and Lepecka (1975) used the same material as above to determine blood morphological indexes, erythrocyte counts, leucocyte counts, haemoglobin level and the haematocrit reading. They discovered a highly significant interaction between the lines and diets in the morphological blood composition and suggested the haematological indexes might represent a sufficiently sensitive parameter for use in studies on genotype x environment interactions.

Substantial interaction was observed in three inbred strains of mice maintained on five normal commercial pelleted diets by Festing and Ford (1981). Most of the interaction could be attributed to the response of strain B10, suggesting that strains of the C57BL type may be more sensitive to dietary ingredients than other common strains. The study showed that the diet which gives the best performance for one strain of mice may not be the best for another.

The effect on 10-week body weight of seven generations of selection in three nutritional regimens for two growth related traits was evaluated by McKay (1985) and McKay, Parker and Guenter (1986). During generation eight a cross-over study was undertaken. No significant genotype x nutrition interactions were detected.

2.3 DOMESTIC SPECIES

2.3.1 POULTRY

Many investigations of the importance of genotype x environment interactions in poultry have concentrated on management aspects i.e., early or late hatches, cage *vs* floor management, cage density, temperature effects, location or year differences. Some have involved aspects of differing nutrition confounded with the other factors. In some cases genotype x environment interactions are very marked, while in others they are apparently unimportant (Hull and Gowe, 1962; Dickerson, 1962; Pani and Lasley, 1972; McDonald, 1985).

2.3.1.1 Feeding Level

Schneider, Bohren and Anderson (1955) tested the effect of restricted feeding of a ration low in protein content during the growing period against a full fed ration of high protein content to determine the effect on egg production. In all cases the two breeds responded in the same manner.

A study on the differential response of genotypes to starvation was made by Abplanalp (1962). He exposed selected (selected for 31 years) and unselected lines to different weekly periods of starvation and found that the difference in average egg production between 33- and 48-hour treatments was larger in unselected lines than in the selected ones, indicating the existence of genotype x environment interactions.

Hull and Gowe (1962) undertook a study to detect the magnitude of genotype x environment interactions for characters of economic significance in poultry, involving two strains of poultry, three locations, three years and two rearing programs - full (*ad lib.*) and restricted feeding. Significant interactions for genotype x rearing treatment were found for the two traits, days to sexual maturity and body weight at 21 weeks. Hull and Gowe (1962) concluded that large and important interactions were found only when the environmental effects were very large and the genetic differences were wide.

Gowe, Lemay and Johnson (1962) compared White Leghorn strains, reared on restricted and full feeding, in a laying house test to 500 days. Strain x rearing treatment interactions were significant for housed body weight and sexual maturity and for egg production in one of the four years. However, interaction variance as a percentage of total variance was low for all traits and they concluded that the significant genotype x environment interactions were of such low magnitude as to have little practical significance.

In another study, Hull, Gowe, Slen and Crawford (1963) reared 15 purebred strains and their crosses at two locations, in each of four years, on either full or restricted (70% of full fed) feeding from 5 to 21 weeks of age. Following this, all groups were tested on the full-feeding regime until 500 days of age. They found no significant interactions of the different strains with feeding regime for any of the six traits under consideration.

Proudfoot and Gowe (1967) included restricted versus full feeding treatments in their study, and found two of the four experiments provided evidence that strain and feed treatment interactions were important. These interactions were evident for the traits egg production and monetary returns. Proudfoot and Gowe (1967) also found significant interaction effects on laying house mortality, whereas these were observed to be unimportant by Gowe *et al.* (1962) and Hull *et al.* (1963).

Effects of feed restriction during the laying period on the performance of two strains of mature cage commercial layers in the humid tropics was investigated by Benyi, Akinokun and Lebbie (1981). Significant strain and treatment interaction effects were found for abdominal fat, egg production and feed efficiency.

Brody, Cherry and Siegel (1983) subjected adult males from lines of chickens selected for high (HW) and low (LW) body weights to either *ad lib.*, forced or restricted feed for 21 days. A preference for glucose solution versus water was tested. There were significant treatment effects for the intake of both the glucose solution and water in the HW but not in the LW line resulting in a significant line x treatment interaction. The line x treatment interaction for glucose preference was also significant.

After the assays were completed for preference for glucose solution versus water, each bird was provided continuous access to both a high protein and a high energy diet. The tendency for the HW males to exhibit relatively high protein intakes and for the LW birds to exhibit increased caloric intakes under choice feeding situations was modified by the nutritional-physiological state of the birds; a significant line x treatment interaction for preference of the high-energy diet was therefore obtained.

2.3.1.2 Protein Levels

Asmundson and Lerner (1940) fed two strains of Bronze turkeys on all-mash rations with two different protein levels. They found no significant ration x strain interactions for any of the traits - body weights to 32 weeks of age, weight of pectoralis major, pectoralis minor, left gonad, bursa fabricii, length of keel, femur, tibiotarsus and tarsometatarsus except one ration x strain effect for body weight.

As well as restricted feeding, Schneider, Bohren and Anderson (1955) tested a high protein laying ration against a laying ration containing a normal protein level. The normal protein laying ration groups were significantly superior in fertility, hatch of fertile eggs and hatch of total eggs set but although in a few instances the breeds differed in the magnitude of their responses, in most cases the two breeds responded in the same manner.

Pullet chicks of three commercial egg production hybrids, and three broiler crosses subjected to four starter rations, each containing a different combination of two levels of protein and two levels of energy, comprised the main varieties of the two experiments by Kondra and Hodgson (1961). There were no significant strain x ration interactions affecting weight gain, total feed efficiency or protein and energy utilization.

However, Harms and Waldroup (1962) found a significant strain x protein level interaction, as measured by rate of egg production when they fed two strains of pullets each of three experimental diets containing 11, 13 or 17 percent protein. The same trend was observed for body and egg weight.

Moreng, Enos, Whittet and Miller (1964), using three diets varying in protein levels (13, 15 and 17 percent) on four commercial strains of egg producing birds, observed significant strain x ration interaction effects on Haugh units, egg production and egg weight but they were not important for egg shell thickness.

When four commercial egg production stocks were subjected to four different protein levels, Deaton and Quisenberry (1965) found a highly significant stock x protein level interaction for body weight, egg production, egg weight, feed efficiency, Haugh unit score and egg shell thickness.

Harms, Damron and Waldroup (1966) fed diets which contained 17, 15, 13 or 11 percent protein to four strains of pullets. A significant strain of pullet x protein level interaction was observed for egg production and body weight gain. Although the strain x protein level interaction was not statistically significant for feed efficiency and egg weight there were some definite trends. Kondra and Sell (1966), however did find a significant strain x protein interaction for egg weight.

A diallel mating design was used by Mahmoud (1966) to obtain estimates of genetic parameters in body weight traits in a non-inbred population of New Hampshire chickens grown on 18% and 24% protein rations. He found the components of variance of male effects, the non-additive heredity and maternal effects to be higher on the high plane than on the low plane. He also observed that selection for eight-week body weight on a high plane of nutrition carried with it no improvement on a low plane of nutrition. Improvement of the genotypes for growth on a low plane resulted in better growth on a high plane. The results of his study indicate the importance of genotype x feed level interaction on body weight in chickens.

Marks, Gyles *et al.*(1969) tested ten egg production stocks at two protein levels (13% or 17%). The stock x protein interaction was non-significant for all traits and responsible for only a minor portion (zero to seven percent) of the explained variation. A further experiment by Marks, Moore *et al*. (1969) also found that the stock x protein interaction was not significant for any trait.

In one experiment Marks (1971) fed two strains of quail isocaloric diets containing 18, 21, 24, 27 and 30 percent crude protein. Population x diet interaction was significant for body weight gain one-two weeks, one-three weeks and one-four weeks, but only for the third week for feed conversion. The interaction was not significant for percentage protein, total lipid and water.

Using two commercial parental genotypes, Proudfoot (1973) studied the effects on broiler performance of a single generation of sire selection for body weight at eight weeks of age. Six combinations of protein and feeding time were imposed during rearing. Genotype x feed treatment interactions occurred for male body weight and percent of grade A female carcasses and interactions approached significance for fertility and hatchability.

Liljedahl, Wilhelmson and Carlgren (1973) tested White Leghorn strains on two feeds, one with a high and the other with a low protein and energy content. Hens from each strain - nutrition combination were divided into two different housing environments - four hens per cage or half the density with one hen per cage. Significant strain x nutrition interactions were found for body weight, rate of lay, egg weight in four-hen cages, hen-day egg production, feed conversion, shell thickness, albumen height and shape index. Even though the strain x nutrition interactions proved clearly significant for virtually all traits, their variance components in percent of the total were small, between zero and six percent, and were more often greater in the single-hen cages than in the four-hen cages.

Wolf, Jalaludin and Mukherjee (1977) fed five commercial hybrid lines five isocaloric diets with different protein levels to study body weight and average daily gain up to eight weeks of age. The genotype x diet interaction was significant for all traits studied, and in some cases accounted for greater than five percent of the variance.

Two half-sib groups of White Plymouth Rock fowls were fed on diets containing either a normal or a reduced amount of protein by Sorenson (1977). A genotype x level of protein interaction was found for body weight at 38 days. The heritability of body weight at 38 days of age for male and female on the low protein diet was 0.45 and 0.31

respectively, versus 0.30 and 0.09 for male and female on the normal diet. Genetic correlations between body weight at 38 days, measured on the two dietary regimes, were 0.25 and 0.32 for male and female respectively when calculated by the interaction method and 0.17 and 0.40 by the covariance method.

Proudfoot and Hulan (1978) found genotype x diet interactions to be of no importance when studying the interrelated effects of feeding diet combinations with different protein and energy levels to males and females of commercial broiler genotypes. Data were collected on mortality, liveweights, carcass weights, carcass grade and feed conversion.

Hulan, Proudfoot, Ramey and McRae (1980) investigated the influence of genotype and diet on general performance and incidence of leg abnormalities of commercial broilers reared to roaster weight. A significant genotype x diet interaction was observed for liveweights at 28 days and 40 days but not at 63 or 82 days. There was no significant interaction in feed conversion at 28, 40 or 82 days but it was significant at 63 days. No evidence was found of a genotype x diet interaction for percent grade A carcasses, which is in agreement with earlier observations with broiler genotypes (Proudfoot and Hulan, 1978). Genotype x diet interactions were considered of no practical importance.

Proudfoot (1980) fed two dietary protein levels, 13.6 and 15.4%, in breeder diets to commercial meat parent genotypes. A diet x genotype interaction occurred for egg weight at 224 days, 44 day female body weights and age at 50% egg production.

Two inbred lines of White Leghorn pullets and their reciprocal crosses were fed a high (16.9%) or low (13.4%) crude protein diet during the laying period until 71 weeks of age by Emsley, Dickerson and Gowe (1980). Interactions between genotype and protein level were not significant.

Thirty crosses of egg-type pullets were fed four practical rations differing in protein and metabolizable energy by Doran, Krueger, Bradley and Quisenberry (1980) to test for evidence of genotype x diet interactions. Diet x stock interactions for egg production, egg size, feed efficiency, egg mass and body weight were not statistically significant. Despite the lack of statistical significance of the interaction, there were stocks that deviated considerably from the average egg production, body weight and feed efficiency, particularly when fed the low protein energy ration and Doran *et al*. (1980) suggested that some stocks should be fed specific laying diets.

2.3.1.3 Energy Concentration

As in pigs, a lot of protein diets also vary or are confounded with energy levels. However, some experiments have been done on energy levels alone.

Kondra and Sell (1966), in their comparison of commercial strains fed rations with different energy levels, observed significant interactions for egg weight, thick albumen weight and percent and thin albumen percent but not for egg production, shell thickness, weight and percent of yolk, twin albumen weight and Haugh units.

Sell, Choo and Kondra (1968) fed rations containing no added fat, 16% of soyabean oil or 16% of rapeseed oil to hens of three different strains to study the influence of dietary fat and strain of chicken on fatty acid composition of egg yolk and adipose tissue. They found interaction effects were important for several fatty acids in the composition of yolk and body fat. However, Kondra, Choo and Sell (1968) reported no significant strain x energy interactions for average yolk weight or for egg weight.

Kondra *et al.* (1968) did find significant interactions for egg production and feed utilization.

Fox, Jennings, Marsden and Morris (1960), in a comparison of two types of laying birds fed two rations differing in energy levels, observed a highly significant breed x ration interaction for egg production.

Sibbald and Slinger (1963) with rations with different energy levels found significant interaction effects on the growth rate to four weeks of age. But Lillie, Twinning and Denton (1964) found no evidence of these effects on eight week body weight or body weight gain.

Komiyama, Yamada and Miyazono (1973) reported on genetic differences in protein and energy requirements of growth of chicks. Significant strain x energy interactions were observed in weight gain, feed conversion and protein and energy utilizabilities. The strain x protein interaction was less prominent than the strain x energy interaction.

In a study to evaluate broiler geese carcasses Hudsky, Lautner and Machalek (1975) fed seven types of broiler geese feed containing 2780 kcal/kg (control) or 3000 kcal/kg (high energy). Interaction of genotype with nutrition had a significant effect on body weight at 56 days but was not significant for dressing percentage, food consumption, percent breast muscle, percent leg muscle, and percent fat.

Robbins (1981) conducted a factorial experiment with two breeds of broilers, two sexes, four energy levels and two methods of altering dietary energy concentration. Feed consumption of the light breed was relatively unaffected by dietary energy level, whereas the heavy breed exhibited marked increases in feed intake as dietary energy level increased demonstrating a genotype x environment interaction.

2.3.1.4 Vitamins

Selection of White Leghorns relatively resistant or susceptible to a deficiency of riboflavin in the diet was practised during six generations by Lamoreux and Hutt (1948). As certain strains resisted the vitamin deficiency better than others, differences in their responses were observed in deficient diets but not in the normal diet; hence a genotype x diet interaction existed.

On a diet deficient in vitamin E, that induced a high incidence of encephalomalacia, White Leghorn, Rhode Island Red and Barred Plymouth Rock chicks were tested for resistance to that disease by Howes and Hutt (1952). As in the study by Lamoreux and Hutt (1948) White Leghorns were more resistant than the heavier breeds to the inadequate diet indicating a genotype x diet interaction.

Kheirelden and Shaffner (1957) investigated sire and dam family differences in tolerance of chicks to toxic levels of Protamone and studied the effects of high levels on the rate of growth and mortality. In the first trial a significant interaction existed between the treatment and sire families, but not between the treatment and the dams within sires. When the level of Protamone was raised from 60 to 120 g per 45.5 kg (100 lb) of feed in the second trial, no significant interaction existed. However, a highly significant difference existed in the mortality of the progeny of the different sires, which may explain why no significant interaction was found in the second trial. The toxic level of 120 g of Protamone may have killed all the birds that were at or below a threshold level of resistance to the drug thus eliminating all the birds that would otherwise have shown treatment response.

2.3.1.5 Amino Acids

McDonald (1957, 1958) supplemented White Leghorn and Australorp chicken diets with methionine. In four experiments, White Leghorn chickens showed a significantly greater early response following addition of DL-methionine than Australorp chickens. In a later experiment White Leghorns showed an increase in growth rate when methionine was added to the basal diet but Australops showed a growth depression. A significant breed x methionine interaction was detected.

Hutt (1961) discussed the possible causes of the White Leghorns ability to withstand nutritional deficiencies better than other heavier breeds. This gives rise to genotype x nutrition interactions in many experiments. Individual variation within the breeds was also discussed, with possibilities for selection for strains more resistant to nutritionally deficient diets.

Harms, Damron and Waldroup (1967) evaluated the sulphur amino acid requirements of commercial egg-production-type pullets. Five diets containing 80, 95, 100, 115 or 130% of the estimated methionine requirement of the laying hen were fed to two strains. A significant breed x methionine interaction was found for egg production, egg weight, body weight gain but not for feed efficiency or feed and amino acid intake.

Genetic variation in arginine and lysine utilization was studied by Nesheim (1968 a,b) on strains of chickens selected for a low or high requirement of arginine. In one experiment chicks were fed diets containing 0.75%, 1.0% or 1.25% L-lysine HCl. There was a significant strain x lysine interaction for liveweight gains to 28 days.

Nesheim (1972) indicated strains of chickens have been differentiated as to their ability to grow when fed a diet low in nicotinic acid providing evidence of a genotype x nutrition interaction.

Marks (1971) fed two protein levels supplemented with two levels of thiouracil to three quail lines. Lines were selected for four week body weight on a 28 percent protein diet (P population) or protein deficient diet (20%) containing 0.2 percent thiouracil (T population), and a random bred control (C) population. Exposure of birds from the T population to the 28 percent protein diet increased body weight. Contrariwise, placing population P birds under the T environment resulted in a decrease in body weight. The average performance of the P population across diets was 2 g superior to the T population in generation five, while the mean performance of the T population was 3 g superior in generation six. These results are in general agreement with Falconer and Latyszewski (1952) who suggested that when mice were reared on a normal diet, the strain selected under this environment was superior but the stressed population did not fall far short of it. However Marks (1971) disagreed with Falconer and Latyszewski's (1952) indication that improvement for rapid growth on a high plane of nutrition carries with it no improvement for growth on a low plane. Population P birds were superior to the non-selected controls under the T environment indicating the expression of at least minor genetic gains.

Four-week body weights of T population birds exposed to a 28 percent protein diet containing 0.2 percent thiouracil (toxic) were equal to or superior to birds from the same population receiving the 28 percent protein diet without thiouracil, while body weights of the P and C populations were reduced.

Al-Mohammadi (1976) investigated genotype x environment interaction in traits of egg-producing poultry stocks fed varying dietary salt levels with addition of bicarbonate and of methionine and choline. Stock x salt level interaction was highly significant with respect to average egg weight and also significant with respect to final body weight, percent large eggs and Haugh units. Interaction of stock with bicarbonate was significant with respect to percent large eggs. Stock x choline interaction and stock x methionine interactions were significant for percent large eggs and large meat spots. Second-order interaction of stock x salt x bicarbonate was significant with respect to average egg weight and percent large meat spots. Stock x choline x methionine interaction was significant with respect to percent small eggs, large eggs and extra-large eggs.

2.3.1.6 Minerals

Lillie, Twining and Denton (1964) found no strain x nutrition interactions in the calcium and phosphorus requirements of broilers as influenced by energy, sex and strain for 8 week body weight.

However, Gardiner (1969) observed significant interaction effects for percent livability to four weeks of age, four-week weight, feed efficiency, percent bone ash and plasma inorganic phosphorus when three levels of phosphorus were fed to two breeds, commercial broilers and White Leghorns.

Washburn (1969) compared four stocks of chickens on two diets, a normal and another deficient in copper and iron and observed a significant stock x diet interaction on packed erythrocyte volume.

2.3.1.7 Other Nutritional Factors - Consistency or Constituents of Rations

Merritt, Downs, Bordeleau and Tinney (1960) fed a broiler ration in mash and pellet form to four different broiler strains. The genotypes all showed a higher growth response to pellets although there was some evidence of a differential response. Limitations in the design of this experiment prevented carrying out a strictly valid statistical test of the interactions between strain x form of feed. Merritt *et al.* (1960) observed the data were, nevertheless, suggestive of a genotype x environment interaction.

Johnson and Abplanalp (1960), in their experiment on feeding two diets (crumbled and mash) to meat stocks, observed a significant stock x diet interaction effect on liveweight at the end of their test in the pullets but not in the cockerels.

Bray, Biely and Pope (1962) in a study involving two rations, differing in their ingredients but similar in chemical composition, found no significant interactions for 62-day average weight, 62-day feed conversion, feed cost per kilogram at 62 days, estimated feed conversion to 1.36 kg (3 lb) and estimated number of days to 1.36 kg.

Fox, Jennings, Marsden and Morris (1960) compared the economic performance of four breeds of laying birds with two types of feed - a home mixed mash and "high energy" laying pellets. Interaction between feed and breed was found, the difference in egg production associated with feeding the diets to one breed was reversed when the diets were fed to another breed.

Lopez, Willis and Perez (1970) compared three broiler lines and one medium-heavy line on maize - and sugar-based diets. With the exception of feed conversion no significant genotype x nutrition interactions occurred. Effects on dressing percentage were difficult to interpret. The Rhode Island tended to have the lowest dressing percentage on both diets but there were marked changes in the order of the remaining breeds providing evidence of a genotype x nutrition interaction.

Maghraby, Stino, Goher and Kamar (1980) fed two breeds of layers rations from two sources but found no significant genotype x nutrition interactions.

2.3.2 PIGS

Although some studies have been done on growth and carcass performance characteristics of growing pigs most are for preweaning traits, with few considering slaughter as a final aim. Very few studies on effects of nutrition of sow on litter size, litter weight at weaning or other reproductive characteristics have been done in pigs.

2.3.2.1 Feeding Level

Fowler and Ensminger (1960) randomly divided a crossbred population of swine into two lines. One was selected for increased average daily gain from weaning to 68 kg under a full-feeding regime and another under limited feeding of 70% as much feed as the full-fed group. After six generations, each line was subdivided and half of each line transferred to the other feed regime, allowing estimation of direct and correlated responses in both planes. The pigs selected on the low plane were more efficient on both regimes than those selected on full feeding (figure 2.3). From these results it was calculated that the genetic correlation between gain in the two environments was 0.7.

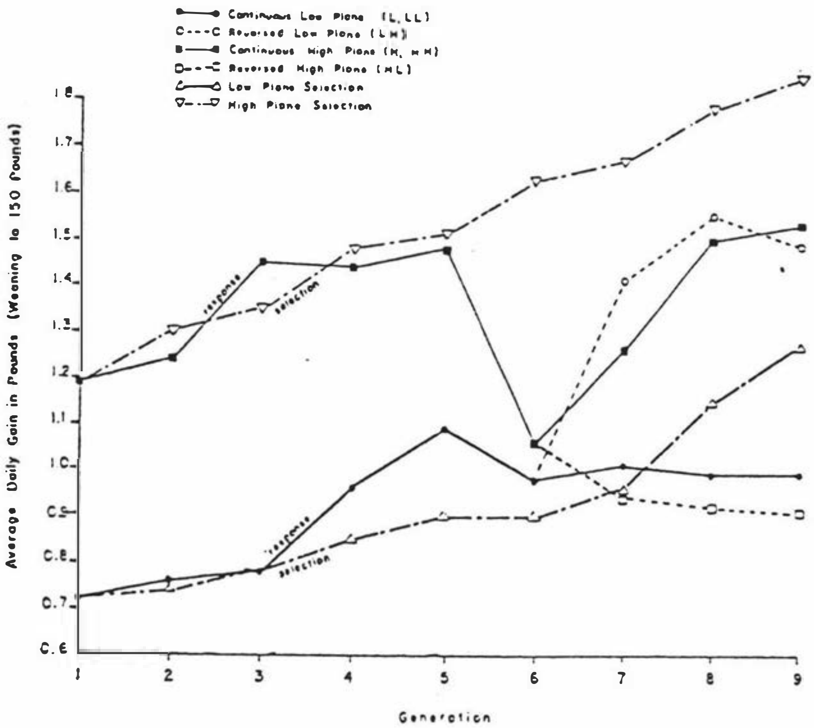

Figure 2.3: Responses to selection in pigs for average daily gain from weaning to 68 kilograms on high and low planes of nutrition. (Fowler and Ensminger, 1960).

Webb and King (1983) conducted an experiment to show the effectiveness of selection for improved food conversion ratio on *ad lib.* group feeding. In generation seven, the selected and an unselected, control line were tested on *ad lib.* or scale (0.77 g/g *ad lib.* daily food intake) feeding. Line x feeding regime interactions were absent for all traits except killing-out proportion and belly thickness. However, the selection procedure adopted was not successful in improving food conversion and no clear conclusions could be drawn from the experiment.

Warren and Dickerson (1952) found that four types of crossbreds showed different liveweight responses to restriction of feeding but there were no interactions for carcass characters. On the other hand, in comparing inbreds with noninbreds and crosses on full and restricted feeding, Gregory and Dickerson (1952) found interactions in carcass characters but not in live weight gains.

Lucas and Calder (1956) using crossbreds on widely differing feeding levels, found interactions in live weight gains, feed efficiency and several carcass characters, but in another experiment with less extreme restriction there was an interaction only in one fat measurement.

Salmela, Rempel and Comstock (1960) compared three kinds of Minnesota crossbred pigs on three feeding regimes and obtained significant breeding x treatment interactions for average daily gain and for age at 91 kg live weight.

In a study involving two breeds and two rations (full and restricted feeding) Zimmerman, Spies *et al*. (1960) found breed x season interactions to have significant effects on age at puberty. The breed x feed level interactions were not significant in the same trait, although trial x breed x feed level interactions were found to be important.

Dailey, Clark *et al.* (1975) used 102 puberal gilts from nine genetic groups to study two morphological types of ovarian follicular loss (haemorrhagic and milky). An interaction of feeding level with genetic group was found for the mean diameter of the follicles. Although the high plane of feeding increased the mean diameter of the Poland China gilts when compared to the limited-fed, little effect was produced in the Hampshire or Yorkshire gilts. Also full feeding decreased the number of milky medium follicles in the Hampshire x Yorkshire gilts while there was an increase in the Yorkshire x Hampshire cross.

Plank and Berg (1963) conducted four trials to study the relative response of specific genetic groups of pigs to differing planes of nutrition (*ad lib*. or 75% *ad lib*.). Genotype x plane of nutrition interactions were significant for average daily feed consumed, average daily gain, length and total Record of Performance score.

Hale and Coey (1963) tested whether intra-strain genotype x environment interactions occurred in a comparison of *ad lib*. and restricted feeding. In liveweight gains, efficiency of feed conversion and a number of carcass measurements there were no significant interactions between litters and the feeding treatments. However, during the experiment it was found that the *ad lib*. pigs did not eat as much as expected, so the difference between feed levels was not very large. Hale and Coey (1963) concluded that their experiment adds support to the hypothesis put forward by Hull and Gowe (1962) that genotype x environment interactions are not likely to be of importance except in cases where environmental and genetic differences are both large.

Nitzsche and Englisch (1967, cited by King, 1971) also examined intrastrain genotype x environment interactions. They looked at 628 progeny from 11 sires on normal and severely restricted feed intakes. They found highly significant interactions for daily gain and less significant ones for fat content.

Kempster (1974) reviewed experiments on feeding level and concluded where *ad lib.* feeding was compared with a restricted diet above 80% of *ad lib*. feeding, there were no rank order changes and differences in variance occurred less frequently than where the comparison was with restricted feeding below 80%. Thus in those experiments which could possibly represent practical circumstances in terms of genotype and environment no significant interactions were found.

2.3.2.2 Protein Levels

Hale and Southwell (1967) compared Duroc and Hampshire pigs on diets containing three levels of protein. No interactions involving carcass characteristics were observed, but a significant interaction was observed in efficiency of food conversion. The two breeds were approximately equal in this respect at the two lower levels of protein, but the Durocs were more efficient at the highest level.

King (1971) reported results of a previously unpublished experiment in which various crossbred pigs were fattened, half to pork weight of 59 kg liveweight and half to a manufacturing weight of 118 kg liveweight. In addition, half of each group were fed on a high protein and half on a low protein ration. No significant cross x diet interactions for leanness were found. Only one significant interaction was found and that was for the pH reading taken soon after slaughter at 59 kg liveweight, but King (1971) noted it is of doubtful importance.

Watkins, Swiger and Mahan (1977) fed various protein levels to several breeds and crosses. Although not significant, there was some indication that pigs varying in lean growth capability responded differently to changes in dietary protein level.

Wood, Lodge and Lister (1979) compared two breeds under conditions that provided the same total amount of feed to each pig, but produced differences in energy and protein intake. Although differences existed between breeds and dietary treatments, the only significant interaction between breeds and diets was for lean content of the hind limbs.

Christian, Strock and Carlson (1980) evaluated the effects of sex, breed cross, dietary protein level and slaughter weight and their first-order interactions on performance and carcass traits of 288 crossbred pigs. Although the lean cross pigs grew more efficiently on the 16% protein diet than on the 12% diet, the average cross pigs did not, resulting in a significant cross x protein interaction for feed efficiency. This interaction was not significant for any other traits.

Davey and Morgan (1969) reported an experiment in which four lines were individually fed, on a scale determined by their body weight. The rations used contained 12% or 20% protein. The interaction obtained between protein level and line was very significant and striking. Pigs from the low fat lines, given 20% dietary protein, had 31% more carcass lean than did the pigs from the high fat line, whereas on the 12% diet the low fat lines had only 6% more lean than those from the high fat lines.

King (1971) concluded that in protein level experiments, interactions can exist with widely different protein levels, but at or around recommended levels, these interactions are much less likely. He also discussed the interesting proposition that the published literature is likely to represent a biased sample, as observers finding no significant interaction would be less likely to report this than alternative. He also suggested that because of the small size of many pig experiments, some of the significant GE interactions reported might be type 2 errors, i.e. apparently significant effects when no real interaction exists due to the small sample of animals used (McDonald, 1985).

2.3.2.3 Energy Levels

Most experiments comparing differences in feeding level have probably restricted growth primarily by the limitation of energy intake (King, 1971; Kempster, 1974). However, there are a number of other experiments designed especially to compare differences in energy intake.

Bowland and Berg (1959) described an experiment in which rations containing combinations of two energy levels and three levels of protein were fed to two crosses of pig. Interactions were found in growth rate, average daily feed intake and food conversion ratio, with one strain tending to eat more, grow faster and more efficiently on a high energy, high protein diet. With one exception, there were no interactions in carcass characteristics.

King (1971) noted that although interpretation is complicated by the addition of other growth-promoting factors, the diets used in the experiment of King (1963) would have differed greatly in energy content. King (1963) with bacon pigs of three genotypes fed two ways found no significant interactions in growth rate, food conversion ratio, food consumption, carcass weight, carcass length or backfat thickness. For streak thickness a significant cross x ration interaction was found. The interaction was due to a change of rank, the Wessex crosses, which had the thickest streak on normal rations, having the thinnest when given the high growth ration.

Davey, Morgan and Kincaid (1969) studied Yorkshire and Duroc pigs from two lines (high- and low-fat) fed either a normal diet or a diet with 25% reduction in gross energy intake. There was a significant breed x line x diet effect on rate of gain as a result of the variable, within line response to energy restriction.

Skitsko and Bowland (1970) described an experiment in which high and low energy diets were given to three different breeding groups, with self-feeding limited to two one-hour periods each day. There was a significant interaction between breeding group and diet for average daily feed intake but although growth rates tended to parallel intakes, the interaction for this trait did not achieve significance. Pigs were slaughtered at one of three different liveweights but no interactions were reported for any carcass measurement.

2.3.2.4 Other Dietary Differences

A variety of other dietary contrasts have been used in interaction experiments.

Jonsson (1959, cited by King, 1971) reported an experiment in which litters of two breeds were divided between standard Danish diets of skimmed milk and barley and one including sugar-beet fed *ad lib*. The diets produced significant differences in performance but there was no interaction between diet and litter for the two characters, daily gain and backfat thickness, which were analysed.

Kuhlers, Chapman and First (1972) investigated the existence of genotype x environment interactions in production and carcass traits in four breeding groups of swine under two feeding regimes - high and low nutrient - at four stages of development. Out of 264 total comparisons only five were detected as having significant breeding group x feeding regime interactions. Kuhlers *et al.* (1972) concluded that this was what would be expected by chance alone, suggesting that interactions of this kind were infrequent at the stages of development studied.

Kuhlers, Chapman and First (1977) individually fed 95 animals from two breeds and their reciprocal crosses from 56 days of age to 90 kg on a low or high nutrient regime. Pooling the breeding group x feeding regime interactions for both the production and carcass traits showed that there was a total of four significant interactions in 45 comparisons. Kuhlers *et al.* (1977) suggested that these interactions may be chance occurrences. All four significant interactions were for sire breed x dam breed x feeding regime indicating the possibility of differential heterosis for the feeding regimes. No sire breed x feeding regime or dam breed x feeding regime interactions were found. The ranking of sires based on crossbred or purebred progeny was similar regardless of which of the two feeding regimes were used.

Duroc and Yorkshire pigs of two sexes were allocated to two different feeding systems (16 and 30% of final molasses) by Rico and Menchaca (1979). The traits under study were average daily gain, weight for age, feed conversion, consumption and ten carcass traits. No important interaction effects on these traits were observed.

Santana, Dieguez *et al.* (1982) fed 182 Duroc and Yorkshire pigs processed swills, final molasses and torula yeast or concentrates from 102 to 241 days old. They found no significant breed x diet interaction for performance traits of the fattening animals and only two interactions in carcass traits - for dorsal fat and fat weight.

One of the experiments described by Nitzsche and Englisch (1967) involved feeding a mixed silage of potatoes and green feed. Some interactions were found for food conversion ratio and for growth rate. In general, there was no interaction for carcass characteristics.

Kroeske (1968) fed Dutch Landrace littermates either a breeding ration or a fattening ration. Fourteen performance and slaughter characters were measured but the litter x ration interaction was significant only for food consumption and for percentage of ham. Kroeske concluded the results indicated that there was little danger of an undesirable interaction between ration and inherited characters.

Nitzsche and Schonmuth (1971) fed two replicate pairs (male castrate and female) from each of 210 German Landrace litters, the progeny of 13 sires, on a high or low nutritional level to 30 kg liveweight. Genotype x environment interactions were found for age and slaughter, eye-muscle area, carcass fat percentage, fat cuts and carcass grade.

Lebeder and Selezneva (1975) reported experiments in which a comparison was made between the progeny of boars and sows grown under different conditions of nutrition: good, satisfactory and bad. They reported the interaction between the genotype and the environment was conspicuous with respect to the growth rate and to the backfat thickness, but was imperceptible with respect to the carcass length and to the loin eye area. They concluded the analysis of variance did not give an adequate reflection of the genotype x environment interaction.

2.3.3 RABBITS

There are few references in the literature to possible genotype x environment interactions in rabbits.

Rico and Menchaca (1973) studied the optimum level of protein in rabbit feeds and the possible effect of genotype x environment interaction, taking the environmental variation as the different levels of protein used. A total of 192 Semi Gigantic, New Zealand, Chinchilla and California rabbits were allocated to two replications of four breeds, four diets and two ages at slaughter combinations. There was no evidence of any interaction in the growth and carcass traits studied, even though a wide range of protein levels were used.

2.3.4 DAIRY CATTLE

Genotype x environment interactions in dairy cattle have been reviewed by Freeman (1967), Syrstad (1976), Taneja and Rao (1982) and Goddard (1985).

2.3.4.1 Milk Production and Associated Traits

Two subpopulations of dairy cows were used by Korver (1982) to estimate the effect of genotype and ration on feed intake, milk production and weight change during lactation. All cows were fed roughage *ad lib.* but one half of the cows received a high roughage ration and the other half was fed a high concentrate ration. None of the traits had significant genotype x ration interactions during the three periods of lactation.

Oldenbroek (1984a) examined performance in first lactation of Holstein Friesians, Dutch Friesians and Dutch Red and Whites on two complete diets with a different amount of roughage. No significant breed x feed composition interactions were found for any of the characteristics - milk production, percent fat and protein production, average body weight and gain.

In a follow-up experiment Oldenbroek (1984b) examined differences in performance between first and second lactation. No evidence for a breed x feed composition interaction was found in the second lactation either.

Korkman (1953), using information from AI sires in Sweden, examined the possibilities of comparing bulls on the basis of progeny tests in herds on different planes of nutrition. No differences were found between herds on different planes of nutrition in the heritabilities.

In Utah, 200 daughters of 14 bulls were split so that half of each sire group were fed on an all-roughage ration, while the other half were given additional concentrates (Lamb, 1964; Lamb and Anderson, 1966). No significant interaction between sire and type of ration was found, but the daughters of a bull from New Zealand were the best producers on all-roughage and the poorest on roughage and concentrates (Freeman, 1967).

One of the most comprehensive studies on interaction between genotype and environment in milk production was carried out by Mao and Burnside (1969). A set of data comprising more than 77 thousand lactations from 1355 herds was grouped according to a series of environmental factors. The only grouping which resulted in a significant interaction between progeny group (sire) and environment was the grouping on amount of concentrates given in the summer, the interaction component accounted for 17% of the total variance in sire proofs. In this case genetic correlations ranging from 0.54 to 0.79 were found. Grouping on level of concentrate fed during winter gave results which suggested an interaction.

Richardson, Owen,Plowman and Miles (1971) fed 228 daughters of 13 Jersey bulls roughage and silage *ad lib.* In addition half were fed one kg of concentrates per three kg milk. The sire x ration interaction approached significance, but accounted for only about three percent of the total variance in milk and fat-corrected milk production. The sire x ration interaction was significant for total estimated net energy consumed and gross efficiency.

Daughters of a bull from New Zealand were also included in this experiment, and this group ranked second highest on all-roughage and next to last on the ration including concentrates.

Warwick (1972) reported that when sire progeny groups were split and fed either forage or forage plus grain, no sire x ration interaction for milk production occurred.

Lamb, Anderson *et al*. (1973) measured the gross feed efficiency for 305 day first lactation for 1,289 daughters of 18 sires. Hay was fed *ad lib*. In trial one, half the daughters received 4.5 kg grain daily while in trial two, half the daughters were fed 1.4 kg grain and the other half 8.0 kg grain daily. Sire x ration interaction, which accounted for only 0.7% of total variation, was significant for all except one measure of gross efficiency in trial one but was non-significant for all measures in trial two. Taneja and Rao (1982) noted that the interaction in trial one came largely through one sire, so practically the interaction was of little importance.

Fimland (1973, cited by Syrstad, 1976) grouped data into three groups according to percent of net energy supplied in concentrates (< 33%, 35-42%, > 42%, respectively). The genetic correlation coefficients between milk yields in the three groups ranged from approximately 0.8 to 1.0.

Lamb, Walters *et al*. (1977) conducted another experiment with Holsteins and found a significant sire x diet interaction for fat, largely due to a New Zealand sire whose daughters ranked more highly on the low grain than the high grain diet.

Wiggins and Van Vleck (1978) classified herds into 10 levels according to the proportion of grain in the diet. The

r_g between milk yield in different levels varied from 0.49 to 1.04 with an average of 0.72. The estimates of r_g did not decrease as the difference between the levels compared increased but this may be due to sampling errors in the r_g estimates.

Mohammad, Lee and Grossman (1982) examined interaction of sires with feeding and management factors in data from Illinois Holstein herds. Components of variance from interaction between sires and the feeding practises were negative and regarded as zero.

Flux, MacKenzie and Wilson (1984) studied plasma metabolite and hormone concentrations in Friesian cows of differing genetic merit measured at two feeding levels - freshly cut pasture fed to appetite or restricted to 70% of appetite. Cows having parents with high breeding values for milk production (high BI) had higher milk production than cows having parents with low breeding values (low BI) at both feeding levels but the high BI cows had a higher reduction in milk production on the restricted feed level indicating the possible presence of a genotype x environment interaction. On the *ad lib.* feeding level the low BI cows gained 32 kg actual liveweight while the high BI cows gained 24 kg; on the restricted feed level both groups gained 3 kg demonstrating a differential response in liveweight gain.

Holmes, Brookes *et al.* (1985) found in one out of three experiments that the milk yield of cows of low breeding index was highest after a period of underfeeding. However, in most experiments the high BI and low BI cows showed the same effect of condition score and feeding level.

Bonnier, Hansson and Skjervold (1948) used 7 pairs of monozygous twins to study the effect of different levels of nutrition on growth and yield. The average production in the first lactation was similar for the two treatment groups, but the differences within pairs varied from +12% to -11%. The coefficient of correlation between the members of the same pair was, however, as high as 0.78. The authors concluded that a considerable interaction between genotype and environment, i.e. level of nutrition, was present (Syrstad, 1976). However, Freeman (1967) concluded that, as the rank order of twins across rations was nearly unchanged, the genotype x environment interaction was practically unimportant.

In an experiment with three pairs of identical twins Hansson (1949) found evidence of a genotype x nutrition interaction, in that in the high-producing pair the total milk production was decreased, while in the low-producing pair it was increased when fed excessive amounts of calcium and phosphorus.

In another monozygotic twin experiment, Hancock (1953a) used 15 pairs, allocated to three ration comparisons. He found no evidence of any important genotype x environment interaction in spite of rather large differences in milk yield from ration to ration. The ranking of pairs was very similar on the various treatments, and the coefficient of correlation between members of the same pair was estimated as 0.90 for milk and 0.86 for fat yield.

In other studies involving identical twins and widely different feeding levels, Hancock (1953b) observed significant set x feeding level interactions on body weight (means of four consecutive weekly weights after calving).

Freeman (1969) and Rindsig and Freeman (1973) reported a study in which pairs of monozygous and dizygous twins were assigned at random to a high ration, a low ration, or split between rations. All animals received roughage *ad lib.*, the difference was in the rate of concentration feeding. No interaction between additive genetic effects and level of nutrition was found for any of the production traits and for growth traits at young ages. The coefficient of correlation between members of monozygous pairs was estimated as 0.71.

A study by Syrstad (1976) of 30 pairs of Norwegian Red-and-White monozygous twins which were fed two different levels of concentrates did not reveal any interaction between genotype and level of concentrate feeding on milk production.

2.3.4.2 Reproductive Traits

The interaction between dietary regime (energy density of diet) and breed or breed of sire on post partum reproduction was examined in two experiments by Hansen, Baik, Rutledge and Hauser (1982). In experiment one, there were breed x diet interactions for interval to first oestrus (IE) in the first and second post-partum periods, as differences in IE between low and high diets were more pronounced for the Holsteins than for the Herefords. In experiment two the Hereford-cross cows fed low diets had longer IE in the second post-partum period than Hereford-cross cows fed high diets, but the other breed-of-sire groups were not influenced by dietary regimen, resulting in a breed of sire x diet interaction.

In two similar experiments cows were fed diets either low or high in energy but Hansen and Hauser (1983) reported no significant genotype x environment interactions in the three consecutive post-partum periods.

2.3.5 BEEF CATTLE

2.3.5.1 Birth and Weaning Weights and Preweaning Growth Rate

Sellers, Willham and de Baca (1969) found breed x management effect was a significant source of variation for weaning weight when Hereford and Angus calves were creep and non-creep fed.

Five breed groups of cows including Brahman, Shorthorn and their crosses were grazed continuously on forage designed to provide low, medium and high nutritional regimes by Peacock, Kroger, Hodges and Kirk (1974). Weaning weight and slaughter grade of the calves were significantly influenced by the interaction of forage system and breed, principally due to differential response by breed to the improved pasture systems.

Significant genotype x nutrition interactions for weaning weight were reported by Hearnshaw and Barlow (1982) in a cattle crossbreeding programme where Hereford cows were inseminated to Simmental, Friesian, Brahman and Hereford sires. The H x H and F_1 females were grazed on good, medium or poor pasture conditions. All the F_1 calves grew faster to weaning and were heavier at weaning than H x H calves. However, the size of the difference between the crosses was related to nutrition.

Rollins and Wagnon (1956) calculated heritabilities from two grade Hereford herds, one received supplements in late summer, fall and winter while the other received minimal supplements. Heritability estimates for weaning weight were not found to be significantly different.

Butts, Koger *et al.*(1971) subdivided two herds of Hereford cows at different locations and transferred half of each to the opposite location. Subsequently, location x origin genotype interactions were apparent in birth, weaning and yearling weights for both sexes. However, Butts *et al.* (1971) noted location effects in this study were confounded with management regime, temperature, kind and amount of feed, humidity and probably disease and parasite levels. Thus the role of a genotype x nutrition interaction was indeterminable.

In a similar experiment Burns, Koger *et al* . (1979) also found highly significant line x location interactions for birth and weaning traits.

2.3.5.2 Post Weaning Growth Rate and Liveweight

Gravir (1961) tested the performance of two lowland and two mountain breeds on mountain and valley pasture. The lowland breeds showed better growth rates at both altitudes.

Bojarskii and Kadievskaja (1966) reared Black Pied and crossbred Aberdeen-Angus bulls on high and low planes of nutrition. The response of the Angus to a higher plane of nutrition was greater.

Maltos and de Alba (1967) compared progeny of one Brahman one Romo Sinuano and two Santa Gertrudis bulls for weight gains after weaning. In one trial, the same calves were subjected first to pasture environment for 100 days after weaning and then immediately to a dry-lot environment. Changes in ranking merit of the bull progenies occurred. However, in the second trial when progeny was divided at random for each environment, no significant bull x environment interaction could be detected.

Bond, Hooven *et al.* (1972) compared the performance of dairy, dual-purpose and beef steers on three feeding regimes - 75% concentrates, all hay or a sequence of hay for most of the period followed by concentrate diet. There was a breed x diet interaction for average daily gain and final weight.

Taylor (1976) studied three-month-old steers from two crosses reared on four combinations of concentrates and forage. Significant breed x nutrition interactions were found for liveweight gain and feed conversion efficiency.

Barlow and O'Neill (1977) measured postweaning weight gains in Hereford, Simmental x Hereford, Friesian x Hereford and Brahman x Hereford heifers on three pasture types. On good pasture, weight gains in the four types averaged 192, 209, 212 and 206 kg respectively *versus* 110, 149, 132 and 165 kg on medium-quality pasture, and 46, 66, 67 and 98 kg on poor pasture. The results were considered to provide good evidence for a genotype x pasture type interaction.

Results from breed-comparison experiments on the sources of differences in growth and slaughter performance at a given feeding intensity were reviewed by Langholz (1977). He concluded these differences tend to increase with increased feeding intensity and longer production periods indicating the existence of genotype x environment interaction.

Baker (1977) reported that performance ranking for daily gain and slaughter weights of crossbred cattle out of dairy cows was similar to that of the purebreds. This applied whether the calves were reared in intensive cereal or in the less intensive grass/cereal systems. Baker (1977) concluded that the results showed no evidence of an interaction between breed and system sufficient to change the order of ranking of breeds and crosses on the basis of growth rates and slaughter weights.

Boer and Hamm (1977) studied the effect of different protein levels on growth and carcass quality of Dutch Black Pied (DBP) and Meuse-Rhine-Yssel (MRY) fattening bulls. At the lowest protein level, there was a tendency for daily gain to be higher in DBPs than in MRYs, while at the highest level the opposite was the case - indicating the presence of a genotype x nutrition interaction.

Female crossbred calves of eight different sire breeds and two dam breeds were distributed in three herds (Andersen and Liboriussen, 1975, cited by Liboriussen, Sorensen and Andersen, 1977). The feeding levels in the three herds were classified as low, medium and high. A significant interaction was found between sire breeds and feeding level for average daily gain from 18 to 24 months of age but not from 0 to 18 months.

Langholz (1977, 1978) fattened three groups of bulls from sire breeds of genetically different growth capacity at two nutritional levels (concentrates or concentrates and silage). Differences between breeds tended to increase with increased feeding intensity and longer production periods, and were more marked in bulls than in steers and heifers, indicating the existence of genotype x environment interactions.

A breed x nutrition interaction was found by Hearnshaw and Barlow (1982) for growth from weaning to 18 months in diverse environments, as well as that found for post-weaning gain and weaning weight.

Lopez, Planas and Ruiz (1982) reported a highly significant genotype x system interaction for the growth traits of purebred Holstein and Zebu cross under two fattening systems - performance test station and grazing. The genotypes with higher proportions of Zebu showed a better performance under the grazing system while purebred Holstein had higher growth rate in the performance test station.

Meissner and Rouz (1982) found no diet x genotype interaction for liveweight adjusted by various methods, when they compared Afrikaner, Hereford and Simmental bull calves fed on either a pelleted concentrate diet or a non-pelleted roughage diet. They discussed the concept of genotype x dietary interaction in relation to performance of bulls and the matching of most suitable genotypes to particular production systems. They concluded what is possibly being interpreted as genotype x diet interaction could be a function of inadequate appreciation of the impact of the effects of scaling for size, the multiplicative (curvilinear) nature of growth and the size of measurement error with different feeds and feeding levels.

Holloway, Butts *et al* . (1985) investigated breed x nutritional environment interactions for beef female weight and fatness, milk production and calf growth. Differential responses from the breeds resulted in large differences in heterosis for the two pasture types. Holloway *et al*. (1985) suggested the lack of agreement of heterosis values was the result of genotype x environment interactions and that the interactions were results of nutritional processes involved in seasonal patterns of responses.

Heritability estimates of range beef heifers from two grade Hereford herds on different nutritional levels were found to be significantly different by Rollins and Wagnon (1956) and Wagnon and Rollins (1959). Heritability estimates for post-weaning gain were 0.25 and 0.27 for herd A and -0.04 and 0.03 for herd B. Heritability estimates for yearling weight were 0.42 and 0.44 for herd A and -0.23 and -0.19. These figures indicate the presence of herd x nutritional level interactions or inaccurate recording in herd B.

Maltos, Aguilar, Lavedo and de Alba (1961) tested the progeny of 10 bulls in tropical feed lots and grass pastures. A significant sire x environment interaction for rate of gain was found. The merit of the sires, based on the performance of their progenies, differed from one year to the next, i.e. poor repeatability, and between environment and genotype.

Varo (1962) fed 12 calves from each of five Ayrshire bulls on *ad lib* . or restricted concentrate feeding. Although there was a difference in growth between the progeny of the different bulls, there was no difference in progeny groups on restricted feeding. The results were not considered reliable due to the small numbers of calves and having obtained them from widely varying conditions.

Haring, Weniger, Gruhn and Langholz (1963) found no interactions of type of feeding and genotype of the progeny for daily weight gain, feed conversion and dressing percent. They tested progeny of three bulls of Black Pied Lowland Cattle fed on green sugar beet tops or on dried beef pulp from 130 to 430 kg.

Lagos and Cartwright (1963) compared the 140-day gains of progeny of 34 sires under two feeding regimes in two environments. In the first, 56 Santa Gertrudis heifers from 10 sires were fed either on a high concentrate ration in the feedlot or on pasture with concentrate supplement. No indication of an interaction was found. The second included 67 steers from 9 Hereford sires and 120 F1 Brahman-Hereford steers from 15 sires. They were split into two feedlot groups, 66% concentrate - 34% roughage ration and 35% concentrate - 65% roughage ration. Sire x ration interactions for both breeds were not statistically significant.

Likewise, no sire x environment interaction effect was found on yearling steer growth by Ahlschwede, Dillard, Legates and Robison (1969) when steer progeny of three Hereford sires were fed on a corn-soyabean ration in drylot or grazed on pasture.

Rave (1973) investigated genotype x environment interactions in two methods of progeny testing cattle for meat production. Two methods of fattening were compared: one based on grain and concentrates to a final weight of 350 kg, and the other based on pasture and roughage to a final weight of 500 kg. No significant interactions were found for the growth and carcass traits. The high genetic correlations indicated that the sires ranked similarly in the two environments.

Andersen and Andersen (1974) reported a Danish investigation where 4 feeding levels (100%, 85%, 70% and 55% of *ad lib*. feed intake) and seven slaughter weights of Red Danish male calves from four sires. The results on sire x feeding level interaction showed that only in the case of average daily carcass gain was a significant interaction present. The interaction was quantified by calculating the intraclass genetic correlation, and it was found to be 0.70 ± 0.14.

Tess, Jeske, Dillard and Robison (1984) tested 12 Hereford bulls. As yearlings, steer progeny were fed a concentrated diet in a feedlot or grazed on pasture. Sire x diet interactions were non-significant for all traits.

Warwick, Davis and Hiner (1964) used monozygotic beef twins with two levels of nutrition - high and low concentrate rations. They observed a significant ration x pair interaction for post-weaning gain.

Burnside, MacLeod and Grieve (1969) reared 48 pairs of male Holstein fraternal twin calves on either a high fat and protein milk replacer from two days of age to market weight or the same ration until the calf reached 56.7 kg with a grain mixture, hay and water fed subsequently. No evidence was found for a significant pair x ration interaction in growth traits.

Kress, Hauser and Chapman (1969, 1971) utilizing both identical and fraternal beef cattle twins, also failed to detect significant set x diet (high and low energy) interactions for several growth traits.

Towner (1975) fed 19 pairs of Hereford and Holstein identical twins high and low rations. The breed x feed interaction was not a significant source of variation for the parameter estimates of any growth curve. The twin set x feed interaction influenced the asymptotes of six growth curves and the rate parameter of two growth curves.

Teslik and Markovic (1980) fed 15 like-sexed pairs of twins either seasonally-available farm feed or commercially-available pellet feed supplemented with silage in winter and fodder in summer. The genotype x nutrition interaction was not significant for any trait - body measurements and weight at various ages from 3 to 18 months.

2.3.5.3 Carcass Traits and Body Measurements

Bond, Hiner *et al.* (1965) fed dairy, dual-purpose and beef steers at two levels of nutrition to slaughter at six months or at 55-60% of mature bull weight. There were no significant breed differences in feed utilization, efficiency or carcass traits at six months. Breed differences were significant at the second slaughter in initial weight gain, final weight, food consumed, efficiency of gain, lean production and fatness of the carcass, but the breed x ration interaction was only significant for the thickness of fat over the ribeye.

Steer calves from Angus, Hereford, Brahman breeds and their crosses were either full-fed or fed at the rate of 2% of body weight per day in an experiment by Huffman, Palmer *et al* . (1967). A significant interaction between feed level and breed group was found for steak and roast tenderness.

Bond, Hooven *et al.* (1972) only found a significant breed x diet interaction for thickness of fat over the ribeye, feed efficiency and slaughter grade.

Tayler (1976) reported a significant breed x nutrition interaction for feed conversion efficiency when two crossbred groups were reared on four combinations of concentrates and forage.

Geay, Robelin and Beranger (1976) fattened Salers, Salers x Charolais and Charolais bulls on three diets - lucerne and beet pulp, restricted barley concentrate or *ad lib.* concentrates. Significant breed x nutrition interactions occurred for empty liveweight, carcass weight, weight of fat and weight of carcass muscle.

Geay and Robelin (1979) compared the meat production capacity between continental beef and dairy beef bulls. They concluded that cattle may have various capacities for meat production according to their genotype, however, the magnitude of the difference between breeds depends on energy. Genotype x nutrition interactions mean there is, for each type of animal, an optimum level of energy supply which enables a maximum feed efficiency.

Willis, Santiago and Santos (1970) found no evidence for sire x diet interactions in any of the growth and carcass traits when progeny from seven sires of five different breeds were group-fed either concentrates or molasses/urea plus forage and protein supplement.

Warwick, Davis and Hiner (1964) found ration x twin pair interactions were significant for feed efficiency and marbling score. Although not statistically significant carcass grade, estimation of fat by ether extract and fat in the 9-10-11 rib sample controlled 19%, 32.7% and > 20% of the variance of random variable effects respectively.

Body measurements made on identical and fraternal twins by Kress, Hauser and Chapman (1971a) were 56-day gains in height at withers, depth of chest, heart girth, circumference of front cannon, length of front leg, length from hocks to pins, width of hocks, width of head and length of head. Although about 12% of the twin sets x diet interactions were significant, in general none of them appeared to be an important source of variation.

Kress, England, Hauser and Chapman (1971), for the same animals as above, reported the set x diet interaction was significant for feed consumption and efficiency between 210 and 701 days of age for one or other type of twin. The interaction was not significant for conformation score or estimated fat thickness.

Burnside, Batra, MacLeod and Grieve (1972) reported the ration x pair interaction effect was non-significant for all growth traits studied including heart girth, height, dry matter consumed and estimated, feed consumed and efficiency of gain.

Batra, Usborne, Grieve and Burnside (1973) investigated carcass traits on the same Holstein fraternal twins reported by Burnside *et al*. (1972). No evidence was found for significant ration x pair interaction for most of the carcass traits except percent kidneys, percent fat in the shoulder, kidneys and minor cuts and bone in flank and breast.

Similarly, Towner (1975) noted that neither breed x feed or twin set x feed interactions were significant for gains in 10 body measurements from 210 to 449 and from 449 to 701 days of age.

2.3.5.4 Reproduction, Milk Production and Associated Traits

Reproductive performance of crossbred and straight bred beef cattle on six different pastures ranging from native range to highly improved, irrigated pasture was studied by Koger, Reynolds *et al*. (1962). Although highly significant breed x lactation and breed x year interactions for percent calves weaned were found, they did not analyse the breed x pasture interaction.

Howes, Hentges, Warnick and Cunha (1963) compared Hereford and Brahman yearling heifers and eight-month calves on two dietary regimes - a normal regime or one having 50% below-normal crude protein content. No breed x feeding regime interaction was found in the interval from first observed mating to calving, or in the number of days from calving to first appearance of corpora lutea in the yearling heifers. However, the breed x diet interaction was significant for the interval from first observed mating to calving with the younger heifers.

Wiltbank, Kasson and Ingalls (1969) determined the age and weight at puberty in Hereford, Angus and crossbred heifers which had been on two different feeding regimes from weaning to puberty. An interaction for age and weight at puberty was found between level of nutrition and breed of heifer.

Peacock, Koger *et al*. (1971) evaluated reproduction of Brahman, Shorthorn and various crosses of these breeds on pasture-management systems which maintained the cattle on low, medium and high nutritional levels. A significant breed of cow x pasture interaction was found for pregnancy and weaning rates but the breed of sire x pasture interaction was non-significant. The significant interaction was accounted for mostly by crossbred cows responding more to improved pastures than did the purebred cows.

A further trial by Peacock, Koger, Hodges and Kirk (1974) also found significant breed x forage system interaction for weaning rate.

Hearnshaw and Barlow (1982) measured the performance of purebred Hereford and Hereford-cross cows maintained on three different pasture conditions by weight of calf weaned per cow joined. They found a significant genotype x environment interaction.

Holloway and Butts (1984) found that large frame Angus cows grazing fescue-legume pasture consumed more digestible energy during the first part of the grazing season, gave more milk throughout and had faster growing calves than small frame cows. The opposite tendency was noted for cows grazing fescue pasture.

In their study of identical and fraternal beef cattle twins Kress *et al.* (1971) found weight change of the cows during the entire first and second lactations was not significantly influenced by the set x diet interaction. However, significant set x diet interactions for weight change during shorter intervals made results inconclusive. Feed consumption during the first lactation was significantly influenced by the set x diet interaction but the proportion of the variance of these traits due to the interaction was not large and changes in rank were not detected. The interaction was not significant for either of these traits in the second lactation. The results on milk and butterfat production indicated that the set x diet interaction was a significant source of variation for these traits.

Towner (1975) found both the breed x feed and twin set x feed interactions influenced the milk and butterfat production of the first two lactations in his study of identical twin beef cattle.

2.3.5.5 Other Traits

Anderson (1960), while comparing Hereford heifers on three levels of winter feeding, observed an increase in the probability of the development of cancer eye with a high level of nutrition. Since eye lid pigmentation is known to reduce the probability of cancer eye, a genotype x level of nutrition interaction is likely to occur through a change in the threshold level of the combination of genetic and environmental factors (Pani and Lasley, 1972).

Holloway, Butts *et al.* (1985) detected breed x pasture type interactions for average and seasonal patterns of both digestibility and intake of forage grazed by lactating Angus, Hereford and Angus x Hereford females. The primary interactions involved the crossbreds. The opposite nature of the interactions for digestibility and intake effectively countered each other so that breed x pasture type interactions were generally not important for digestible DM intake. Interactions were important when intake was expressed as a ratio of metabolic weight. Interactions were important for digestibility during seasons of high digestibility and for intake during seasons of low digestibility.

2.3.6 GOATS

As with rabbits, there are few references in the literature to studies involving genotype x environment interactions in goats.

Louca and Hancock (1977) utilized data on 111 twin sets of the Damascus breed of goat, fed three pelleted diets with different protein contents, to evaluate the importance of genotype x environment interactions for postweaning growth. With the exception of the 16-week weight gain in unlike-sexed twins the set x diet interactions were not significant for growth rates for 16 weeks postweaning. They concluded that genotype x environment interactions for postweaning growth in goats were not of importance.

2.3.7 SHEEP

2.3.7.1 Growth Characteristics

King and Young (1955) reported the effects of overwintering ewe hoggets of the Blackface, Cheviot and Wiltshire breeds under two nutritional and two temperature regimes. Dilution of oats by chaff was used to restrict the diet of half the hoggets. Neither breed x temperature nor breed x plane of nutrition interactions were significant in yearling weight. Skeletal measurements, such as length of hind-cannon and tibia, length of pelvis, width of hind-cannon and heart girth, showed significant breed x plane of nutrition interactions due to more rapid growth of Blackface sheep on the high plane of nutrition. King, Watson and Young (1959) suggested these interactions were possibly attributed to the age differences present in the sheep.

Marston, Pierce and Carter (unpub., cited by Turner and Young, 1969) examined strain x environment interaction in Australia. Two Merino strains (strong wool and fine wool) were fed at two nutritional levels. The strong wool strain showed a greater body weight response to good nutrition.

King, Watson and Young (1959) studied the differential response of lambs to different planes of nutrition. Twin lambs of two breeds and five crosses of sheep were wintered in high-high, high-low, low-high and low-low nutritional environments and subsequently brought to the same weight for slaughter. In body weight the main feature of the experiment was the similarity of response to different treatments by all the crosses. Body measurements also showed conformity between breeds in responses to environment.

Ercanbrack and Price (1969) studied whether the effect of early weaning on growth rate was the same in Rambouillet, Targhee and Columbia breeds. All lambs were reared in the same flock to an average age of 75 days, then half were weaned and placed in dry lot. Among inbred lambs (33% inbred), no significant interaction between breed and weaning time was observed, but there was a significant interaction in the non-inbred group where Targhees were superior in daily gain among lambs not weaned. Targhees were also superior among certified lambs, but Columbias were superior among lambs having access to pasture.

Glimp (1971) found a significant breed x ration concentrate level interaction on rate and efficiency of lamb growth. The trial was divided into three periods and six feeding schedules with lambs from eight breeds. Suffolk and Hampshire lambs gained faster when the ration energy level was increased above the level provided in the first two treatments while no differential response to energy level was observed among other breeds.

Peters and Heaney (1974) either creepfed and reared lambs on their dams or reared them artificially with a liquid plus solid diet. Although a significant breed x rearing system interaction was found for weight from 35 to 70 days, lambs on the two systems of rearing did not alter significantly in weight at 70 or 140 days.

Hohenboken, Kennick and Bogart (1974) and Hohenboken, Corum and Bogart (1976) reported a study of lambs from a diallel cross among three breeds, replicated in two management environments (dry land hill pastures and irrigated valley pastures). No significant sire or dam breed x management system interactions were found for birth weight. For weaning weight the breed of sire x management system interaction was significant, but not the breed of dam x management system interaction. Sire breed x management system interactions for growth traits were caused by larger breed differences on hill pastures than on irrigated pastures.

Joyce, Clarke *et al*. (1976) and Joyce, Clarke, MacLean and Cox (1976) reported on a long term experiment involving four genotypes of sheep at three stocking rates (26 ewes/ha, 21 ewes/ha and 16 ewes/ha). There was no change in the relative ranking of genotypes in terms of ewe liveweight. Ewe mortality was similar for all genotypes and all stocking rates. Increasing stocking rates reduced lamb birthweight by five percent, the effect being more marked for multiple born lambs than for single born. Results of analyses of genotype x environment interactions have not been published.

Jankowski, Dawidowicz and Roguska (1983) found that from birth to six months of age, Polish Lowland (PL) ram lambs had a higher growth rate than Texel x PL crossbreds when confined and fed concentrates and dried grass meal, but had a lower growth rate when grazed on pasture. The breed x environment interaction was significant for growth rate.

Morley (1956) exposed a number of Australian Merino half-sib groups to either a high or low plane of nutrition from three to 17 months of age. Heritability, as indicated by the within-sire correlation, did not vary with plane of nutrition. Genotype x treatment interactions were not present for six-month body weight but were large and highly significant for weight at 12 or 17 months.

Stakan, Soskin and Vorocenko (1963) found that the heritabilities were lower under poor than good environmental conditions. Studies were conducted involving two groups of lambs reared on two planes of nutrition, high and low; heritability estimates of 0.15 and 0.05 respectively were found for weight. Variation of this character was less in high plane than in low plane.

Dunlop (1962, 1963) and Dunlop and Young (1966) presented results of an experiment in which five strains of the Australian Merino were run as breeding groups in three wool-growing regions. Significant strain x location interactions were found in most body and wool traits, However, although nutrition was a contributing factor, the environment differences in other factors such as humidity, rainfall, management etc meant the importance of genotype x nutrition interactions could not be determined.

Williams and Winston (1965) fed three levels of nutrition (high, intermediate and low) in three flocks genetically different in wool production. They found no significant flock x level of nutrition interaction for adult body weight.

Osman and Bradford (1965) studied body weights and gains as well as a range of fleece traits at two locations which varied mainly due to nutrition ("poor" annual grassland or "good" irrigated clover and grass pasture). There was no evidence of large genotype x environment interactions. In a further experiment Osman and Bradford (1967) found significant sire x plane of nutrition interactions for postweaning average daily gain and for final weight but not for body measurements and carcass traits except for carcass weight in ram lambs.

Testing and evaluation of progeny of sires under different environments in USSR were carried out by Gol'tsblat and Budanstev (1973). Three sire groups totalling 70 young Precoce rams were each reared under different sets of management conditions; group one was on pasture, and groups two and three at testing stations on group and individual feeding respectively. There were no significant genotype x environment interactions for growth or food conversion, and the sires ranked in the same order on the three sets of test conditions for their progeny.

Effectiveness of selection of sheep of the Kuchugurg breed group under different feeding regimes was studied by Anfinogenova (1970) in the USSR. When ewes were fed an adequate diet or a diet 23% less than adequate, the genetic variance among their progeny amounted to 12.0 and 29.7% respectively. The percentage of lambs classed as elite or grade one rose from 42 to 51.1 for progeny of grade one or grade two dams and from 7 to 43.2 for progeny of grade four dams when dams on the inadequate diet were placed on an adequate diet.

Another experiment on the effect of type of selection and level of nutrition in Soviet Merino sheep was reported by Burdukovskaya and Timashev (1971). The heritability estimates of birth weight in two flocks were 0.58 to 0.76 and 0.52 to 0.76 respectively on the higher plane of nutrition. For sheep on lower plane of nutrition the corresponding estimates were 0.34 and 0.23.

Due to low heritability of lamb performance under natural rearing, Cameron and Smith (1985) assessed the merit of 100-day weight of artificially reared rams as a criterion for selection by studying the correlated responses in the performance of naturally reared lambs from crossbred ewes. They found the co-heritability ($r_A h_1 h_2$) estimates for weight, in the two environments, were similar to the heritability for natural rearing, which suggested that the advantage of reducing maternal effects by artificial rearing was offset by the genetic correlation being markedly less than one.

Lasslo, Bradford, Torell and Kennedy (1985a, b) selected for weaning weight in Targhee sheep in two environments. Response to selection was estimated as the difference between selected and control line linear regression coefficients of adjusted line means on year. Genetic improvement made on a higher plane of nutrition was expressed, but to a lesser degree, under range conditions. Selection under better feed conditions resulted in at least as much improvement in growth rate in a range environment as did selection under range conditions.

Fertility and survival data indicated that, under range conditions, the line selected under drylot conditions was less fit than the line selected under range conditions. As a result of the decreases in lamb survival and fertility, none of the selected lines produced more total lamb weight weaned per ewe than the controls, in spite of the significant direct response to selection.

2.3.7.2 Carcass Characteristics

With one exception (cannon body weight), King *et al*. (1959) found no significant interaction for carcass measurements in an experiment to study differential response of lambs and various breeds and crosses to different planes of nutrition.

Hohenboken *et al*. (1976) studied genotype x environment interaction effects on carcass merit in their experiment with lambs in two grazing management systems. Breed of sire x management system interaction was highly significant for carcass weight per day of age, and was also significant for finish score and USDA quality grade but no important breed rank changes occurred. No breed of dam x management system interactions were significant. Under irrigated management, there was little difference in sire breed effects, while under hill pasture management, breed differences were manifested.

Hofmeyr, Rensburg, Kroon and Olivier (1976) investigated differences in food conversion efficiency in lambs of three breeds. Of 120 lambs, representing the Bapedi, South African Merino and South African Mutton Merino breeds, 56 were slaughtered at 63 days of age to determine initial body composition, while the remainder were allotted to five levels of feeding. There were significant breed x feeding level interactions for the efficiency of energy utilization and food conversion.

Budantsev (1973) analysed data on ram lambs, sired by three rams, either group-fattened indoors or pasture-fattened. Significant genotype x nutrition and genotype x environment interactions were evident for growth, food conversion, slaughter weight, dressing percentage, carcass composition and meat characters.

2.3.7.3 Wool Characteristics

Daly and Carter (1955) maintained ewes of four breeds on two nutritional regimes - *ad lib.* and progressively restricted, to examine fleece growth and wool components (eg. wax, suint) production. Although they did not specifically study interactions, they concluded that with few exceptions, the absolute and relative values of the characters measured formed a smooth series from the fine Merino through the Polwarth and Corriedale to the Lincoln - either in ascending or descending order or showed little or no difference between the breeds. The relative positions of the breeds were generally maintained as food intake was reduced.

Responses in wool weight and some of its components exhibited by young ewes of three breeds were studied by King and Young (1955). Significant breed x nutrition interaction was found for clean weight of all fibres and of wool fibres but not for density, average length of all fibres and of wool fibres, average diameter and average length of fibres. The interaction in wool production was due to the outstanding ability of Blackface to increase the size of fibres in the medullated fraction of the fleece.

Neither greasy wool weight nor fibre length showed any cross x plane of nutrition or the twin pairs within a cross x plane of nutrition interactions when King *et al.* (1959) examined twin lambs of two breeds and five crosses in four nutritional environments.

Significant genotype x environment interactions for wool production were found by Hohenboken (1976) for the study detailed by Hohenboken *et al*. (1976a, b). The ewe breed x management system interaction was expressed as greater breed differences in the more favourable environment for wool and production than in the less favourable environment.

Kelly (1949, cited by Chopra, 1978) carried out an experiment in which strong wool and fine wool Merinos gave 8.0 lb and 7.3 lb of wool on a 'low plane' of nutrition and 18.4 and 13.3 lb on a 'high plane'. The increased difference between the strains could be attributed to a great extent to changes in the cross sectional area in four nutritional environments.

Genotype x treatment interactions were not significant for any fleece characters studied by Morley (1956) in an experiment on selected flocks of Australian Merino sheep. The intraclass correlation among half-sibs for fleece characters was similar in both planes of nutrition.

Weston (1959) found that his high-production Merino group, under pen conditions, grew 22% more wool on restricted intakes and 37% more wool on *ad lib.* intakes than did the low-production group.

Stakan *et al*. (1963) obtained heritability estimates of fleece weight as 0.20 and 0.19 in the 'high' and 'low' planes of nutrition respectively. Variation was less in the high plane than in the low plane for fleece weight at 15 months of age.

Williams and Winston (1965) examined the relative efficiencies of conversion of feed to wool at three levels of nutrition in flocks genetically different in wool production. Flock x level of nutrition interaction was significant for clean wool production, though it was not significant for efficiency. The interaction for wool weight was evident but only when the nutritional differences became extreme, ie. on the low level.

Stakan (1966) concluded that unfavourable environmental factors, especially low planes of nutrition, reduce the heritability of wool characters.

No significant interactions for efficiency of conversion of fodder to wool were observed by Dunlop and Young (1966) when they fed three strains of Merino two levels of nutrition. They concluded that the effect of sire x location interactions on clean wool weight were at times of sufficient magnitude to hinder selection, although on average, the expected gains would be reduced by about five percent by selecting at a different location. Woolaston (1985) noted that the data sets of Dunlop and Young (1966) were much smaller than the minimum size suggested by Robertson (1959) and it could be shown that even if sire x location interactions were quite large and of biological significance, one would not have expected the analyses of Dunlop and Young (1966) to have been effective in detecting them.

Williams (1966) investigated the efficiency of conversion of feed to wool during limited and unlimited feeding of the above flocks selected on clean fleece weight. A significant genotype x environment interaction was found due to a greater wool growth response in rams of the flock selected for high clean fleece weight relative to those of the other flocks. There was also a genotype x environment interaction for efficiency of conversion and for fibre cross-sectional area, but not for fibre length.

Dunlop, Dolling and Carpenter (1966) also studied the efficiency of conversion of food to wool at two nutritional levels in a fine-wool, a medium-wool and a strong-wool strain of Merino. Interactions of strains and nutritional levels were not significant. Individual sheep within strains tended to remain in a similar order of efficiency from one nutritional level to the other, the within-strain correlation between levels being estimated as 0.89.

In a study by Osman and Bradford (1967) grade Targhee ram lambs and wether lambs by different sires were fed a high or low energy ration for seven weeks. Subsequently all animals were fed the high energy ration for another seven weeks. Sire x plane of nutrition was significant for staple length (Period one) in the wether lambs and clean fleece weight (Period two) in the ram lambs.

Dolling and Piper (1968) measured clean wool production, gross energy intake and body weight of Peppin ewes from a random selected flock and from a flock selected for high clean wool weight on restricted and unrestricted food intakes in pens but no significant group x nutritional level interaction was observed in any character.

Piper and Dolling (1969a) described an experiment in which two groups of sheep genetically different in clean wool production, as used by Dolling and Piper (1968), were compared under *ad lib.* feeding of three diets differing in crude protein content but similar in gross energy. When differences between the selected and control groups on the high and medium protein diets were averaged and contrasted with the differences between them on the low protein diet, there were significant group x diet interactions in clean wool weight and efficiency of conversion of gross energy to wool and appreciable but not significant interactions in fibre number per unit area of skin, fibre cross-sectional area and staple length. The group x diet interaction was not significant for any character when the difference between groups on the high protein diet was contrasted with the difference between them on the medium protein diet.

In a further experiment on the previous sheep Piper and Dolling (1969b) compared the apparent digestive ability of the two groups of sheep. The order of merit of the groups did vary with diet but not sufficiently so for the group x diet interaction to be significant in any instance.

Giles (1968) compared flocks also studied by Morley (1956) and found significant selection flock x plane of nutrition interactions for greasy fleece weight, staple length and crimps per inch, but not for clean fleece weight.

Hamilton and Langlands (1969) found that the differences in efficiency of wool production between sheep with genetic differences in wool production declined when nutrient intake was reduced.

Burdukovskaya and Timashev (1971a) found the heritability of wool length in progeny of Soviet Merino rams having long wool was 0.39 to 0.52 and 0.17 to 0.25 in two flocks fed on higher and lower planes of nutrition respectively. For rams with wool of moderate length, the corresponding heritabilities were 0.30 to 0.45 and 0.13 to 0.23.

Heritability of fleece weight in the progeny of ewes having high fleece weight was 0.59 and 0.52 when their mates (rams) had high and moderate fleece weight respectively, the flock being kept on a high plane of nutrition. For sheep on a lower plane of nutrition, the corresponding heritabilities were 0.34 and 0.24 (Burdukovskaya and Timashev, 1971b).

Saville and Robards (1972) examined efficiency of conversion of food to wool in selected and unselected Merino types when fed at a range of nutritional levels. Gross efficiency decreased significantly with each increase in the level of nutrition. The efficiency differences between selected and unselected sheep increased, then decreased, with increasing intake. However, the decrease in efficiency differences at higher intakes did not appear to influence the ranking of selected or unselected sheep. They suggested that the genotype x nutrition interaction may not occur at all intakes.

Williams (1976) conducted a study on two year old Merino ewes from the fleece plus and fleece minus selection flocks kept on two dietary treatments (600 or 1100 g/day of pelleted lucerne hay). A significant interaction between genotype and dietary treatments for wool production was found. The results were in general agreement with Williams (1966) that the wool production per unit area of skin and wool production per sheep were greater in the flock selected for high clean fleece weight; the difference between the flocks was more pronounced as level of intake of food increased.

Chopra (1978) examined sire x stocking rate interactions in the New Zealand Romney. Interactions for fleece characteristics tended to be small and unimportant except for cotting grade and soundness grade. Intra-trait genetic correlations between the two stocking rates were close to unity except for yield, greasy colour grade and scoured colour grade.

In a review of the efficiency of conversion of feed into wool, Butler and Maxwell (1984) noted differences in wool production and efficiency are generally maintained, and even increased, at increased levels of nutrition. An exception may occur at very low levels of nutrition, when differences can be difficult to detect (Williams and Winston, 1965; Piper and Dolling, 1969). As the level of nutrition increases, the differences in efficiency between genotypes are increased. This can be interpreted as a genotype x environment interaction due to the greater ability of animals of high potential wool production to respond to a given change in feed intake.

2.3.7.4 Reproductive Traits

The importance of genotype and mating system x environment interactions for reproduction traits in ewes were studied by Hohenboken, Corum and Bogart (1974, 1976a). Sire breed x management interactions were not significant for fertility, prolificacy and lamb survival. Dam breed x management interactions involving changes in rank were found for ewe fertility and productivity. Sire breed x dam breed x management system interaction for total ewe productivity was significant suggesting interaction of mating system with environment.

Ewes of two genotypes which differed with respect to potential fertility were subjected to three nutritional regimes to estimate the importance of genotype x environment interaction for various reproductive traits by Meyer (1972). The effects of genotype x environment interaction were of limited importance for most traits measured. Interaction approached significance for pre-flushing ovulation rate but was absent for ovulation rate measured one cycle after flushing. No interaction effects were found for oestrous cycle length or lambing performance, although the breed groups differed in the incidence of silent heats and ova success rates on the various treatments. Meyer (1972) concluded that genetic improvement originating in one nutritional environment is likely to be expressed, at least in part, in other nutritional environments.

Ewes of eight crossbred groups were maintained on irrigated or dryland hill pastures by Hohenboken and Clarke (1981). Breed x management system interactions did not affect lamb survival percentages significantly. However, for number of lambs born, a sire breed x management system interaction was indicated at later ages, while the dam breed x management system interaction was significant and important from the third year onward. Breed x management system interaction effects were similar for number of lambs weaned. Both sire breed and dam breed x management system interactions were significant for longevity.

In another report, Clarke and Hohenboken (1983) noted breed of dam x management system interaction was significant for ewe weight at mating and number of lambs born, while breed of sire x management system interaction was significant for fertility, litter weight in April and at weaning. These results agree very well with those of Hohenboken and Clarke (1981) except in one instance - breed of dam x management system interaction for number of lambs weaned. In this study it was not a significant source of variation, while it was in the previous study. Hohenboken *et al* . (1976) did not find a genotype x environment interactions for litter weight at weaning.

Saoud and Hohenboken (1984) found that crossbred group x management system interactions generally influenced lifetime income from lambs produced and from orphans sold, gross income, total cost and net revenue per ewe.

Hohenboken (*pers. comm.*) conducted an experiment to evaluate industry Coopworth, industry Romney and Waihora Romney ewes (a strain selected for 10 years for increased ewe productivity) in a variety of nutritional and management treatment combinations. Traditional cross-classified analyses of variance did not reveal large, consistent nor economically important ewe breed x nutritional treatment interactions. The concept of 'breed sensitivity versus stability' both on an across and a within environment basis was adapted from a plant breeding perspective. Waihora Romney ewes were the most 'stable', with industry Romney and Coopworth ewes equal in their 'sensitivity'.

Munro (1962) reported on three well-defined types of Scottish Blackface and showed that one type (Lewis) was better on reseeded pasture whereas the Newton Stewart type was better on the hill for milk yield and for lamb weaning weight.

Ch'ang (1963) studied the response of Romney Marsh ewes born as singles or twins when grazed on an oestrogenic red clover sward or on a control pasture. The genotype x pasture interactions were not significant for date of lambing, but were significant for percent barrenness in one year. Among the red clover ewes there was a differential reduction in fertility according to whether the ewes were themselves born as singles or as twins.

Lax and Turner (1965) examined strain x location and other interactions on survival rate to weaning of five strains of Merino lambs at three locations. At one of the locations (Armidale), performance on native and on improved pasture was tested. There was no significant location x strain interaction.

Dunlop (1963) also found no significant strain x location interaction either in number of lambs born or number weaned. In a further report de Haas and Dunlop (1969) found significant location x strain interactions in lambing performance but noted the interactions were not large enough to suggest any marked adaptation of strains to particular locations.

Giles (1968) examined the effect of nutrition from weaning to 14 months of age on lamb production and possible genotype x plane of nutrition interactions in the production characters of five Merino sheep flocks. There were significant plane of nutrition x selection flock interactions in the percentage of ewes pregnant and percentage of lambs that survived to weaning. These were not systematic in regard to the selection applied, and since the sub-flock numbers were small, they were considered to be due to chance effects.

Tierney (1976) reported studies on genetic aspects of puberty in Merino ewes at two different levels of nutrition which revealed a significant interaction between strain and level of nutrition for the percentages of ewes exhibiting oestrus by 7 and 15 months of age, respectively.

Purser (1980, cited by Steane, 1983) reported on the reproductive performance of lines selected for canon bone length. The results on two farms differing in environment (upland and hill) clearly showed on interaction for number of lambs born and mortality.

Purser (1982) showed a genotype x environment interaction by the different correlated effects on lamb production in two environments after selection for canon bone length in Scottish Blackface lambs.

2.3.7.5 Other Traits

Blood characteristics were examined in the study by King *et al*. (1959), involving twin lambs of two breeds and five classes under four nutritional environments. They found significant cross x plane of nutrition interactions for N.P.N. (mg/100)^2 but not for Hb, total protein, albumin/globulin ratio, sugars, inorganic phosphate, serum alkaline phosphatase. Their results indicated a differential response of the genotypes to different planes of nutrition and so the necessity of using uniform genotypes in nutritional experimental designs was felt (Pani and Lasley, 1972).

Hohenboken (1976) found an important ewe breed x management interaction for total gross income, on irrigated pastures Suffolks and Willamettes were nearly identical but on hill pastures Willamettes exceeded Suffolks.

Wiener (1979) studied the inheritance of dietary copper and showed clear breed differences. The North Ronaldsay eats seaweed in its natural environment and is also very efficient in terms of copper absorption. The Welsh Mountain is also an efficient absorber of copper whereas the Scottish Blackface is not. On what is regarded as normal sheep diets the North Ronaldsay is clearly disadvantaged since it suffers from copper poisoning.

Changes in copper concentration in the livers of adult Scottish Blackface (B), Welsh Mountain (W) and B x W ewes fed diets containing 4, 9, 17 and 29 mg Cu/kg D.M. were measured over a 28-week period by Woolliams, Suttle, Wiener *et al* (1983). Levels of Cu varied with breed and with diet. Blackface ewes retained no more from the highest intake of Cu than they did when they received 0.59 of the amount. This suggested a saturation of the mechanism of absorption and thus a limited capacity to absorb Cu.

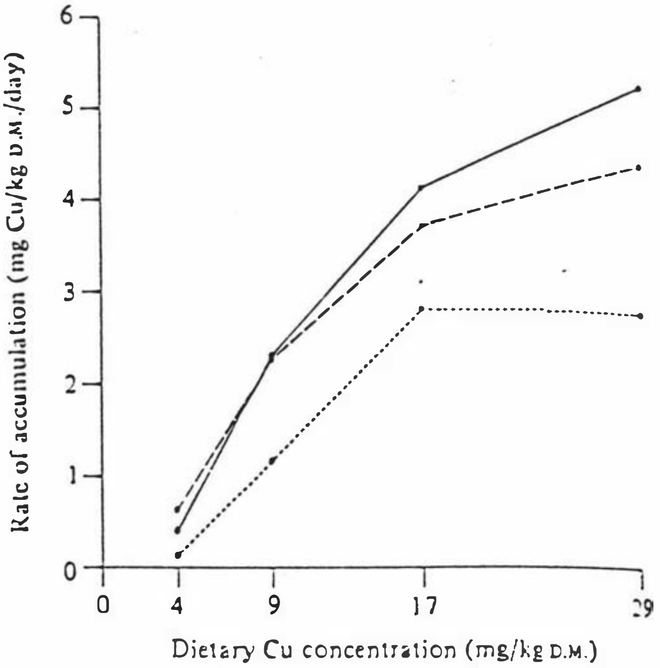

Figure 2.4 Estimated initial rate of increase of Cu concentration in the liver (p) ..., Blackface; --, Blackface x Welsh; ___, Welsh. (Woolliams *et al.*, 1983)

The absence of breed differences during period 3, when the basal diet was supplemented with ammonium molybdate, may reflect the fact that Mo, by reducing the availability of Cu, reduced the effect of differential absorption by the breeds.

Woolliams, Wiener, Suttle and Field (1983) investigated the copper content of wool in relation to breed and the concentrations of copper in the liver and plasma. The Cu concentration of the wool showed an interaction between breed and diet. Neither the Welsh nor the crossbred showed a pattern of wool Cu corresponding to the Cu concentrations of the diets.

CHAPTER THREE

MATERIALS AND METHODS

3.1 MATERIALS

3.1.1 SOURCE OF DATA

The data studied in the present investigation resulted from a long-term experiment initiated at Massey University in 1966 to detect and evaluate the importance of sire x stocking rate and sire x year interactions in controlling various traits in New Zealand Romney sheep.

The origin and earlier management of the flock has been described in other papers (Rae, 1958; Ch'ang, 1967). Since its establishment in 1944 this flock has been maintained by a system of random breeding and random selection of female replacements. No artificial selection has been practised within the flock i.e. ewes were kept once they had entered the flock whether barren or not until culling at 5 1/2 years of age. This was the main flock used for deriving early genetic parameters in the New Zealand sheep industry (Rae, 1958; Ch'ang, 1963; Tripathy, 1966; Lundie, 1971; Ch'ang and Rae, 1970, 1972).

In March 1966 the flock was split into two sub-flocks by dividing each age group at random. One subflock was allocated to a high stocking rate farmlet (HSR), the other to a control stocking rate farmlet (CSR). The grazing units and their management have been described by Sumner (1969). A summary of the important aspects relevant to this study are:

HSR: Approximately 220 mixed-age Romney ewes were grazed on a 10.1 ha farmlet. Until 1976 most of the ewe hoggets were also reared on this farmlet, giving an overall stocking rate of about 26 ewe equivalents per ha. However stock performance was very low over several drought years and from 1976 onwards the ewe hoggets were reared off the farmlet dropping the stocking rate to about 23 ewe equivalents per ha.

CSR: These mixed-age ewes were grazed on an adjoining 17.4 ha at a stocking rate of about 16 ewe equivalents per ha. This flock was slightly larger but of similar age structure to the HSR flock.

Replacement hoggets to enter the subflocks were selected at random from the stock born and bred on the unit. From 1976 onwards all female hoggets were reared together.

Wether lambs were removed from the experimental area at weaning or soon after.

Both flocks were self supporting except for rams. Young rams were obtained from various Romney ram-breeding flocks and from the Massey University flock which had subgroups selected for higher greasy fleece weight, open faces and at random. There was little likelihood that inbreeding occurred in the flock.

The same rams were used for both units. Each group of rams were used for two years, allowing investigation of the possible occurrence of sire x year interaction. Until 1976 each ram was hand mated to approximately 22 ewes in the HSR and to 25 ewes in the CSR. These ewes were removed from their farmlet and placed with the ram for one day after they had been marked by a vasectomized ram harnessed with a mating crayon. Since 1976 mating groups from both stocking rates have been paddocked together for 51 days, each with a single sire on one or the other unit. In all years the ewes were randomly allocated to each sire.

All routine farm operations such as drenching, crutching and shearing were carried out as nearly alike as possible on both units.

3.1.2 DESCRIPTION OF THE DATA

The female progeny of the New Zealand Romney sires used over the period 1966-1983 were studied. Initially 10 sires were used for each two year sire mating period but in 1966/1967 and 1972/1973 the loss of some rams between years meant the data from the progeny of only 7 sires were used for analyses. After 1975 only 5 rams were used in each period. The data from daughters of sires which were not used in both years were excluded.

After being chosen at random from the yearlings available ewes remained in the main flock for four years. There was no culling over these four years but some deaths and disappearances occurred. Only those animals with four years of records as breeding ewes together with their yearling record were included in the ewe analyses. The data available were therefore based on records collected over six two-year sire periods for the ewe analyses (44 sires represented) and seven sire periods for hogget analyses (49 sires represented).

Approximately 1000 daughter-dam pairs with complete record sets were available for daughter-dam regression analyses.

Table 3.1: Numbers of records used for paternal half-sib analyses

Sire Group	Years sires used	No of Sires	No of progeny for Hogget analyses CSR	HSR	Ewe analyses CSR	HSR
One	1966/1967	7	179	128	74	71
Two	1968/1969	10	171	149	93	99
Three	1970/1971	10	146	131	98	89
Four	1972/1973	7	77	92	62	68
Five	1974/1975	5	71	84	51	50
Six	1977/1978	5	160	151	78	86
Seven	1979/1980	5	210	195	-	-
			1014	930	456	463
			1944		919	
				(= 3676 ewe records)		

Data on the following characteristics were recorded:

Liveweight (AWT or SWT : kg)

The liveweight used in this study was the post-shearing (spring) weight of hoggets at 14-15 months of age and the premating (Autumn) liveweight of ewes taken early March. Initially measurements were taken to the nearest pound but later measurements were recorded to the nearest 0.5 kg.

Greasy fleece weight (GFW : kg)

GFW was recorded immediately after shearing (belly wool was included). The measurement of GFW represented a growth of only 9-10 months for the hoggets and of 13 months for the two year old ewes.

Clean fleece weight (CFW : kg)

CFW was calculated from the greasy fleece weight and yield measurements.

Clean scoured yield (Y : %)

For the calculation of yield mid-side samples were removed at shearing for scouring. The methods have been described by Sumner (1969). Y was calculated as 100 x clean weight/ greasy weight of the sample where the clean weight was obtained after the wool had been in a humidity room at 6% RH for at least 48 hours.

Quality number (QN)

QN is a visual appraisal of the spinnability and hence fineness of wool. Bradford quality numbers were used, where 46/48 is written as 47.

Mean fibre diameter (MFD : μm)

MFD was measured on the scoured mid-side sample. For hoggets 150 fibres from each sample were measured by projection microscope and the mean calculated. Ewe samples were measured by airflow. Incomplete measurement of MFD meant this trait was not analysed in sire group 4 of the hogget data.

Staple length (SL : cm)

The length of a greasy mid-side staple was measured.

Total crimp number (TCN)

The number of crimps were counted over the whole length of a greasy mid-side staple.

Crimp frequency (CF : crimps per cm)

CF was calculated from TCN and SL.

Staple strength (SST : Newtons/ktex)

The maximum load before breaking of 5 greasy mid-side staples was measured on a Hounsfield Tensometer. After calculating the mean this was corrected for the yield and converted into Newtons/kilotex.

Character, lustre, tippiness, cotting, soundness, handle, greasy colour and scoured colour were subjectively assessed on the mid-side samples. These were graded on a 1 to 9 scale, the score 9 being allocated to the expression considered most desirable and 1 to the least desirable. The system of grading was designed so that theoretically a normal distribution might be expected but in practice this might not have occurred.

Character (CHG)

CHG reflects the clarity and evenness of staple crimp, absence of tapering tip and medullation. A staple with well-defined crimps was given a high score.

Lustre (LUS)

LUS grades were assigned without reference to fineness, wools with a mirror-like reflectance received higher grades.

Tippiness (TIP)

TIP reflects the degree of tapering of the tip with highly graded staples being flat (blocky) at the tip.

Cotting (COT)

COT was an estimate of the degree of fibre entanglement on the mid-side position. Fleece samples that were very free with no binding between fine staples received top grades.

Soundness (SOU)

A "standard" sized small staple was tested under hand tension. Those with high grades showed little sign of breaking.

Handle (HND)

HND was assessed without regard to QN, with the sample screened from the view of the assessor. Soft wool was given a higher grade.

Greasy colour (GCM) and scoured colour (SCM)

These, taken on the mid-sample before and after scouring, reflected the amount of discolouration.

Cotted area (CAG) and discoloured area (GCF) grades were assessed on the fleece at the time of shearing. CAG was dependent on the degree and extent of entanglement over the whole fleece, while GCF was estimated mainly on the basis of how far the discolouration extended over the fleece with account taken of severity of discolouration. Measurement of CAG and GCF was discontinued in 1979.

Number of lambs born per ewe mated (NLB)

Within two days of birth live lambs were tagged and their dams recorded. NLB was the number of live lambs a ewe had when the shepherd tagged them. No allowance is made for those ewes who carried lambs but which were born dead or died soon after lambing.

Number of lambs weaned per ewe mated (NLW)

Number of lambs weaned per ewe is a record of whether zero, one or two lambs born to a ewe were recognized in the flock at weaning.

Weight of lamb weaned (WLW)

At weaning lamb weights were measured. WLW was the total weight of the lamb(s) the ewe weaned.

Weight per lamb weaned (WPL)

The average weight of each lamb weaned by a ewe.

As reproductive traits are particularly subject to environmental variation lifetime performance was also investigated as total number of lambs born, total number of lambs weaned and total weight of lambs weaned by a ewe in the four years she was in the ewe flock.

Table 3.2: Trait Abbreviations

Trait	Abbreviation	Trait	Abbreviation
Weaning weight	WWT	Cotting grade	COT
Liveweight - Autumn	ALW	Cotted area grade	CAG
- Spring	SLW	Soundness grade	SOU
Greasy fleece weight	GFW	Handle grade	HND
Clean fleece weight	CFW	Greasy colour - midside	GCM
Yield	Y	Scoured colour - midside	SCM
Quality number	QN	Discoloured area - fleece	GCF
Mean fibre diameter	MFD	Number lambs born	NLB
Staple length	SL	Number lambs weaned	NLW
Total crimp number	TCN	Weight lamb weaned	WLW
Crimp frequency	CF	Weight per lamb weaned	WPL
Staple strength	SST	% lamb survived	LSP
Character grade	CHG		
Lustre grade	LUS		
Tippiness grade	TIP		

Note: Subscripts are used to denote age at which trait
refers to ie GFW_2 is 2 yr old fleece weight

LUS_5 is lustregrade of 5 year old ewes

3.2 STATISTICAL METHODS

3.2.1 LEAST SQUARES ANALYSES AND COMPUTING METHODS

As the distribution of numbers of observations in subclasses was non-orthogonal, generalized least squares analyses were carried out. The principles of least squares analyses and the detailed steps used in the estimation process have been discussed by Kempthorne (1952) and Harvey (1960).

A general mathematical model can be written in the matrix notation as:

$$\underset{\sim}{y} = \underset{\sim}{X}\,\underset{\sim}{b} + \underset{\sim}{e}$$

where $\underset{\sim}{y}$ = a known (N x 1) vector of observations (N is the total number of observations);

$\underset{\sim}{X}$ = a known (N x p) incidence matrix (p is the number of factors in the model);

$\underset{\sim}{b}$ = an unknown (p x 1) vector of parameters to be estimated; and

$\underset{\sim}{e}$ = an unknown (N x 1) vector of random residual effects, assumed to be normally and independently distributed with an expected value of zero and variance-covariance matrix of $\underset{\sim}{I}\sigma^2$, where $\underset{\sim}{I}$ is an (N x N) identity matrix.

With var($\underset{\sim}{e}$) equal to $\underset{\sim}{I}\sigma^2$, the application of ordinary least squares generates best linear unbiased estimates of estimable functions of $\underset{\sim}{b}$. Least squares estimation of $\underset{\sim}{b}$ involves minimizing the sum of the observations from their expected values. However, given that some individuals had a common sire (half-sibs) and some individuals (twins and triplets) had both dam and sire common (full-sibs), the validity of the assumption var($\underset{\sim}{e}$) = $\underset{\sim}{I}\sigma^2$ is questionable suggesting use of generalized rather than ordinary least squares estimation.

As the equations do not have full rank some constraints were needed before a solution could be obtained. The constraints used, although not the only ones available, were of the form $\Sigma t_i = 0$, that is the "sum to zero" constraints.

REG, a generalized linear models computer programme (Gilmour, 1985) was available for least squares analyses. Other programs were developed as required.

3.2.2 FITTING MODELS TO THE DATA

Preliminary analyses were aimed at identifying which fixed effects should be included in the linear models applied to the data. Initially, main effects and all first and second order interactions were fitted for fixed and random effects, those interactions consistently nonsignificant at the 5% level were then dropped from further analyses. To simplify computing procedures general models were developed for traits involving similar significant fixed effects.

The final univariate model to describe quantitatively measured traits was:

$$y_{ijklmno} = \mu + b_i + a_j + w_k + t_l + r_m + ba_{ij} + bt_{il} + at_{jl}$$

$$+ bat_{ijl} + wt_{kl} + tr_{lm} + br_{im} + s_n + sb_{in}$$

$$+ st_{ln} + e_{ijklmno}$$

where μ = overall population mean

b_i = effect of the i^{th} birthyear

$i = 1,2$ denoting the first or second year sire was used

a_j = effect of the j^{th} age of ewe
$j = 1,..,4$ denoting the 2^{nd}, 3^{rd}, 4^{th} and 5^{th} years of age of a ewe respectively

w_k = effect of the k^{th} class of number of lambs born and weaned
$k = 1$ denotes 0 lambs born i.e. dry dry
$k = 2$ denotes 1 lamb born but none present at weaning
$k = 3$ denotes 1 lamb born and weaned
$k = 4$ denotes 2 lambs born but none weaned
$k = 5$ denotes 2 lambs born, 1 present at weaning
$k = 6$ denotes 2 lambs born and weaned
(note : triplets, a rare occurrence, were included in twin categories)

t_l = effect of the l^{th} stocking rate
$l = 1$ or 2 denoting control or high stocking rates

r_m = effect of the m^{th} rearing rank of the ewe
$m = 1$ or 2, specifying ewe reared as a single or twin

ba_{ij} = interaction between i^{th} birthyear and j^{th} age of ewe

bt_{il} = interaction between i^{th} birthyear and l^{th} stocking rate

at_{jl} = interaction between j^{th} age of ewe and l^{th} stocking rate

bat_{ijl} = second order interaction between i^{th} birthyear, j^{th} age of ewe and l^{th} stocking rate

Other interactions similarly denoted

s_n = effect of n^{th} sire
$n = 1,..,7$ for sire groups 1 and 4
$n = 1,..,10$ for sire groups 2 and 3
$n = 1,..,5$ for sire groups 5,6 and 7

sb_{in} = interaction of n^{th} sire and i^{th} birthyear

st_{ln} = interaction of n^{th} sire and l^{th} stocking rate

$e_{ijklmno}$ = random error peculiar to the ijklmnoth observation, denoting the deviation of the observation from the expected value under the model

All factors in the model were considered as fixed effects except the $e_{ijklmno}$, s_n, sb_{in} and st_{ln}, which are defined as random effects with zero mean and variance σ^2_e, σ^2_s, σ^2_{sb} and σ^2_{st} respectively. The error is further assumed to be normally distributed for the purposes of the significance testing.

The model describing categorical traits was similar except that interactions with ewe rearing rank and between number of lambs born and weaned with stocking rate were not included.

The model for the reproductive traits number of lambs born and number of lambs weaned did not include ewe rearing rank as a fixed effect since fitting this could result in removal of some of the genetic variation associated with the traits. For weight of lamb weaned the model also included βx_{ijlmno} where β = the partial regression coefficient of weight on age at weaning and x_{ijlmno} = the age at weaning (in days) of the lamb(s) born to the 0th ewe in the ith birthyear, at the jth age, on the lth stocking rate, raised in the mth rearing class. Weight per lamb weaned also included correction for the number of lambs a ewe weaned.

A model to describe hogget data was generated in the same way as for ewe data but without reproductive influences. The final model for hogget traits was:

$$y_{ijkl} = \mu + b_i + t_j + r_k + \beta X_{ijkl} + s_n + sb_{in}$$

$$+ st_{jn} + e_{ijkl}$$

where terms are as described previously.

3.2.3 PARTITIONING THE VARIATION

The analysis of variance (F test) will show when subclass means differ significantly in a statistical sense, but will give limited information on the size of the difference when large numbers of observations result in many error degrees of freedom, since very small differences in subclass means will then be statistically significant. To overcome this, the proportion of variance accounted for by each factor in the final model was calculated from the random effect variance components and fixed effect quadratic components. Quadratic components were estimated by treating all fixed effects as random, with estimated variance components approximating the quadratic components.

Variation accounted for by each effect was determined as a percentage of overall variance. For example, variance due to birthyear ($\%V_b$)

$$\%V_b = \frac{q_b^2 \times 100}{q_b^2 + q_a^2 + q_w^2 + q_t^2 + q_r^2 + q_{ba}^2 + \ldots + \sigma_s^2 + \sigma_{sb}^2 + \sigma_{st}^2 + \sigma_e^2}$$

3.2.4 LEAST SQUARES ESTIMATES

Least squares estimates and standard errors of main fixed effects and significant interactions were computed for all sire group periods for the combined stocking rate analyses. Main effect estimates of interest were presented, excluding birthyear as these were specific to each sire group and particular year. Sires were ignored to obtain estimates of the magnitude of environmental effects. These estimates were required as correction factors for later analyses and to allow evaluation of possible sources of the differences which lead to large between-group variances.

3.2.5 ESTIMATION OF VARIANCE AND COVARIANCE COMPONENTS

Henderson's method 3 was the preferred method because variance and covariance components were required from a mixed model. The variance components were estimated by equating the reductions due to fitting submodels to their expectations under the full model (Henderson, 1953; Harvey, 1960; Searle, 1966; Cunningham, 1970).

Negative variance component estimates were minimized such that

$$\min \underset{\sim}{\sigma}^2 \; (\underset{\sim}{c}\underset{\sim}{\sigma}^2 - \underset{\sim}{f})^2 \text{ subject to } \underset{\sim}{\sigma}^2 \geqq 0$$

$$\text{ie } \sigma_i^2 \geqq 0 \text{ for } i = 1, \ldots, k$$

since $\underset{\sim}{c}$ and $\underset{\sim}{f}$ were known. Lawson and Hanson (1974) described a procedure for solving the constrained minimization problem above, which is discussed by Anderson (1978).

The variance component estimates of sire, sire x stocking rate and sire x year interactions derived from the analyses in combined stocking rates, within separate stocking rates and within age levels were used in determining the importance of genetic factors and genotype by environment interactions on the traits under investigation.

Although not totally of genetic origin the sire x stocking rate and sire x year interaction variance components were referred to as the genetic variance as well as the sire variance. This provided simplicity when referring to these sources of variance and enabled distinction from the environmental sources of variance.

Chopra (1978) used three criteria derived from intraclass relationships between the variance components to investigate importance of GEI:

1. The relative magnitude of the interaction variance components (individually or combined) to the total variance

   ie $$\frac{\sigma^2_{sb}}{\sigma^2_s + \sigma^2_{sb} + \sigma^2_{st} + \sigma^2_e} \quad \text{or} \quad \frac{\sigma^2_{st}}{\sigma^2_s + \sigma^2_{sb} + \sigma^2_{st} + \sigma^2_e}$$

$$\frac{\sigma^2_{sb} + \sigma^2_{st}}{\sigma^2_{s} + \sigma^2_{sb} + \sigma^2_{st} + \sigma^2_{e}}$$

2. The proportions which the sire x stocking rate and sire x year interaction variance components contribute to the total genetic variance
ie

$$\frac{\sigma^2_{sb}}{\sigma^2_{s} + \sigma^2_{sb} + \sigma^2_{st}} \qquad \frac{\sigma^2_{st}}{\sigma^2_{s} + \sigma^2_{sb} + \sigma^2_{st}}$$

$$\frac{\sigma^2_{sb} + \sigma^2_{st}}{\sigma^2_{s} + \sigma^2_{sb} + \sigma^2_{st}}$$

3. A comparison of the relative magnitude of the two parts of the genetic variance
ie

$$\frac{\sigma^2_{sb} + \sigma^2_{st}}{\sigma^2_{s}} \qquad \text{(or } \frac{\sigma^2_{sb}}{\sigma^2_{s}} \text{ in separate stocking rates)}$$

If the ratio is large, the performance of a genotype would be less repeatable over all environments and vice versa.

Henderson's method 2 was utilized for estimating covariance components, as covariances between traits with different models meant precorrection for fixed effects was required. Covariance components were determined by utilizing the formula:

$$\text{var}\ (a+b) = \text{var}\ (a) + \text{var}\ (b) + 2\ \text{cov}\ (a,b)$$

therefore,

$$\text{cov}\ (a,b) = \frac{\text{var}\ (a+b) - \text{var}\ (a) - \text{var}\ (b)}{2}$$

3.2.6 POOLING OF SIRE GROUP PERIOD ANALYSES

In this study, as there was no continuity between sire group two year periods, sire and year effects were confounded. It was thus decided to carry out analysis within each sire group period.

In order to pool the results of least squares analyses over all the sire group periods, the method suggested by Cunningham (1970) was used. Using this method, the sums of squares and degrees of freedom were added to obtain overall totals. The variance components coefficients were obtained by averaging separate sire k's, weighting each by its corresponding sire degrees of freedom.

3.2.7 GENETIC AND PHENOTYPIC PARAMETERS

Use of data corrected for environmental effects for estimating genetic and phenotypic parameters means that the heritabilities and correlations derived are only applicable to situations where the data have been similarly corrected eg. breeding schemes. Applying an estimate of heritability derived from data where adjustments had been made for non-genetic effects to a situation where data were not normally adjusted would lead to inflated predictions of likely genetic progress from selection.

Estimates of heritabilities (h^2) and genetic correlations (r_g^2) were derived for ewe hoggets, ewe performance, ewe average lifetime performance, within each stocking rate and within each age as well as overall.

3.2.7.1 Standard Errors

As the estimates of the parameter are also used to calculate the standard error, standard error estimates tend to vary in magnitude with variation in the parameter estimated. This is observed with low heritabilities tending to have small standard errors and high heritabilities large standard errors.

Hence current methods of estimating standard errors are often inadequate, resulting in biased estimates. Standard errors, where presented, were calculated for completeness only.

Wickham and McPherson (1985) noted that genetic correlations exhibit a high degree of variability which is not readily explainable in terms of the published standard errors. Heritabilities, phenotypic and genetic correlations are ratios and there is no theoretical basis for the calculation of the standard errors of ratios.

3.2.7.2 Phenotypic Correlations and Repeatability

The phenotypic correlation between characters x and y was defined as:

$$r_{P_{xy}} = \frac{\text{cov } PxPy}{(\sigma^2_{Px}\ \sigma^2_{Py})^{1/2}}$$

where x and y were recorded on the same individual in the same or different years. Standard errors were not presented.

Repeatability is often calculated as the regression of a later record (x) on an earlier record (y) (Turner and Young, 1969; Falconer, 1960).

$$\text{i.e.} \quad \frac{\mathrm{cov}(x,y)}{\mathrm{var}(y)}$$

This assumes that, apart from the effects of natural selection, the trait has the same variance at both ages, a useful assumption for a situation such as where selection would lead to invalid estimates of the later variance. However, if the traits were in fact different at the various ages, then this assumption is invalid. For example, hogget fleece weight is considered likely to have a different genetic basis than ewe fleece weight. As no systematic selection (other than natural) had been carried out on the sheep, between age correlations were used to estimate repeatabilities for this study.

3.2.7.3 Genetic Parameters

3.2.7.3.1 Paternal Half-Sib Estimates

Most of the published estimates obtained by the paternal half-sib method are based on analyses of the sire effects nested within years in a single stocking rate and hence would include the sire x year interactions as part of the sire effect. To study the effects of these aspects of the normal methods of obtaining genetic parameters, the heritability and genetic correlation estimates were obtained by both excluding (EI) and including (II) the sire interaction terms.

Heritability

Heritabilities were estimated as:

a) combined stocking rate analyses

$$h^2_{EI} = 4 \frac{\sigma^2_s}{\sigma^2_s + \sigma^2_{sb} + \sigma^2_{st} + \sigma^2_e}$$

(notation as used earlier in analyses of variance)

$$h^2_{II} = 4 \frac{\sigma^2_s + \sigma^2_{sb} + \sigma^2_{st}}{\sigma^2_s + \sigma^2_{sb} + \sigma^2_{st} + \sigma^2_e}$$

b) separate stocking rate analyses

$$h^2_{EI} = 4 \frac{\sigma^2_s}{\sigma^2_s + \sigma^2_{sb} + \sigma^2_e}$$

$$h^2_{II} = 4 \frac{\sigma^2_s + \sigma^2_{sb}}{\sigma^2_s + \sigma^2_{sb} + \sigma^2_e}$$

Since the denominators of the heritability estimates in this study contained the interaction variance components, the method of estimating the variance of heritability derived by Swiger *et al.* (1964) was inappropriate. A large-sample variance of heritability using mean squares rather than variance components (Kempthorne, 1957; Rae, pers comm) was adapted to calculate the approximate standard errors of the estimated heritabilities.

Using large sample theory, if

$$\hat{\theta} = \frac{u_1A + u_2B + u_3C + \ldots}{v_1A + v_2B + v_3C + \ldots} = \frac{W}{Z}$$

where u_i and v_i are constants and A,B,C,... etc are mean squares, then large sample variance of $\hat{\theta}$ is

$$v(\hat{\theta}) = \frac{v(W)}{Z^2} - \frac{2W\ \mathrm{Cov}(WZ)}{Z^3} + \frac{W^2}{Z^4}\,v(Z)$$

$$\text{where } v(W) = u_1{}^2v(A) + u_2{}^2v(B) + u_3{}^2V(C) + \ldots$$

$$v(Z) = v_1{}^2v(A) + v_2{}^2v(B) + v_3{}^2v(C) + \ldots$$

$$\mathrm{Cov}(WZ) = u_1v_1v(A) + u_2v_2v(B) + u_3v_3v(C) + \ldots$$

ie. for the within stocking rate $h^2{}_{EI}$ case:

$$W = \sigma_s^2$$

$$Z = \sigma_s^2 + \sigma_{sb}^2 + \sigma_e^2$$

from mean squares

$$W = (\frac{1}{k3})\ \mathrm{MSS} + (-\frac{k2}{k1k3})\ \mathrm{MSSB} + (\frac{k2}{k1k3} - \frac{1}{k3})\ \mathrm{MSE}$$

$$Z = (\frac{1}{k3})\ \mathrm{MSS} + (\frac{1}{k1} - \frac{k2}{k1k3})\ \mathrm{MSSB} + (1 - \frac{1}{k1} - \frac{1}{k3} + \frac{k2}{k1k3})\ \mathrm{MSE}$$

$$\text{So} \quad u_1 = \frac{1}{k3} \quad u_2 = -\frac{k2}{k1k3} \quad u_3 = \frac{k2}{k1k3} - \frac{1}{k3}$$

$$v_1 = \frac{1}{k3} \quad v_2 = \frac{1}{k1} - \frac{k2}{k1k3} \quad v_3 = 1 - \frac{1}{k1} - \frac{1}{k3} + \frac{k2}{k1k3}$$

$$A = MSS \qquad B = MSSB \qquad C = MSE$$

$$\text{then} \quad V(A) = V(MSS) = \frac{2A^2}{k+2} \quad \text{where } k = df\ (\text{sire})$$

$$V(B) = V(MSSB) = \frac{2B^2}{k+2} \qquad k = df\ (SSB)$$

...

etc

Inter-trait Genetic Correlations

The genetic correlation between the traits x and y was estimated from the sire and interaction variance and covariance components as:

$$r_{g_{xy}} \ EI = \frac{cov(S_x S_y)}{(\sigma^2_{S_x} \ \sigma^2_{S_y})^{1/2}}$$

$$r_{g_{xy}} \ II = \frac{cov(S_x S_y) + cov(SB_x \ SB_y) + (cov \ ST_x \ ST_y)}{[(\sigma^2_{S_x} + \sigma^2_{SB_x} + \sigma^2_{ST_x})(\sigma^2_{S_y} + \sigma^2_{SB_y} + S^2_{ST_y})]^{1/2}}$$

Tallis (1959) estimated approximate sampling errors of the genetic correlations, but the presence of genotype by environment interactions made that method inapplicable. Instead standard errors were estimated by the ratio method (Rae, 1950; Reeve, 1955; Kempthorne, 1957) for mean squares, as for heritabilities.

Intra-trait Genetic Correlations

Yamada (1962) presented a formula to estimate the genetic correlations between performance in two stocking rates as a quantitative expression of sire-stocking rate interaction.

$$r_g = \frac{\sigma_S^2 - \frac{1}{2}\sigma_{ST}^2}{\sigma_S^2 + \frac{1}{2}\sigma_{ST}^2 - \frac{1}{2}(\sigma_{S1} - \sigma_{S2})^2}$$

where σ_{s1} and σ_{s2} refer to genetic standard deviations in the separate stocking rates
and σ_{ST}^2 the sire x stocking rate variance in the combined analysis.
Standard errors were estimated by Robertson's (1959) formula

$$v'(\hat{r}_g) = \frac{[nt(1-r_g^2)+(1-t)]^2+r_g^2(1-t)^2}{(N-1)n^2t^2} + \frac{r_g^2(1-t)^2}{N(n-1)n^2t^2}$$

where N = number of sire groups
n = pairs of observations (harmonic mean of number in each environment)
t = 1/4 h^2 - intraclass correlation of combined stocking rates

If t is small and N is large

$$v(\hat{r}_g) = \frac{\left[1 + nt(1-r_g^2)\right]^2 + r_g^2}{(N-1)n^2t^2}$$

Falconer (1952) stated that the ratio of the 'correlated response' ($\Delta' G_1$) in environment 1 to the 'direct response' (ΔG_1) is

$$\frac{\Delta' G_1}{\Delta\ G_1} = \frac{h_2}{h_1} r_G$$

where h_2 and h_1 are the square roots of the heritability in environment 2 and 1 respectively and r_G is the intra-trait genetic correlation between the two environments. An assumption of equal intensity of selection was made in deriving the equation. From the above expression it follows, that an advantage of selection in the secondary environment would accrue only through an increase of heritability. The increase in heritability would have to be great enough to offset the loss of efficiency through selection being made in one environment that has not exactly the same genetic basis as the other environment, i.e., $h_2 r_G$ must be greater than h_1.

Genetic Regressions

Genetic regressions were calculated simultaneously with genetic correlations. They are especially useful in providing information on the magnitude of the response where correlations exist. Also if the estimate of the genetic variance of one of the traits is zero, meaning r_g is indeterminate, then the genetic regression can still provide information on the relationship between the traits.

$$bg_{x\ EI} = \frac{cov(S_x S_y)}{var(S_x)} \qquad bg_{y\ EI} = \frac{cov(S_x S_y)}{var(S_y)}$$

$$bg_{x\ II} = \frac{cov(S_x S_y) + cov\ (SB_x SB_y) + cov(ST_x ST_y)}{var(S_x) + var(SB_x) + var(ST_x)}$$

$$bg_{y\ II} = \frac{cov(S_x S_y) + cov(SB_x SB_y) + cov\ (ST_x ST_y)}{var(S_y) + var(SB_y) + var(ST_y)}$$

3.2.7.3.2 Daughter - Dam Regressions

The covariance between parent and offspring phenotypes estimates half the additive genetic variance (Falconer, 1960). This covariance can be used to estimate heritability (Lush, 1940) and is required for determining genetic correlations (Hazel, 1943).

Lewer (1978) discussed the three methods available for the estimation of the regression of offspring on parent when more than one offspring may occur per parent. Kempthorne and Tandon (1953) and Bohren, McKean and Yamada (1961) concluded that, unless progeny numbers per parent were high, then the regression of each offspring on the parent, with the parents record repeated for each additional progeny, was more efficient than the regression of the phenotypic mean of all progeny on the parents record and at least as efficient as the weighted regression technique.

Since the accuracy of an estimate is dependent upon the number of observations and small progeny groups would have had to be eliminated, it was decided to ignore sires rather than calculating the regression on an intra-sire basis. Turner *et al.*(1969) indicated that when all sire groups are run together and mating is at random the between sire covariances have zero expectation.

Heritability

Heritability can be estimated as either twice the regression of daughter on dam, or twice the daughter-dam correlation. The true estimate of heritability is computed when both dam and daughter are of the same age. Heritabilities were thus calculated within each age pair ie dam hogget record-daughter hogget record, 2 yr dam record - 2 yr daughter record and later combined across ages. However each animal in the pair will then have been observed in different years for which there is no applicable correction. The analysis was therefore carried out on the data corrected for main environmental effects including years and interactions, with the corrected sums of squares, cross products and degrees of freedom being accumulated at the end of each pair of dam and daughter record years.

$$h^2 = 2 \frac{\mathrm{cov}(P,O)}{\sigma_P^2}$$

P = parent
O = offspring

The standard errors of the heritabilities were calculated by the method given by Falconer (1960).

$$\sigma_{\hat{b}}^2 = \frac{1}{N-2} \left(\frac{\sigma_O^2}{\sigma_P^2} - b^2 \right)$$

$$\text{Std error } h^2 = 2\sigma_b$$

Genetic Correlations

Combining the covariances between traits X and Y measured on both parent and offspring, forms the basis for genetic correlation (Hazel, 1943).

$$r_g = \frac{\mathrm{cov}\ P_x O_y + \mathrm{Cov}\ P_y O_x}{2[(\mathrm{Cov}\ P_x O_x)\ (\mathrm{Cov}\ P_y O_y)]^{1/2}}$$

Standard errors were estimated by the method given by Reeve (1955)

$$V(r_g) = \frac{1}{f}\Big[\frac{1}{2}(1-r_g{}^2)^2 + \frac{1}{2}(1-r_g{}^2)\Big(\frac{1}{D} - \frac{v_p v_g}{c}\Big) + \frac{2k}{n}\Big(\frac{r_g}{D} - \frac{v_p}{c}\Big)^2$$

$$+ \frac{(1-v_g{}^2)}{n}\Big\{ \frac{k(1-v_p{}^2)}{C^2} - \frac{1}{2D} + \frac{V_p V_g}{2C} \Big\}\Big]$$

where $C = h_1 h_2$

$^1/D = \frac{1}{2} \left(\frac{1}{h_1} 2 + \frac{1}{h_2} 2\right)$

n = progeny measured in each of f families

3.2.8 CATEGORICAL ANALYSES

Categorical variables occur when responses are recorded according to which of a small number of classes the animal falls into rather than as measurements on a continuous scale. Sometimes the categories have a natural order and can be regarded as different levels of a single underlying variable - this is a threshold model. When there is no natural order the extremal model applies, it assumes each category represents a different underlying variable. For example, number of lambs born can be considered an extremal trait, since it involves fertility (0 or 1 lambs) and fecundity (1 or 2 lambs).

Binomial Traits

With binomial data the mean is related to the variance violating the assumptions of constant error variance and zero covariance between error terms, required in least squares analyses.

The method of least squares (as described earlier) is still a convenient procedure for analysing binomial traits on the (0,1) scale; it is quite robust to departures from normality but, under a mixed model, predicted probabilities are not constrained to the interval 0 to 1, especially if continuous covariates are included in the model. The probit transformation is commonly used to overcome the problem but an alternative, the logit transformation, has recently been promoted because it is "closely similar" to the probit and easier to compute. The standard logistic distribution has mean zero, variance $\pi^2/3$ and known density function (Gilmour, 1983; Gilmour, Anderson and Rae, 1985).

The logit transformation was applied to reproductive data to analyse the binomial traits:

had a lamb or not (fertility)
had 1 or 2 lambs - having had a lamb (fecundity)
weaned a lamb or not - having lambed
weaned twins or single - having had twins
weaned 1 lamb or not - having had 1 lamb

Multinomial Traits

When a categorical trait is definitely ordered, it has been common to analyse category codes as a continuous variable. As the subjectively graded traits in this study were generated to be normally distributed this would seem adequate. However extreme grades were rarely used and it was more appropriate to consider them as extremal or multiple threshold traits.

Traits analysed as multinomial traits in this study included:

subjectively assessed wool traits
    (CHG, LUS, TIP, COT, CAG, SOU, HND, GCM, GCF, SCM)
number of lambs born (0,1,2)
number of lambs weaned (0,1,2)
number of lambs weaned, when the ewe had had twins (0,1,2)

Models of the same general form as those used in analysing continuous data were fitted in order to construct analyses of deviance. The deviances are distributed as Chi-square variables. Tests of significance were performed under the transformed scale, but for ease of interpretation, least squares estimates of treatment effects were retransformed to the original scale.

Heritability estimates were derived from intra-class correlations obtained by the logistic linear mixed models procedure (Gilmour, 1983; Gilmour, Anderson and Rae, 1985). The procedure involves setting up mixed model equations, absorbing the random effects and obtaining maximum likelihood solutions by iterative reweighted least squares analyses. The random effects were obtained by back-solution using the final fixed effects. Standard errors were not obtained.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 ESTIMATION OF NON-GENETIC FACTORS

4.1.1 PROPORTION OF VARIANCE CONTROLLED

Table 4.1 summarized the proportion of variance attributable to each of the factors in the model for each variable in the combined stocking rate analyses, pooled over the different sire group periods for hoggets and ewes, respectively.

In both hogget and ewe analyses liveweight, greasy fleece weight and clean wool weight had the highest percent variation accounted for by the models, with only 22 - 27% of the variation not explained (except ewe CFW, error = 38%). The model also controlled a high proportion of variation for lamb weaning weight (Table 4.1.1). Liveweight and fleece weight may have been more accurately measured, with less observer variation than other traits.

The ewe model for a trait consistently explained a higher proportion of the total variation than the hogget model. Most hogget models explained only 10 - 20% of the variation, while the ewe models explained 40 - 60%.

In the ewe analyses more variation was accounted for by the model for quantitatively measured traits (SL, TCN, Y, MFD, SST) than for assessed traits (CHG, LUS, TIP,COT, CAG, HND, GCM). This trend was not observed in the hogget traits.

The reproductive traits NLB and NLW had a low proportion of variance controlled by their models. The weight of lamb weaned model controlled only 28% of the variation but the inclusion of the number of lambs meant the model for weight per lamb weaned controlled 71% of the variation.

Table 4.1.1: Percent of total variance attributable to each factor in the combined stocking rate analysis pooled from the different sire group periods for weaning weight

Factor	Percent variance accounted for	
	both sexes	ewe lambs
Year	6.5	7.6
Dam age	2.7	4.0
Sex	2.3	na
Birth-rearing rank	20.9	22.0
Stocking rate	30.7	28.1
Age weaned	0.1	0.1
Year.age	-	na
Age weaned .sr	-	na
Sr .dam age	2.2	na
Sire	0.8	1.3
Sire.year	0.3	0.8
Sire.sr	-	-
Error	33.5	36.1

Table 4.1.2: Percent of total variance attributable to each factor in the combined stocking rate analysis pooled from the different sire group periods for hogget traits

Factor	SLW	GFW	CFW	Y	QN	MFD	SL	TCN	CF	SST
Year	19.4	30.7	26.4	2.2	10.8	4.0	-	4.5	1.7	9.6
Rearing rank	2.2	1.5	2.4	-	2.3	-	-	9.1	9.3	-
Stocking rate	52.3	31.9	23.0	0.7	3.1	0.2	0.7	-	-	1.1
Age weaned	-	-	-	-	-	-	-	6.7	6.9	-
Year.sr	0.5	5.2	3.8	7.9	2.9	5.0	2.6	-	-	6.3
Sire	0.4	1.8	3.2	4.3	5.7	7.4	10.8	9.7	8.1	3.4
Sire.yr	1.4	1.5	1.7	0.5	-	1.9	1.6	0.2	-	0.8
Sire.sr	0.4	0.4	0.8	2.3	0.9	1.0	-	1.4	-	-
Error	23.3	27.0	38.7	82.1	74.3	80.5	84.3	68.4	74.0	78.8

Table 4.1.2: Continued

Factor	CHG	LUS	TIP	COT	CAG	SOU	HND	GCM	SCM	GCF
Year	3.2	2.7	0.4	1.8	5.8	-	3.1	1.5	-	-
Rearing rank	-	-	4.9	-	2.5	-	-	-	-	-
Stocking rate	0.1	0.2	-	0.5	0.3	3.0	-	0.9	0.9	1.0
Age weaned	-	-	7.5	-	2.8	-	-	-	-	-
Year.sr	2.2	2.1	-	2.9	-	15.5	0.6	3.2	5.8	5.7
Sire	5.4	5.7	3.4	5.5	3.8	2.4	3.6	2.4	1.1	2.4
Sire.yr	-	-	0.6	-	1.0	0.8	2.7	4.3	2.2	-
Sire.sr	1.8	0.9	-	-	-	-	1.5	3.2	1.8	-
Error	87.3	88.4	83.2	89.3	83.8	78.3	88.5	84.5	88.2	90.9

Table 4.1.3: Percent of total variance attributable to each factor in the combined stocking rate analysis pooled from the different sire group periods for adult traits

Factor	ALW	GFW	CFW	Y	QN	MFD	SL	TCN	CF	SST
Birth year	0.7	1.5	1.3	0.3	1.2	2.4	0.4	0.9	0.7	2.2
Age	5.4	21.9	24.2	11.3	8.0	4.1	39.4	30.9	3.4	4.3
No lambs born/weaned	5.9	2.2	2.0	4.3	1.2	2.3	0.4	0.4	0.4	4.3
Stocking rate	47.9	25.7	21.9	2.3	1.3	15.9	4.9	0.3	1.8	17.1
Rearing rank	1.1	0.8	0.7	0.2	0.6	1.7	1.2	-	0.6	-
Age.byr[1]	4.1	11.7	13.0	14.0	11.1	12.6	7.2	8.8	5.0	12.0
Stocking rate.byr	0.3	0.3	0.2	0.6	0.7	0.4	0.1	2.0	2.0	0.4
Stocking rate.age	3.1	0.7	0.4	1.2	0.4	1.1	0.2	0.1	0.5	2.7
Age.byr.sr	1.6	0.6	0.8	1.9	0.4	-	-	0.6	1.5	6.0
Nlbw.sr	1.8	0.2	0.6	1.1	-	-	0.6	-	0.1	1.9
Sr.rr	1.0	0.8	1.2	2.0	2.2	-	1.4	1.5	3.1	-
Byr.rr	0.8	0.3	0.7	1.1	3.6	3.0	1.4	1.9	3.2	0.7
Sire	0.7	2.5	2.6	1.6	3.0	5.9	2.8	2.6	3.4	0.8
Sire.byr	1.0	2.0	1.6	2.1	2.6	3.3	2.0	1.3	3.1	1.3
Sire.sr	2.0	1.1	1.1	1.3	1.7	2.2	1.6	1.6	1.6	1.7
Error	22.6	27.7	27.7	54.7	62.0	45.1	36.4	47.1	69.6	44.6

[1] Confounded with year of record

Table 4.1.3: Continued

Factor	CHG	LUS	TIP	COT	CAG	SOU	HND	GCM	SCM	GCF
Birth year	0.7	3.4	1.4	1.8	0.1	1.4	3.0	2.8	0.3	2.6
Age	15.4	14.5	16.9	10.5	5.1	6.0	8.0	11.4	11.0	5.9
No lambs born/weaned	0.9	1.1	0.4	1.0	2.7	3.3	1.9	3.5	0.2	1.1
Stocking rate	0.7	1.3	0.6	0.4	3.8	17.8	1.9	0.6	1.0	2.5
Rearing rank	0.2	0.1	0.1	0.8	0.8	-	2.4	-	0.5	0.2
Age.byr[1]	15.3	14.5	13.2	17.4	3.6	8.4	12.2	8.5	15.1	13.0
Stcking rate.byr	0.5	0.1	0.5	0.6	0.1	0.2	-	1.3	1.8	1.0
Stocking rate.age	1.9	3.0	0.6	0.9	2.4	4.1	1.8	1.2	1.7	2.2
Age.byr.sr	3.2	5.6	-	4.6	4.7	7.4	2.9	6.8	11.2	14.7
Sire	1.5	0.3	3.5	1.4	4.1	0.6	2.9	-	0.1	0.3
Sire.byr	1.6	0.9	0.7	2.8	1.8	-	1.9	2.0	0.2	0.8
Sire.sr	0.8	0.8	0.6	1.2	1.9	1.1	0.4	0.2	1.4	0.3
Error	57.3	54.4	61.5	56.6	68.9	49.7	60.7	61.7	55.5	55.4

Table 4.1.3: Continued

Factor	NLB	NLW	Lifetime NLB	Lifetime NLW
Birth year	0.6	0.8	2.7	1.9
Age of ewe	4.9	4.4	na	na
Stocking rate	3.3	2.7	15.5	8.8
Ewe liveweight	-	0.3	0.1	0.1
Age.b yr[1]	3.3	3.3	na	na
Stocking rate.byr	-	-	0.4	0.3
Stocking rate.age	0.3	0.8	na	na
Age.byr.sr	2.1	1.6	na	na
Sire	-	-	2.4	1.4
Sire.byr	2.4	1.6	-	-
Sire.sr	0.3	2.2	-	-
Error	82.8	82.3	78.9	87.5

Table 4.1.3: Continued

Factor	WLW	WPL	Lifetime WLW	Lifetime WPL
Birthyear	1.3	0.5	10.8	0.9
Age of ewe	5.7	4.1	na	na
Stocking rate	8.5	17.3	61.8	48.6
Ewe liveweight	1.2	-	0.1	-
Age at weaning	-	-	0.1	-
No lambs weaned	na	34.9	na	34.3
Age.byr	5.4	6.9	na	na
Stocking rate.byr	0.4	1.6	0.9	0.3
Stocking rate.age	0.8	2.1	na	na
Age.byr.sr	1.3	2.3	na	na
Sire	-	0.2	1.6	-
Sire.byr	1.3	-	-	-
Sire.sr	2.3	1.1	-	2.0
Error	71.8	29.0	24.7	13.9

The total variation explained by these models is higher than the variation explained by models used by Lewer (1978) for his Perendale ewe analyses. His model contained similar environmental effects, although it did not include stocking rate, but explained only 18 - 25% of variation for MFD and 30 - 40% for FWT, although his models for QN, CHG and NLW explained similar amounts of variation. There was some variation in the overall percent variation accounted for by the model between this study and those reported by Chopra (1978), probably arising from different estimation procedures. However, the magnitude of importance of factors in the model was in agreement.

Although the overall model was statistically significant ($P < 0.05$) it could be seen that the percentage of variation controlled by some factors, especially interactions, was low. Some researchers have used greater than 2% as a criterion for indicating that effects were reasonably important in a model (Hazel and Terrill, 1945 , 1946).

For most hogget traits year and stocking rate and their interaction explained the highest proportion of variation. Similarly for ewe traits, with age and interactions of age with birthyear and stocking rate also of importance. In the ewe model birth year was relatively unimportant, while age x birthyear interaction was highly significant. Age x birthyear was comparable to a record year effect, although some other components were included.

Rearing rank had no significant effect on most traits in the ewe analyses but was included for completeness in the final models.

Sire and sire interactions generally controlled around 5% of the total variation but varied from 1.4 to 10%. The proportion was low for reproductive traits indicating the importance of chance and unrecognized effects and the influence of the ram the ewe was mated to as well as that of the sire of the ewe.

Sire x age interactions were investigated but as they were non-significant they were not included in the final model.

4.1.2 ESTIMATES OF ENVIRONMENTAL EFFECTS

4.1.2.1 Liveweight

Weaning weight

The overall mean for WWT, corrected to average age at weaning (90.3 days), was 22.3 kg which is of similar magnitude to that determined in other studies (Ch'ang and Rae, 1961; Jury, Johnson and Clarke, 1979; Newman, Wickham, Rae and Anderson, 1983). Direct comparison is difficult as age at weaning is variable.

Table 4.2.1 gives the mean weaning weight and least squares estimates of the environmental effects estimated for each sire group. Both sexes were included, with females being 0.9 - 1.0 kg lighter than wethers in half the sire groups and 1.4 - 1.6 kg lighter in the other groups. Rae (1961), Tait (1983) and Newman *et al.* (1983) noted males were 1.5 kg heavier than females.

Lambs from 3 year old ewes had the highest weaning weight with a slight decrease in WWT of lambs from 4 year old ewes and a large decrease for 5 year old ewe offspring. Most other studies have found offspring from 4 year old ewes to be heaviest (Newman *et al.*, 1983). However, in the current study the age effect is affected by stocking rate and the unusual trends may be due to the higher stocking rate ewes producing lighter lambs at later ages than the CSR ewes. e.g. in sire group two the overall effect on lamb WWT of a 5 year old dam is -0.44 ± 0.20 kg but the interaction with stocking rate indicates that the CSR

Table 4.2.1: Least squares estimates and standard errors of environmental effects for weaning weight (kg)

Factor	Sire group 1 1966/1967	Sire group 2 1968/1969	Sire group 3 1970/1971	Sire group 4 1972/1973	Sire group 5 1974/1975	Sire group 6 1977/1978	Sire group 7 1979/1980	Sire group 8 1981/1982
Age of Dam								
2 years	-1.42±0.23	-0.56±0.19	0.19±0.25	-0.38±0.27	0.91±0.31	-0.31±0.22	-1.37±0.20	-0.84±0.23
3 years	-0.11±0.21	0.56±0.19	0.64±0.21	1.30±0.26	1.38±0.29	0.05±0.22	0.79±0.18	0.50±0.21
4 years	1.07±0.21	0.44±0.19	0.27±0.22	0.48±0.25	-0.36±0.30	0.16±0.22	0.61±0.18	0.37±0.20
5 years	0.46±0.22	-0.44±0.20	-1.10±0.23	-1.40±0.26	-1.93±0.32	0.10±0.22	-0.03±0.18	-0.03±0.21
Sex								
Female	-0.82±0.12	-0.83±0.11	-0.46±0.13	-0.45±0.15	-0.64±0.17	-0.47±0.13	-0.47±0.10	0.69±0.12
Wether	0.82±0.12	0.83±0.11	0.46±0.13	0.45±0.15	0.64±0.17	0.47±0.13	0.47±0.10	-0.69±0.12
Birth Rearing Rank								
1 1	2.37±0.24	2.40±0.21	2.09±0.30	2.02±0.28	1.95±0.36	2.60±0.22	2.08±0.18	2.22±0.20
2 1	-0.00±0.40	-0.17±0.34	0.25±0.49	0.10±0.45	0.77±0.59	-0.08±0.36	0.18±0.27	0.27±0.29
2 2	-2.37±0.23	-2.24±0.22	-2.34±0.31	-2.12±0.34	-2.72±0.40	-2.51±0.23	-2.27±0.18	-2.49±0.19
Stocking rate								
Control	1.20±0.14	2.41±0.15	2.74±0.16	2.17±0.17	2.44±0.19	0.97±0.13	2.79±0.11	2.22±0.12
High	-1.20±0.14	-2.41±0.15	-2.74±0.16	-2.17±0.17	-2.44±0.19	-0.97±0.13	-2.79±0.11	-2.22-0.12
Age at Weaning (kg/day)	0.11±0.01	0.09±0.01	0.18±0.01	0.15±0.01	0.16±0.02	0.19±0.01	0.14±0.01	0.15±0.01
General mean - corrected to average age at weaning	23.27±0.22	19.98±0.20	20.54±0.28	20.91±0.27	24.21±0.34	23.53±0.20	21.62±0.16	24.66±0.16

effect is +1.04 kg while the HSR effect is -1.04 kg. The poor performance of older ewes on the HSR was probably related to teeth wear in drought years.

Stocking rate was the effect controlling most of the variation in WWT (30%). Table 4.2.1 indicates that the high stocking rate lambs were 1.8 to 5.6 kg lighter than the CSR lambs at weaning. Joyce, Clarke, Maclean and Cox (1976) found a difference of 2.4 and 2.8 kg in WWT between lambs from ewes on high (26 e/ha) and medium (21 e/ha) compared with those from a low (16 e/ha) stocking rate. Numerous studies have established that a low plane of nutrition during pregnancy results in the birth of light lambs and that low levels of feed intake between birth and 4 months results in a slower growth rate (Schinckel and Short, 1961; Allden, 1970; Langlands, Donald and Paull, 1984a).

Of the total variation, 20% was controlled by birth-rearing rank, with lambs born and reared as singles being 1.5 - 2.5 kg heavier than lambs born as twins and reared as singles and 4.2 - 5.0 kg heavier than those born and reared as twins. The reduction in body weight of twins was similar to those found in other studies (Ch'ang and Rae, 1961; Lundie, 1971; Hight and Jury, 1971; Baker *et al.*, 1974; Jury, Johnson and Clarke, 1979; Baker *et al.*, 1974; Elliott *et al.*, 1979; Rendel, 1985; Newman *et al.*, 1983).

Barnicoat, Logan and Grant (1949, cited by Ch'ang and Rae, 1970) noted that the estimates of age of dam and type of birth and rearing effects are thought to be essentially reflections of the magnitude of pre-weaning nutritional handicap resulting from a lower milk production of the younger dams, or in the case of twins, having to share pre-natal uterine environment and post-natal milk supply. Ch'ang and Rae (1970) suggested that the effect of being born or reared as a twin was sufficient to trigger post weaning compensatory growth, whereas the effect of being born to a young dam was insufficiently severe to invoke compensatory growth.

The linear regression coefficients of weaning weight on age at weaning ranged from 0.09 to 0.19 kg/day, and were similar to those reported previously (Clarke and Rae, 1976; Jury *et al.*, 1979; Rendel, 1985; Wewala,1981).

Except for stocking rate x dam age, interactions were not important for weaning weight.

Hogget Spring Liveweight

Table 4.2.2 gives the mean spring liveweights of the hoggets. In the first four sire group periods the least squares estimates show there was a considerable stocking rate effect on hogget liveweight, with LW depressed in the HSR group. These results are in close agreement with the results of earlier studies on this flock by Sumner (1969) and Chopra (1978).

In early spring the HSR hogget nutrition was severely restricted to allow lambing ewes more pasture and this treatment retarded the body growth of the hoggets. After 1976 the hoggets were removed from the flocks and run together, effectively removing the practical stocking rate effect on hogget liveweight and decreasing the stocking rate intensity in the HSR ewe flock. As a result the difference in liveweight between the stocking rates is lower in the last three sire group periods, lower even than the difference at weaning since the hoggets from the high stocking rate have compensated to some extent.

Several experiments (Coop and Clarke, 1955; Donald and Allden, 1959) have observed that body weight differences between weaning and 12 months of age were eliminated subsequently when all animals were exposed to a common

Table 4.2.2: Least squares estimates and standard errors of environmental effects for hogget liveweight (kg)

Factor	Sire group 1 1966/1967	Sire group 2 1968/1969	Sire group 3 1970/1971	Sire group 4 1972/1973	Sire group 5 1974/1975	Sire group 6 1977/1978	Sire group 7 1979/1980
Stocking rate							
Control	4.93±0.23	4.78±0.32	2.89±0.25	3.81±0.29	1.10±0.31	0.47±0.24	0.92±0.21
High	-4.93±0.23	-4.78±0.32	-2.89±0.25	-3.81±0.29	-1.10±0.31	-0.47±0.24	-0.92±0.21
Rearing Rank							
Single	0.53±0.23	0.71±0.31	1.17±0.30	0.96±0.42	-0.25±0.44	1.06±0.25	0.76±0.21
Twin	-0.53±0.23	-0.71±0.31	-1.17±0.30	-0.96±0.42	0.25±0.44	-1.06±0.25	-0.76±0.21
Age weaned (kg/day)	0.06±0.02	0.03±0.03	0.07±0.02	0.12±0.02	0.12±0.03	0.13±0.02	0.09±0.02
General Mean - corrected to average age at weaning	32.51±2.29	33.56±2.48	29.06±1.75	33.60±2.07	34.57±3.05	34.68±1.81	38.11±1.87

favourable environment. However, Henderson (1953) observed that at 52 weeks of age, Romney Marsh sheep which were subject to poor nutritional environment from birth to 20 weeks of age were 28 lb (12.4 kg) lighter than animals favoured by a good nutritional environment during this period. Reardon and Lambourne (1966) found the group initially on a low plane of nutrition made substantial compensatory weight gains when placed on improved pasture at nine months of age.

The animals reared as singles were heavier than those reared as twins but although 22% of the variation in lamb weaning weight was attributable to birth-rearing rank only 2.2% was controlled by this trait in hoggets. In an early study on this flock Ch'ang and Rae (1970) noted that type of birth and rearing simulate artificially imposed levels of nutritional treatments and their effects on post-weaning weight gains of the individual may be interpreted as measurements of the degree of compensatory growth. The estimates of type of birth and rearing effect suggested that a variable degree of post-weaning compensatory growth over the hogget stage occurred in the individuals born and reared as twins, in contrast with those born and reared as singles or twins reared singly. A similar situation was found in this study as the difference between liveweight of hoggets reared as twins or singles was lower than differences existing between the rearing ranks in weaning weight.

Between-year effects are caused by factors such as nutrition, climate and management peculiar to each year. This study suggests that liveweight was easily affected by year with 19.4% of the total variation controlled.

Ewe Autumn Liveweight

Liveweights tended to increase over the period studied. Several factors were probably involved. Probably the most important was that from 1969/1970 onward there were several years of quite severe droughts with the high stocking group receiving particularly poor autumn nutrition. Pasture quality appeared to improve on the intensive area over the years studied and from 1976 onward the stock units carried on the intensive area were reduced. These factors will have affected age effects also.

These factors were also reflected in the stocking rate effects, with the difference decreasing in sire groups 5 and 6. Stocking rate controlled the majority of the variation, explaining 47.9% of the total.

Birth year was not an important source of variation; however age x birthyear, which included a record year component, was significant (4.1% of variation controlled).

Three or four year old ewes had the highest liveweight. Stocking rate x age interaction was significant, controlling 3.1% of the variation. Langlands, Donald and Paull (1984) found that liveweight in early adult life and some body dimensions were reduced by a low plane of nutrition (20 cf 10 sheep/ha) but the differences declined with time and were not significant after 2 1/2 years in ewes stocked as adults at 10/ha or after 5 1/2 years in ewes stocked at 20/ha.

Reproductive status of the ewe statistically controlled 5.9% of the variation. However, since ewe liveweight was taken premating it is likely that the biology of the relationship was that the number of lambs born and weaned was influenced by ewe liveweight. Ewes which did not bear or wean lambs had the highest liveweights, followed by those that did not wean lambs born to them. Estimates

Table 4.2.3: Least squares estimates and standard errors of environmental effects for ewe liveweight (kg)

Factor	Sire group 1 1966/1967	Sire group 2 1968/1969	Sire group 3 1970/1971	Sire group 4 1972/1973	Sire group 5 1974/1975	Sire group 6 1977/1978
Age of ewe						
2 years	-0.70±0.31	-2.06±0.37	-0.04±0.38	-3.82±0.40	-2.50±0.38	-7.82±0.43
3 years	1.53±0.31	0.93±0.36	3.01±0.38	-1.70±0.40	4.14±0.37	1.06±0.42
4 years	0.21±0.31	1.84±0.36	-0.13±0.38	2.59±0.40	0.73±0.38	4.63±0.43
5 years	-1.04±0.31	-0.71±0.36	-2.84±0.38	2.94±0.40	-2.37±0.38	2.13±0.43
No of Lambs						
Born/Weaned						
0 0	3.20±1.44	1.88±0.80	3.17±0.81	2.01±0.71	3.80±0.61	4.32±0.65
1 0	-0.07±1.44	0.19±0.82	1.95±0.82	2.51±0.96	2.17±0.69	1.85±0.94
1 1	-0.58±1.41	-1.61±0.67	-1.51±0.67	-1.34±0.53	-2.05±0.42	-2.31±0.49
2 0	-1.85±6.11	3.01±1.69	-2.78±2.65	0.24±1.85	1.32±1.18	3.03±1.30
2 1	-0.64±1.17	-3.56±2.53	0.18±1.38	0.55±0.92	-1.05±0.85	-1.79±0.81
2 2	-0.07±1.56	0.10±0.96	-1.01±1.04	-3.97±0.69	-4.20±0.54	-5.10±0.54
Stocking Rate						
Control	6.99±1.41	7.07±0.63	6.21±0.69	5.59±0.77	3.82±0.45	4.62±0.38
High	-6.99±1.41	-7.07±0.63	-6.21±0.69	-5.59±0.77	-3.82±0.45	-4.62±0.38
Rearing Rank						
Single	0.24±0.18	0.47±0.23	-0.10±0.46	0.65±0.66	0.19±0.39	1.45±0.26
Twin	-0.24±0.18	-0.47±0.23	0.10±0.46	-0.65±0.66	-0.19±0.39	-1.45±0.26
General mean	41.94±1.40	44.30±0.63	46.10±0.74	50.78±0.78	53.17±0.45	56.61±0.38

of the effect on ewe liveweight of bearing twins but weaning none had a higher standard error reflecting the low number of ewes in this class.

Number of lambs born/weaned x stocking rate interaction controlled 1.8% of the variation, reflecting the different effect on ewe liveweight of the number of lambs born/weaned in the two stocking rates.

4.1.2.2 Greasy and Clean Fleece Weight

The overall averages and least squares estimates of environmental effects are presented in tables 4.2.4 and 4.2.5. The hogget fleece weights represented the 9 - 10 months wool growth between lamb and hogget shearing while the 2 year old ewe fleece represented 13 months growth compared to 12 months for the older ewes.

Hogget Fleece Weight

In all the sire group periods the CSR animals had higher GFW and CFW than the HSR animals, except sire groups 5 and 6, when the hoggets were grazed together from weaning till shearing and there was no difference in GFW or in CFW. There is considerable evidence that the fleece weight is inversely related to the stocking rate and is approximately proportional to herbage intake (Bublath, 1969; Joyce *et al.*, 1976; Chopra, 1978). Schinckel and Short (1961) and Allden (1970) found that low levels of feed intake between birth and 4 months resulted in 12% less wool as adults, owing to a smaller fibre weight. In early work on this flock Sumner and Wickham (1969) noted that weights of wool samples clipped each month indicated a more marked and more prolonged winter and early spring

Table 4.2.4: Least squares estimates and standard errors of environmental effects for hogget fleece weight (kg)

Factor	Sire group 1 1966/1967	Sire group 2 1968/1969	Sire group 3 1970/1971	Sire group 4 1972/1973	Sire group 5 1974/1975	Sire group 6 1977/1978	Sire group 7 1979/1980
GREASY FLEECE WEIGHT (kg)							
Stocking Rate							
Control	0.32 ±0.03	0.54 ±0.04	0.13 ±0.03	0.40 ±0.04	-0.002±0.04	0.02 ±0.03	0.10 ±0.02
High	-0.32 ±0.03	-0.54 ±0.04	-0.13±0.03	-0.40 ±0.04	0.002±0.04	-0.02 ±0.03	-0.10 ±0.02
Rearing Rank							
Single	0.02 ±0.03	0.08 ±0.04	0.04 ±0.04	-0.02 ±0.06	0.04 ±0.06	0.06 ±0.03	0.06 ±0.02
Twin	-0.02 ±0.03	-0.08 ±0.04	-0.04 ±0.04	0.02 ±0.06	-0.04 ±0.06	-0.06 ±0.03	-0.06 ±0.02
Age Weaned (kg/day)	0.014±0.003	0.005±0.004	0.008±0.002	0.01 ±0.003	0.02 ±0.004	0.01 ±0.002	0.01 ±0.002
General Mean - corrected to average age at weaning	3.16 ±0.31	3.20 ±0.32	2.99 ±0.22	3.00 ±0.30	3.62 ±0.41	3.07 ±0.20	3.12 ±0.20
CLEAN FLEECE WEIGHT (kg)							
Stocking Rate							
Control	0.25 ±0.03	0.38 ±0.03	0.10 ±0.03	0.33 ±0.03	0.02 ±0.03	0.009±0.02	0.08 ±0.02
High	-0.25 ±0.03	-0.38 ±0.03	-0.10 ±0.03	-0.33 ±0.03	-0.02 ±0.03	-0.009±0.02	-0.08 ±0.02
Rearing Rank							
Single	0.02 ±0.03	0.06 ±0.03	0.03 ±0.03	-0.02 ±0.05	-0.01 ±0.05	0.04 ±0.02	0.04 ±0.02
Twin	-0.02 ±0.03	-0.06 ±0.03	-0.03 ±0.03	0.02 ±0.05	0.01 ±0.05	-0.04 ±0.02	-0.04 ±0.02
Age weaned (kg/day)	0.01 ±0.003	0.004±0.003	0.007±0.002	0.009±0.003	0.02 ±0.004	0.008±0.002	0.01 ±0.002
General Mean - corrected to average age at weaning	2.47 ±0.28	2.44 ±0.24	2.29 ±0.19	2.40 ±0.25	3.21 ±0.34	2.42 ±0.17	2.60 ±0.17

depression of wool growth on the intensively grazed area (HSR).

Hoggets reared as singles had heavier fleece weights than those reared as twins in most sire group periods. The differences ranged from 0.4 - 1.6 kg. These are of the same magnitude as estimates obtained from other studies (Tripathy, 1966; Hight and Jury, 1971). However Baker, Clarke and Carter (1974) only obtained a difference of 0.1 in their study on Romney hoggets, which is of the same order as that estimated by Chopra (1978) of 0.06 and Tait (1983) of 0.02 - 0.09. In Merinos the lowered clean fleece weight in twins was mainly due to a lower total follicle number (Turner, 1961; Dun and Grewal, 1963). This arose mainly from a deficiency in secondary follicles. However, in Romneys although Sumner and Wickham (1970) indicated a delaying of secondary follicle maturation among twin animals this delay was only transient for by one year of age a similar secondary/primary ratio was observed for singles and twins. Hence the difference in wool weight may be attributable to lower body size or other factors lowering the output per follicle (Ryder and Stephenson, 1968).

Estimates of the effect of age at weaning are in agreement with estimates of age shorn effect of other authors. In this study the range was 0.005 - 0.02 kg/day. Hight and Jury (1971) obtained estimates of 0.009 and 0.014 kg/day, while Baker *et al.* (1974) estimated 0.1 kg/day. Tait (1983) fitted date of birth and calculated a -0.01 kg/day effect.

Year and stocking rate x year interactions were significant and contributed 30.7% and 5.2% of the total variability respectively for GFW and 26.4% and 3.8% for CFW.

Ewe Fleece Weight

As with the hoggets, most of variation in fleece weight is due to stocking rate, the CSR animals producing significantly more than the HSR animals.

Langlands *et al*. (1984) found that clean wool production of Merino ewes grazed at the high stocking rate was consistently lower than that of sheep at the low stocking rate.

Age and age x birthyear interaction were also highly significant. Although the 2 year old ewes appear to have the highest fleece weight the earlier shearing of hoggets and hence longer period of growth of the 2 year old fleece would have contributed to this. Hight, Atkinson, Sumner and Bigham (1976) reported that in Romney and Border Leicester x Romney ewes GFW reached maxima at 3 years and declined thereafter. Bigham, Sumner and Dalton (1978) confirmed this trend for a variety of breeds, after correcting for shearing interval in the 2-year-olds.

Although the effect was not consistent, barren ewes produced about 0.15 kg more greasy wool than those which reared lambs. This is similar to Lewer *et al*. (1983) who reported barren Perendale ewes produced about 0.1 kg more wool than those with singles and 0.2 kg more than those with twin lambs. The effect of reproductive status on clean fleece weight is less clear, although barren ewes had higher CFW in half the sire groups. Langlands *et al*. (1984) found that rearing a lamb reduced Merino wool production by 0.15 and 0.09 kg at the high and low stocking rates respectively.

Table 4.2.5: Least squares estimates and standard errors of environmental effects for ewe greasy fleece weight (kg)

Factor	Sire group 1 1966/1967	Sire group 2 1968/1969	Sire group 3 1970/1971	Sire group 4 1972/1973	Sire group 5 1974/1975	Sire group 6 1977/1978
Age of ewe						
2 years[1]	0.77±0.03	0.52±0.04	0.66±0.04	0.29±0.04	0.81±0.04	0.44±0.04
3 years	0.28±0.03	0.02±0.03	0.20±0.04	-0.11±0.04	0.01±0.04	-0.03±0.04
4 years	-0.27±0.03	-0.08±0.03	-0.41±0.04	0.15±0.04	-0.48±0.04	-0.10±0.04
5 years	-0.78±0.03	-0.46±0.03	-0.45±0.04	-0.33±0.04	-0.35±0.04	-0.38±0.04
No of Lambs Born/Weaned						
0 0	0.16±0.16	0.01±0.08	-0.05±0.08	0.04±0.07	0.14±0.06	0.16±0.05
1 0	-0.09±0.16	-0.05±0.08	-0.14±0.08	-0.03±0.10	0.10±0.07	0.01±0.08
1 1	-0.06±0.15	0.02±0.07	-0.19±0.07	0.04±0.05	0.04±0.04	0.00±0.04
2 0	0.01±0.67	0.12±0.16	0.16±0.27	-0.26±0.19	-0.19±0.12	-0.08±0.11
2 1	-0.03±0.13	-0.17±0.25	0.16±0.14	0.23±0.09	0.05±0.09	-0.01±0.07
2 2	0.02±0.17	0.06±0.09	-0.06±0.10	-0.03±0.07	-0.03±0.06	-0.08±0.05
Stocking Rate						
Control	0.52±0.15	0.56±0.06	0.28±0.07	0.11±0.08	0.16±0.05	0.20±0.03
High	-0.52±0.15	-0.56±0.06	-0.28±0.07	-0.11±0.08	-0.16±0.05	-0.20±0.03
Rearing Rank						
Single	-0.01±0.02	0.00±0.02	0.04±0.05	0.01±0.07	-0.02±0.04	0.13±0.02
Twin	0.01±0.02	-0.00±0.02	-0.04±0.05	-0.01±0.07	0.02±0.04	-0.13±0.02
General mean	3.71±0.15	3.59±0.06	3.84±0.07	4.06±0.08	4.40±0.05	4.44±0.03

[1] represents 13 months wool growth

Table 4.2.5: (continued) Least squares estimates and standard errors of environmental effects for ewe clean fleece weight (kg)

Factor	Sire group 1 1966/1967	Sire group 2 1968/1969	Sire group 3 1970/1971	Sire group 4 1972/1973	Sire group 5 1974/1975	Sire group 6 1977/1989
Age of ewe						
2 years[1]	0.64±0.03	0.38±0.03	0.62±0.03	0.15±0.04	0.77±0.04	0.41±0.03
3 years	0.20±0.03	0.08±0.03	0.15±0.03	-0.08±0.04	-0.44±0.04	-0.11±0.03
4 years	-0.24±0.03	-0.04±0.03	-0.38±0.03	0.20±0.04	-0.44±0.04	-0.11±0.03
5 years	-0.60±0.03	-0.04±0.03	-0.38±0.03	-0.27±0.04	-0.37±0.05	-0.36±0.03
No of lambs Born/weaned						
0 0	0.08±0.14	0.07±0.06	0.00±0.07	0.06±0.07	0.27±0.12	0.17±0.05
1 0	-0.01±0.14	-0.04±0.07	-0.10±0.07	0.02±0.09	0.23±0.13	0.01±0.07
1 1	-0.03±0.13	-0.01±0.05	-0.17±0.06	-0.02±0.05	0.05±0.11	-0.01±0.04
2 0	0.02±0.59	0.11±0.13	0.16±0.22	-0.22±0.19	-0.49±0.53	0.01±0.12
2 1	0.01±0.12	-0.12±0.20	0.11±0.11	0.25±0.09	0.05±0.14	-0.06±0.06
2 2	-0.07±0.15	-0.00±0.08	-0.00±0.09	-0.08±0.07	-0.11±0.12	-0.12±0.04
Stocking Rate						
Control	0.40±0.13	0.40±0.05	0.22±0.06	0.18±0.08	0.21±0.12	0.18±0.03
High	-0.40±0.13	-0.40±0.05	-0.22±0.06	-0.18±0.08	-0.21±0.12	-0.18±0.03
Rearing Rank						
Single	-0.02±0.02	-0.00±0.02	0.03±0.04	0.07±0.07	0.01±0.05	0.08±0.02
Twin	0.02±0.02	0.00±0.02	-0.03±0.04	-0.07±0.07	-0.01±0.05	-0.08±0.02
General Mean	2.74±0.13	2.72±0.05	2.90±0.06	2.99±0.08	3.33±0.11	3.35±0.03

4.1.2.3 Clean Scoured Yield

Hogget Clean Scoured Yield

The model used controlled a low proportion (17.9%) of the total variance in clean scoured yield of hoggets. The average yield was consistently about 75% across all sire groups (Table 4.2.6).

The stocking rate effects controlled only 0.7% of the variation. Estimated stocking rate effects differ for the various sire group periods. Sumner (1969) reported higher means for Y in the CSR animals group. Morley (1956) also observed higher Y in the 'High Plane' animals as compared with 'Low Plane' animals, though the difference was not significant.

Year effects controlled 2.2% of the variation, with year x stocking rate interactions controlling 7.9%. These effects could be due to differences in rainfall and other climatic factors between years or differing degrees of contamination with mud or dirt between years and stocking rates.

Ewe Clean Scoured Yield

Table 4.2.7 shows that, as with hoggets, average fleece yield in ewes was consistent across sire groups, at about 75%.

Birth year was unimportant but age x birthyear interactions controlled 14% of the total variation. Age controlled 11% but estimated effects appeared inconsistent across sire group periods. 2-year-olds generally had the highest yield, with yield decreasing as age increased in most sire groups.

Table 4.2.6: Least squares estimates and standard errors of environmental effects for hogget clean scoured yield (%)

Factor	Sire group 1 1966/1967	Sire group 2 1968/1969	Sire group 3 1970/1971	Sire group 4 1972/1973	Sire group 5 1974/1975	Sire group 6 1977/1978	Sire group 7 1979/1980
Stocking Rate							
Control	-0.30±0.25	-0.80±0.27	-0.20±0.33	1.24±0.37	0.48±0.43	-0.08±0.27	0.03±0.18
High	0.30±0.25	0.80±0.27	0.20±0.33	-1.24±0.37	-0.48±0.43	0.08±0.27	-0.03±0.18
Rearing Rank							
Single	0.28±0.25	-0.21±0.26	-0.23±0.38	-0.22±0.54	-0.98±0.60	-0.22±0.28	-0.17±0.18
Twin	-0.28±0.25	0.21±0.26	0.23±0.38	0.22±0.54	0.98±0.60	0.22±0.28	0.17±0.18
Age weaned (%/day)	0.06±0.03	0.02±0.02	0.04±0.02	0.03±0.03	0.01±0.04	0.02±0.02	0.02±0.02
General Mean - corrected to average age at weaning	77.37±2.56	76.64±2.06	77.88±2.26	76.66±2.67	76.80±4.17	78.85±2.08	77.53±1.62

Table 4.2.7: Least squares estimates and standard errors of environmental effects for ewe clean scoured yield (%)

Factor	Sire group 1 1966/1967	Sire group 2 1968/1969	Sire group 3 1970/1971	Sire group 4 1972/1973	Sire group 5 1974/1975	Sire group 6 1977/1978
Age of ewes						
2 years	0.97±0.30	-0.24±0.31	3.33±0.25	-2.00±0.34	3.27±0.44	1.23±0.27
3 years	-0.38±0.30	2.00±0.29	0.33±0.25	-0.24±0.33	0.94±0.43	1.01±0.26
4 years	-0.66±0.30	0.67±0.30	-2.15±0.25	2.10±0.33	-1.45±0.43	-0.68±0.27
5 years	0.08±0.30	-2.43±0.29	-1.51±0.25	0.14±0.34	-2.76±0.44	-1.55±0.27
No of Lambs Born/Weaned						
0 0	2.19±0.125	0.45±0.66	0.93±0.54	1.58±0.60	4.01±1.21	2.07±0.43
1 0	1.49±1.24	-0.14±0.68	-0.23±0.55	0.47±0.78	3.60±1.27	-0.29±0.58
1 1	0.90±1.21	-0.44±0.55	-0.72±0.45	-0.14±0.44	0.57±1.10	-0.30±0.32
2 0	-3.66±5.32	0.73±1.39	1.07±1.77	1.14±1.54	-7.99±5.13	1.64±0.93
2 1	-0.38±1.12	0.72±2.07	-0.22±0.92	-0.38±0.77	0.21±1.36	-1.21±0.51
2 2	-0.54±1.35	-1.32±0.79	-0.82±0.70	-2.68±0.60	-0.40±1.21	-1.91±0.35
Stocking Rate						
Control	0.55±1.21	-0.80±0.51	0.26±0.46	1.99±0.68	2.66±1.14	0.59±0.25
High	-0.55±1.21	0.80±0.51	-0.26±0.46	-1.99±0.68	-2.66±1.14	-0.59±0.25
Rearing Rank						
Single	-0.27±0.18	-0.16±0.19	0.02±0.30	1.66±0.61	-0.35±0.48	-0.23±0.17
Twin	0.27±0.18	0.16±0.19	-0.02±0.30	-1.66±0.61	0.35±0.48	0.23±0.17
General Mean	74.25±1.19	75.65±0.51	75.10±0.50	73.04±0.69	75.40±1.11	75.47±0.25

Stocking rate was important, with the control stocking rate having a significantly higher yield, except in sire group period 2. Stocking rate interactions were unimportant. Langlands *et al.* (1984) found no significant effects of stocking rate on yield, but they found yield increased with age of ewe to 5.2 years and then declined at the low stocking rate although this trend was not observed at the high stocking rate.

Reproductive status controlled 4.3% of the variation, with barren ewes having the highest yield. Langlands *et al.* (1984) however found yield was not significantly affected by whether a ewe reared a lamb.

4.1.2.4 Quality Number

Quality number is a subjective assessment of fineness based on crimp frequency and lustre with some influence of length and softness of handle (Wickham, 1971; Wickham and Bigham, 1973).

Hogget Quality Number

In the first five sire group periods, QN was higher in HSR sheep. Bublath (1969) and Chopra (1978) obtained similar results. Chopra (1978) noted that the softness of handle is closely related to the fineness of fibres and longer staples tend to be marked down in QN, probably in the belief that they must therefore be coarser. After the management change there is little difference between the stocking rates indicating QN is little affected by previous nutritional levels.

Table 4.2.8: Least squares estimates and standard errors of environmental effects for hogget quality number (units)

Factor	Sire group 1 1966/1967	Sire group 2 1968/1969	Sire group 3 1970/1971	Sire group 4 1972/1973	Sire group 5 1974/1975	Sire group 6 1977/1978	Sire group 7 1979/1980
Stocking rate							
Control	-0.17±0.10	-0.23±0.12	-0.51±0.14	-0.04±0.15	-0.14±0.16	0.16±0.11	0.06±0.11
High	0.17±0.10	0.23±0.12	0.51±0.14	0.04±0.15	0.14±0.16	0.16±0.11	-0.06±0.11
Rearing Rank							
Single	0.07±0.10	0.18±0.11	0.12±0.16	0.57±0.21	0.39±0.22	-0.05±0.12	-0.12±0.12
Twin	-0.07±0.10	-0.18±0.11	-0.12±0.16	-0.57±0.21	-0.39±0.22	0.05±0.12	0.12±0.12
Age weaned (units/day)	-0.01±0.01	-0.01±0.01	0.00±0.01	0.02±0.01	0.01±0.02	-0.02±0.01	-0.01±0.01
General Mean - corrected to average age at weaning	48.48±0.97	48.56±0.91	48.64±0.95	49.50±1.05	49.99±1.53	49.90±0.89	49.69±1.02

Table 4.2.9: Least squares estimates and standard errors of environmental effects for ewe quality number (units)

Factor	Sire group 1 1966/1967	Sire group 2 1968/1969	Sire group 3 1970/1971	Sire group 4 1972/1973	Sire group 5 1974/1975	Sire group 6 1977/1978
Age of Ewe						
2 years	0.18±0.12	0.10±0.10	-0.99±0.12	-0.30±0.12	0.48±0.14	0.24±0.12
3 years	0.39±0.12	-0.14±0.09	-0.56±0.12	0.51±0.12	-0.15±0.14	0.14±0.12
4 years	-0.14±0.12	-0.50±0.09	0.39±0.12	0.28±0.12	0.02±0.14	0.34±0.12
5 years	-0.44±0.12	0.54±0.09	1.16±0.12	-0.49±0.12	-0.36±0.14	-0.71±0.12
No of Lambs Born/Weaned						
0 0	0.09±0.51	0.12±0.20	0.10±0.25	-0.42±0.21	-0.37±0.39	0.08±0.19
1 0	0.14±0.51	0.18±0.21	0.20±0.25	0.43±0.28	-0.02±0.41	0.27±0.26
1 1	0.10±0.50	0.02±0.17	0.31±0.20	0.07±0.16	0.13±0.36	-0.03±0.14
2 0	-1.35±2.20	-0.43±0.43	0.09±0.81	-0.30±0.55	1.04±1.66	-0.43±0.42
2 1	0.73±0.47	0.77±0.64	-0.73±0.42	0.34±0.27	-0.23±0.44	0.14±0.23
2 2	0.29±0.56	-0.66±0.25	0.03±0.32	-0.14±0.21	-0.55±0.39	-0.03±0.16
Stocking Rate						
Control	-0.19±0.50	0.10±0.16	-0.40±0.21	-0.02±0.24	-0.13±0.37	-0.16±0.11
High	0.19±0.50	-0.10±0.16	0.40±0.21	0.02±0.24	0.13±0.37	0.16±0.11
Rearing Rank						
Single	0.24±0.07	0.13±0.06	-0.28±0.14	0.13±0.22	0.18±0.16	-0.01±0.08
Twin	-0.24±0.07	-0.13±0.06	0.28±0.14	-0.13±0.22	-0.18±0.16	0.01±0.08
General Mean	46.25±0.49	45.79±0.16	46.64±0.23	47.97±0.24	47.43±0.36	47.54±0.11

A large proportion of the variation in quality number was controlled by year. This may reflect the importance of temporary environmental effects such as management variations, season or similar factors. Chopra (1978) noted that part of the effect of year could be due to variations in the standards of different observers during the years under study. Year x stocking rate interactions were also important, controlling 2.9% of the variation.

Hoggets reared as singles had higher QN than those reared as twins before the management change. After 1976, when the hoggets were run together, the effect of rearing rank was reversed.

Ewe Quality Number

Average quality number of the ewes was lower than that of the hoggets 46-48, rather than 48-50.

Stocking rate controlled only 1.3% of the total variation, with the effect inconsistent across sire groups. Stocking rate interactions were also unimportant sources of variation. Sumner and Wickham (1969), in analyses of QN on ewes of this flock, reported that the fleeces were judged to be coarser at the high stocking rate. This was perhaps due to the wool grown at the high stocking rate being more lustrous than that grown at the low stocking rate (Chopra, 1978).

Age effects controlled 8.0% of the total variation but age differences were inconsistent across sire group periods. Lewer *et al*. (1983) found that 2 and 5 year old ewes were most affected by year effects. Younger and older sheep may be more sensitive to nutritional stress than those of intermediate ages. In this study stocking rate x age interaction effects were unimportant.

Age x birthyear interaction controlled 11.1% of the total variation in QN, indicating the importance of year-to-year variation.

4.1.2.5 Mean Fibre Diameter

Hogget Mean Fibre Diameter

Although HSR hoggets had lower MFD than CSR hoggets in the first two sire group periods, there were no significant differences between stocking rates in the other sire group periods. This was reflected in the pooled analyses with stocking rate controlling only 0.2% of the overall variation. In his study on the earlier hogget records in this flock Chopra (1978) suggested that MFD had decreased with the increased stocking rate but he had presented records from only two sire group periods, one in which the stocking rate effect was non-significant.

There is however, considerable evidence that MFD tends to decrease with increased stocking rate (Sumner and Wickham, 1969; Canon, 1972; Lipson and Bacon-Hall, 1974; White and McConchie, 1976).

Between year differences and year x stocking rate interactions were significant, contributing 4.0% and 5.0% of the total variation respectively.

Table 4.2.10: Least squares estimates and standard errors of environmental effects for hogget mean fibre diameter (μ)

Factor	Sire group 1 1966/1967	Sire group 2 1968/1969	Sire group 3 1970/1971	Sire group 4 1972/1973	Sire group 5 1974/1975	Sire group 6 1977/1978	Sire group 7 1979/1980
Stocking rate							
Control	0.56±0.17	0.22±0.15	-0.12±0.19		-0.18±0.22	-0.18±0.22	0.08±0.12
High	-0.56±0.17	-0.22±0.15	0.12±0.19		0.18±0.22	0.18±0.22	-0.08±0.12
Rearing Rank							
Single	0.16±0.17	-0.28±0.14	-0.03±0.23		0.18±0.32	-0.42±0.15	-0.34±0.12
Twin	-0.16±0.17	0.28±0.14	0.03±0.23		-0.18±0.32	0.42±0.15	0.34±0.12
Age weaned (μ/day)	0.08±0.02	0.03±0.01	0.05±0.01		0.08±0.02	0.06±0.01	0.02±0.01
General Mean - corrected to average age at weaning	35.55±1.71	33.22±1.13	34.78±1.34		33.44±2.21	34.01±1.13	32.95±1.04

Table 4.2.11: Least squares estimates and standard errors of environmental effects for ewe mean fibre diameter (μ)

Factor	Sire group 1 1966/1967	Sire group 2 1968/1969	Sire group 3 1970/1971	Sire group 4 1972/1973	Sire group 5 1974/1975	Sire group 6 1977/1978
Age of Ewe						
2 years	0.52±0.42	-0.31±0.17	0.71±0.16	-0.98±0.16	0.47±0.16	-0.47±0.16
3 years	-0.45±0.33	0.81±0.16	0.29±0.16	0.06±0.16	-0.28±0.15	0.56±0.16
4 years	0.24±0.18	0.67±0.16	-0.63±0.17	1.41±0.16	-0.35±0.15	0.25±0.16
5 years	-0.31±0.18	-1.17±0.16	-0.38±0.16	-0.49±0.16	0.16±0.16	-0.35±0.16
No of Lambs Born/Weaned						
0 0	-0.50±0.84	-0.34±0.36	-1.13±0.35	0.19±0.29	-0.06±0.25	0.54±0.24
1 0	-0.71±0.84	-0.02±0.37	-0.24±0.35	-0.18±0.39	0.03±0.28	-0.24±0.36
1 1	-0.66±0.83	0.12±0.30	-0.41±0.29	0.35±0.21	-0.27±0.17	-0.13±0.19
2 0	3.47±3.60	0.86±0.77	0.93±1.14	-1.01±0.75	-0.24±0.49	0.03±0.49
2 1	-0.42±0.69	-1.10±1.13	0.93±0.60	0.33±0.37	0.08±0.35	-0.19±0.30
2 2	-1.18±1.00	0.50±0.43	-0.09±0.46	0.32±0.28	0.46±0.22	-0.01±0.20
Stocking Rate						
Control	0.79±0.84	1.42±0.28	0.66±0.30	0.66±0.31	0.09±0.18	0.26±0.14
High	-0.79±0.84	-1.42±0.28	-0.66±0.30	-0.66±0.31	-0.09±0.18	-0.26±0.14
Rearing Rank						
Single	-0.06±0.11	-0.59±0.10	-0.05±0.20	0.25±0.27	-0.47±0.16	-0.08±0.10
Twin	0.06±0.11	0.59±0.10	0.05±0.20	-0.25±0.27	0.47±0.16	0.08±0.10
General Mean	37.37±0.82	36.40±0.28	36.99±0.32	35.82±0.31	37.95±0.18	37.49±0.14

Ewe Mean Fibre Diameter

Stocking rate controlled the largest amount of variation in ewe MFD, with the CSR having a higher MFD for all sire group periods although the difference decreased considerably in the last two sire group periods where the HSR stocking intensity was reduced. Henderson (1953) and Schinckel and Short (1961) showed that the level of nutrition of the young lamb can affect MFD at maturity but the nature of the effect is not simple. They found that nutritional deprivation during the prenatal phase was associated with fewer, coarser and longer fibres, whereas low nutritional levels during early post-natal life caused finer fibres to be produced at maturity.

Although reproductive status of the ewes controlled 2.3% of the variation, table 4.2.11 shows that the effects were inconsistent across sire group periods. However, the birth year x number lambs born and weaned interaction controlled 3.0% of the variation which suggests that the effects of reproductive status vary with year. However, there were small numbers in some subclasses.

Birthyear, age and age x birthyear interaction were important effects. Although Lewer *et al*. (1983) found MFD to be greatest at 4 years of age and the same trend was reported by Ross (1965) for a sample of Romney fleeces, in this study results were inconsistent, probably due to the effects of age x birthyear interactions and the confounding with record year.

MFD was one of the few traits in which rearing rank of the ewe controlled a significant part of the variation (1.7%) and the birthyear x rearing rank interaction was important. Ewes reared as twins tended to have a higher MFD. Lewer *et al.* (1983) also found that twin-reared ewes had a higher MFD than single ewes. They suggested that low prenatal nutrition caused by competition between lambs may explain the differences they observed.

4.1.2.6 Staple Length

Hogget Staple Length

In the pooled analyses the only factors of importance in the model fitted to hogget SL were year x stocking rate interactions and sire effects, with sire x year interactions approaching importance.

Hoggets from the HSR had lower SL than hoggets on the CSR, as was found by Chopra (1978). Staple length has been observed by various workers to decrease with increased stocking rate (Sumner, 1969; Canon, 1972; White and McConchie, 1976). As noted by Chopra (1978), between stocking rates SL differed more markedly during the sire group 2 period which were summer drought years. After the management change in 1976 when the hoggets were run together there was no difference in the SL of the hoggets from the two stocking rates.

Although Chopra (1978) found that hoggets reared as singles had slighter shorter SL than those reared as twins, the effect was not significant in this study.

Ewe Staple Length

As with fleece weight, 2-year-old ewes had 13 months wool growth but even allowing for that they still had the greatest staple length. Langlands *et al.* (1984) in Merinos, Hight *et al.*(1976) in Romneys and Bigham *et al.* (1973), Lewer *et al* . (1983) in Perendales reported that staple length reached a maximum in 3 year old ewes.

Staple length was lower in the high stocking rate ewes, however this effect was reduced once the high stocking rate was lowered. Although reproductive status was non

Table 4.2.12: Least squares estimates and standard errors of environmental effects for hogget staple length (cm)

Factor	Sire group 1 1966/1967	Sire group 2 1968/1969	Sire group 3 1970/1971	Sire group 4 1972/1973	Sire group 5 1974/1975	Sire group 6 1977/1978	Sire group 7 1979/1980
Stocking Rate							
Control	0.31±0.10	0.89±0.11	0.31±0.14	0.39±0.13	-0.04±0.14	-0.17±0.09	-0.06±0.08
High	-0.31±0.10	-0.89±0.11	-0.31±0.14	-0.39±0.13	0.04±0.14	0.17±0.09	0.06±0.08
Rearing Rank							
Single	-0.14±0.10	0.49±0.12	-0.10±0.16	-0.42±0.19	-0.52±0.20	-0.34±0.09	-0.20±0.09
Twin	0.14±0.10	-0.49±0.12	0.10±0.16	0.42±0.19	0.52±0.20	0.34±0.09	0.20±0.09
Age weaned (cm/day)	0.03±0.01	0.01±0.01	-0.00±0.01	0.01±0.01	0.04±0.01	0.05±0.008	-0.000±0.008
General Mean - corrected to average age at weaning	14.64±1.02	13.77±0.96	13.63±0.94	13.33±0.92	14.73±1.40	13.25±0.67	14.79±0.76

Table 4.2.13: Least squares estimates and standard errors of environmental effects for ewe staple length (cm)

Factor	Sire group 1 1966/1967	Sire group 2 1968/1969	Sire group 3 1970/1971	Sire group 4 1972/1973	Sire group 5 1974/1975	Sire group 6 1977/1978
Age of Ewe						
2 years	3.15±0.11	2.24±0.12	2.61±0.13	1.29±0.12	2.72±0.12	2.15±0.11
3 years	0.71±0.11	-0.16±0.11	-0.26±0.13	0.11±0.12	-0.15±0.11	0.18±0.10
4 years	-1.14±0.11	-0.40±0.11	-1.34±0.13	-0.23±0.12	-1.04±0.11	-0.61±0.10
5 years	-2.72±0.11	-1.68±0.11	-1.02±0.13	-1.17±0.12	-1.53±0.12	-1.72±0.10
No of Lambs Born/Weaned						
0 0	1.29±0.52	0.23±0.25	0.38±0.28	0.42±0.21	0.68±0.18	0.26±0.16
1 0	0.44±0.52	0.17±0.26	0.01±0.28	-0.06±0.29	0.37±0.21	-0.30±0.23
1 1	0.79±0.51	0.15±0.21	0.02±0.23	-0.13±0.16	0.10±0.13	-0.10±0.12
2 0	-2.89±2.22	-0.36±0.54	-1.05±0.91	-0.12±0.56	-0.70±0.36	0.52±0.32
2 1	-0.36±0.43	-0.59±0.30	0.63±0.47	0.11±0.28	-0.35±0.26	-0.04±0.20
2 2	0.73±0.57	0.39±0.31	0.01±0.36	-0.46±0.21	-0.10±0.17	-0.34±0.13
Stocking rate						
Control	1.46±0.51	0.53±0.20	0.60±0.24	0.00±0.23	0.07±0.14	0.38±0.09
High	-1.46±0.51	-0.53±0.20	-0.60±0.24	-0.00±0.23	-0.07±0.14	-0.38±0.09
Rearing Rank						
Single	-0.26±0.07	-0.18±0.07	0.22±0.16	-0.04±0.20	-0.44±0.12	0.03±0.06
Twin	0.26±0.07	0.18±0.07	-0.22±0.16	0.04±0.20	0.44±0.12	-0.03±0.06
General Mean	14.41±0.51	14.68±0.20	15.25±0.25	15.98±0.23	16.90±0.14	16.04±0.09

significant, stocking rate x reproductive status interactions were important. This agreed with work done by Langlands *et al.* (1984) who reported that staple length was reduced at the high stocking rate, the mean difference between stocking rates being 0.5 and 0.3 cm for ewes which did and did not rear a lamb respectively.

4.1.2.7 Total Crimp Number

Hogget Total Crimp Number

Table 4.2.14 indicated that over the first four sire groups, prior to management changes, total crimp number was increasing, although the change was not significant.

Stocking rate and year x stocking rate interactions were unimportant. Least squares estimates of stocking rate effects reflect this with the standard errors generally greater than estimated stocking rate effects.

Age weaned as a lamb appeared to have a significant effect, controlling 6.9% of the variation. This effect was difficult to interpret, suggesting a possible link to other factors not included in the model such as liveweight or growth rate or confounding of factors.

Although found to be non-significant by Chopra (1978), in this study rearing rank of the hoggets controlled a large proportion of the total variation (9.1%). Initially hoggets reared as singles had a higher total crimp number than those reared as twins, except in sire group 3 where no significant differences was found. After the hoggets were run together no significant differences were found between the rearing ranks.

Table 4.2.14: Least squares estimates and standard errors of environmental effects for hogget total crimp number

Factor	Sire group 1 1966/1967	Sire group 2 1968/1969	Sire group 3 1970/1971	Sire group 4 1972/1973	Sire group 5 1974/1975	Sire group 6 1977/1978	Sire group 7 1979/1980
Stocking rate							
Control	-0.01±0.16	0.03±0.19	-0.58±0.23	0.26±0.26	-0.20±0.29	0.19±0.20	-0.10±0.16
High	0.01±0.16	-0.03±0.19	0.58±0.23	-0.26±0.26	0.20±0.29	-0.19±0.20	0.10±0.16
Rearing Rank							
Single	0.11±0.16	0.25±0.18	-0.22±0.25	0.45±0.38	0.62±0.41	-0.13±0.21	-0.05±0.16
Twin	-0.11±0.16	-0.25±0.18	0.22±0.25	-0.45±0.38	-0.62±0.41	0.13±0.21	0.05±0.16
Age weaned (TCN/day)	-0.00±0.02	-0.005±0.02	0.001±0.02	0.03±0.02	0.02±0.03	-0.03±0.02	-0.03±0.02
General Mean - corrected to average age at weaning	15.32±1.58	15.54±1.45	16.17±1.59	19.02±1.89	18.05±2.87	19.65±1.55	20.92±1.45

Table 4.2.15: Least squares estimates and standard errors of environmental effects for ewe total crimp number

Factor	Sire group 1 1966/1967	Sire group 2 1968/1969	Sire group 3 1970/1971	Sire Group 4 1972/1973	Sire group 5 1974/1975	Sire group 6 1977/1978
Age of Ewe						
2 years	2.80±0.10	1.68±0.17	4.12±0.18	2.14±0.19	2.40±0.16	3.33±0.18
3 years	0.10±1.71	-0.01±0.17	-0.39±0.18	-0.39±0.18	-0.61±0.16	-0.10±0.18
4 years	-1.49±0.17	0.04±0.17	-1.92±0.18	-0.77±0.18	-0.77±0.16	-0.49±0.18
5 years	-1.41±0.17	-1.71±0.17	-1.81±0.18	-0.98±0.19	-1.01±0.16	-2.75±0.18
No of lambs Born/Weaned						
0 0	0.76±0.79	-0.22±0.37	0.10±0.39	-0.19±0.34	0.54±0.26	0.21±0.27
1 0	0.56±0.79	0.07±0.38	-0.20±0.39	0.46±0.46	0.09±0.29	-0.20±0.40
1 1	0.45±0.77	-0.45±0.31	0.13±0.32	0.11±0.25	0.21±0.18	0.26±0.21
2 0	-2.40±3.34	0.00±0.79	0.75±1.27	-0.72±0.88	-0.11±0.50	0.51±0.55
2 1	-0.14±0.64	1.59±1.18	-0.50±0.66	0.59±0.43	0.09±0.36	-0.48±0.34
2 2	0.78±0.85	-1.00±0.45	-0.29±0.50	-0.24±0.33	-0.82±0.23	-0.31±0.23
Stocking Rate						
Control	0.73±0.77	0.34±0.29	-0.17±0.33	0.18±0.37	0.03±0.19	0.02±0.16
High	-0.73±0.77	-0.34±0.29	0.17±0.33	-0.18±0.37	-0.03±0.19	-0.02±0.16
Rearing Rank						
Single	-0.04±0.10	0.13±0.11	-0.24±0.22	0.20±0.31	0.38±0.16	0.12±0.11
Twin	0.04±0.10	-0.13±0.11	0.24±0.22	-0.20±0.31	-0.38±0.16	-0.12±0.1
General Mean	13.45±0.76	14.53±0.29	15.06±0.36	15.54±0.37	16.06±0.19	17.16±0.16

Ewe Total Crimp Number

Table 4.2.15 indicated that, as for hoggets, the mean for ewe TCN was increasing, from 13.45 ± 0.76 in the first sire group period to 15.54 ± 0.37 in sire group period 4 and to 17.16 ± 0.16 in sire group period 6.

Stocking rate and stocking rate interactions were non-significant, as was birthyear and reproductive status.

The factors controlling most of the variation were age (30.9%) and age x birthyear interactions (8.8%). Although 2-year-old ewes had the highest total crimp number it represented a longer growth period. At the other age levels total crimp number decreased as age increased.

Chapman and Jackson (1972) and Jackson and Chapman (1975) studied irregularity of staple crimp, commonly known as 'doggy' wool or 'rough fleece', where the crimp frequency is markedly reduced. The staple crimp abnormality was associated with hyperplasia and cyst formation in the outer root sheaths of wool follicles (Chapman, Short and Hyland, 1960). Crimp abnormality increased with age i.e. a reduction in total crimp number occurred with age, as was found in this study.

4.1.2.8 Crimp Frequency

Hogget Crimp Frequency

Crimp frequency analyses results were very similar to those determined for total crimp number.

Stocking rate was not significant in the pooled analyses but table 4.2.17 indicated that the CSR hoggets had lower CF than HSR hoggets.

Table 4.2.16: Least squares estimates and standard errors of environmental effects for hogget crimp frequency (crimps per inch)

Factor	Sire group 1 1966/1967	Sire group 2 1968/1969	Sire group 3 1970/1971	Sire group 4 1972/1973	Sire group 5 1974/1975	Sire group 6 1977/1978	Sire group 7 1979/1980
Stocking Rate							
Control	-0.07 ±0.03	-0.18 ±0.04	-0.16 ±0.06	-0.05 ±0.07	-0.03 ±0.06	0.07 ±0.05	0.00 ±0.04
High	0.07 ±0.03	0.18 ±0.04	0.16 ±0.06	0.05 ±0.07	0.03 ±0.06	-0.07 ±0.05	-0.00 ±0.04
Rearing Rank							
Single	0.03 ±0.03	0.09 ±0.04	0.02 ±0.07	0.21 ±0.11	0.21 ±0.09	0.08 ±0.05	0.04 ±0.04
Twin	-0.03 ±0.03	-0.09 ±0.04	-0.02 ±0.07	-0.21 ±0.11	-0.21 ±0.09	-0.08 ±0.05	-0.04 ±0.04
Age Weaned (cr/"/day)	-0.004±0.004	-0.003±0.004	0.001±0.005	0.002±0.006	-0.006±0.006	-0.010±0.005	-0.006±0.004
General Mean - corrected to average age at weaning	2.73 ±0.35	2.91 ±0.32	3.05 ±0.44	3.59±0.53	3.10 ±0.63	3.79 ±0.40	3.59 ±0.34

Table 4.2.17: Least squares estimates and standard errors of environmental effects for ewe crimp frequency (crimps per inch)

Factor	Sire group 1 1966/1967	Sire group 2 1968/1969	Sire group 3 1970/1971	Sire group 4 1972/1973	Sire group 5 1974/1975	Sire group 6 1977/1978
Age of Ewe						
2 years	-0..01±0.03	-0.08±0.04	0.23±0.04	0.13±0.04	-0.05±0.03	0.15±0.04
3 years	-0.11±0.03	0.01±0.04	-0.01±0.04	-0.08±0.04	-0.07±0.03	-0.04±0.04
4 years	-0.10±0.03	0.08±0.04	-0.08±0.04	-0.09±0.04	0.04±0.03	0.04±0.04
5 years	0.22±0.03	-0.01±0.04	-0.14±0.04	0.05±0.04	0.08±0.03	-0.16±0.04
No of Lambs Born/Weaned						
0 0	-0.11±0.16	-0.10±0.08	-0.05±0.08	-0.09±0.07	-0.02±0.05	-0.01±0.05
1 0	0.01±0.16	-0.02±0.08	-0.03±0.08	0.09±0.09	-0.05±0.06	0.01±0.08
1 1	-0.09±0.15	-0.09±0.07	0.02±0.06	0.04±0.05	0.01±0.03	0.06±0.04
2 0	0.18±0.67	0.02±0.17	0.34±0.26	-0.13±0.17	0.11±0.10	0.03±0.11
2 1	0.06±0.13	0.40±0.25	0.17±0.13	0.05±0.08	0.07±0.07	-0.09±0.07
2 2	-0.04±0.17	-0.21±0.10	-0.10±0.10	0.04±0.06	-0.12±0.04	0.01±0.05
Stocking Rate						
Control	-0.15±0.15	-0.03±0.06	-0.12±0.07	0.04±0.07	-0.02±0.04	-0.05±0.03
High	0.15±0.15	0.03±0.06	0.12±0.07	-0.04±0.07	0.02±0.04	0.05±0.03
Rearing Rank						
Single	-0.04±0.02	0.06±0.02	-0.08±0.04	0.04±0.06	0.12±0.03	0.02±0.02
Twin	0.04±0.02	-0.06±0.02	0.08±0.04	-0.04±0.06	-0.12±0.03	-0.02±0.02
General Mean	2.47±0.15	2.55±0.06	2.54±0.07	2.50±0.07	2.46±0.04	2.74±0.03

A tendency for CF to increase with increased stocking rate was also noted by Sumner (1969). An increase in fibre length caused by nutrition could result in a decrease of CF, if crimp is a periodic function of time (Chopra, 1978). Robards *et al*. (1974) studied the differences in intake of food on crimp frequency and observed no significant effect.

Age weaned was again significant in the pooled analyses but the least squares estimates and standard errors suggest that the regression coefficients do not differ significantly from zero.

Rearing rank controlled the same amount of variation and followed the same trend as for total crimp number.

Ewe Crimp Frequency

Stocking rate was not significant, controlling only 1.8% of the total variation in the pooled analyses for this trait. As for hoggets, estimates of ewe CF effects showed that CSR ewes tended to have a lower CF than ewes from the HSR. Since total crimp number was consistent across stocking rates, this effect was due to the CSR ewes having longer SL.

As with TCN, stocking rate x birthyear interactions controlled 2.0% of the total variation.

Age x birthyear interactions controlled the largest amount of variation, 5%, with age x birthyear x stocking rate interactions controlling a further 1.5%. This could have resulted from the differences in climatic conditions, such as rainfall in particular, during the years, inaccuracies of measurements and technician variation (Chopra, 1978).

Wickham and Bigham (1973) suggested that the staple crimp can be affected by disorientation of crimp-waves of individual fibres which results from several environmental conditions such as weathering and brushing of fleece against objects.

Age effects were important but variable, the 2 year old and 5 year old ewes tended to have higher CF. In Merinos and Polwarths Mullaney *et al* . (1970) found that crimps per inch was highest at age three with a continued decline from 3 to 8 years.

Although reproductive status was unimportant, both the interactions with stocking rate and birth year were significant.

4.1.2.9 Staple Strength

Hogget Staple Strength

As table 4.2.18 indicated staple strength was not measured in hoggets prior to the management change except in sire group period 3. Fleeces can vary in staple strength from 0 to 90 N/Ktex. The mean hogget staple strength in this study ranged from 15.66 ± 5.24 to 27.64 ± 5.24 N/Ktex as compared to 32.6 ± 0.13 to 38.4 ± 1.1 N/Ktex for Romney ewe hoggets in the review by Bigham *et al*. (1983).

The pooled analyses indicated that year, stocking rate, year x stocking interactions and sire were important sources of variation. However the large standard errors associated with fixed effect estimates meant most were not significantly different from zero and no trends could be observed. Inverse relationships between pasture allowance and the incidence of fleece tenderness have been

Table 4.2.18: Least squares estimates and standard errors of environmental effects for hogget staple strength (N/ktex)

Factor	Sire group 1 1966/1967	Sire group 2 1968/1969	Sire group 3 1970/1971	Sire group 4 1972/1973	Sire group 5 1975/1975	Sire group 6 1977/1978	Sire group 7 1979/1980
Stocking Rate							
Control			0.32±0.74		0.19±0.53	-0.42±0.47	-1.11±0.58
High			-0.32±0.74		-0.19±0.53	0.42±0.47	1.11±0.58
Rearing Rank							
Single			0.67±0.88		-0.62±0.75	-0.50±0.49	0.00±0.59
Twin			-0.67±0.88		0.62±0.75	0.50±0.49	-0.00±0.59
Age weaned (N/ktex/day)			-0.08±0.05		0.07±0.05	0.12±0.04	-0.01±0.06
General Mean - corrected to average age at weaning			23.25±5.10		15.66±5.24	21.40±3.64	27.64±5.24

Table 4.2.19: Least squares estimates and standard errors of environmental effects for ewe staple strength (N/ktex)

Factor	Sire group 1 1966/1967	Sire group 2 1968/1969	Sire group 3 1970/1971	Sire group 4 1972/1973	Sire group 5 1974/1975	Sire group 6 1977/1978
Age of Ewe						
2 years	NA	-6.84±1.04	0.14±0.42	-3.96±0.43	-2.35±0.51	2.38±0.45
3 years	0.56±0.60	6.46±0.79	2.45±0.42	0.94±0.42	0.72±0.50	-0.82±0.44
4 years	2.20±0.47	0.50±0.47	-1.49±0.42	0.67±0.42	1.98±0.51	-0.12±0.44
5 years	-2.76±0.47	-0.13±0.46	-1.11±0.42	2.35±0.44	-0.35±0.51	-1.44±0.44
No of Lambs Born/Weaned						
0 0	5.42±2.82	2.70±0.98	5.48±0.90	4.79±0.80	3.15±0.81	5.94±0.68
1 0	4.09±2.81	0.09±0.97	-0.13±0.91	-1.05±1.07	2.48±0.93	-1.28±0.99
1 1	4.82±2.78	0.08±0.79	1.53±0.75	2.69±0.62	0.63±0.56	2.00±0.51
2 0	-15.24±11.91	-1.28±2.17	-4.21±2.93	-2.17±2.30	-3.04±1.59	-2.89±1.35
2 1	-0.99±2.13	0.81±2.82	-0.75±1.53	-2.02±1.03	-1.13±1.17	-1.92±0.84
2 2	1.89±3.28	-0.76±1.20	-1.93±1.20	-2.24±0.78	-2.09±0.74	-1.85±0.57
Stocking Rate						
Control	3.73±2.83	3.64±0.76	3.22±0.77	0.78±0.86	0.76±0.60	4.36±0.40
High	-3.73±2.83	-3.64±0.76	-3.22±0.77	-0.78±0.86	-0.76±0.60	-4.36±0.40
Rearing Rank						
Single	0.17±0.34	0.48±0.28	0.00±0.51	-0.07±0.73	-0.90±0.51	-0.07±0.27
Twin	-0.17±0.34	-0.48±0.28	-0.00±0.51	0.07±0.73	0.90±0.51	0.07±0.27
General Mean	10.04±2.78	12.11±0.76	13.30±0.82	14.26±0.87	18.47±0.60	13.81±0.40

demonstrated for both hoggets and mixed-age ewes (Bigham *et al.*, 1983).

Ewe Staple Strength

Stocking rate was the largest source of variation in the ewe staple strength model, with HSR ewes having a lower staple strength than CSR ewes. Initial studies on this flock (Sumner and Wickham, 1969) indicated a marked and more prolonged winter and early spring depression of wool growth on the intensively grazed area which was associated with a greater thinning of the wool fibres. They also noted there was a tendency for the wool from the intensive sub-flock to be slightly more tender (lower tensile strength), although this was only a subjective assessment.

Ewe SST was consistently lower than hogget SST estimates. Bigham *et al*. (1983) noted whilst this may be partly due to the hoggets being preferentially fed, hoggets have less seasonal variation in fibre diameter than older ewes. 2 year old ewes had the lowest SST in general, with 3 or 4 year olds having the highest. In Bigham *et al.* (1983) two-tooth ewes consistently showed more fleece tenderness than older ewes which were generally similar. They suggested this difference may possibly be explained where two-tooth ewes are actively growing and the demands of pregnancy reduce the amount of nutrients available for wool growth.

Stocking rate x age interactions were significant. The greater decline in SST in older ewes on the HSR was possibly associated with teeth wear and other stress factors having a greater effect in the HSR.

Birthyear and age x birthyear interactions controlled 2.2% and 12.0% of the total variation respectively, indicating the importance of year-to-year variation on ewe staple strength.

Barren ewes had the highest SST, with SST declining as the number of lambs born and reared increased. Although the small subclass number means that the effect of a ewe having had twins and lost both had a high standard error, this category had the lowest SST. This may reflect the poor condition of the ewe which lead to both effects. Similar effects of pregnancy and lactation were reported by Bigham *et al*. (1983).

The significant interaction of stocking rate x reproductive status indicated that this effect was different in the control and high stocking rates. As expected the effect of reproductive status led to a greater reduction in SST in the HSR than in the CSR as number of lambs born and reared increased.

4.1.2.10 Character Grade

Character is an assessment based on staple crimp clarity and evenness, staple formation, blockiness of the staple tip and freedom from medullation (Wickham and Bigham, 1973).

Hogget Character Grade

As with most of the assessed traits the model described less than 20% of the total variation.

Table 4.2.20: Least squares estimates and standard errors of environmental effects for hogget character grade

Factor	Sire group 1 1966/1967	Sire group 2 1968/1969	Sire group 3 1970/1971	Sire group 4 1972/1973	Sire group 5 1974/1975	Sire group 6 1977/1978	Sire group 7 1979/1980
Stocking Rate							
Control	0.02 ±0.06	0.16 ±0.06	-0.10 ±0.06	0.31 ±0.08	0.05 ±0.07	0.00 ±0.05	0.05 ±0.04
High	-0.02 ±0.06	-0.16 ±0.06	0.10 ±0.06	-0.31 ±0.08	-0.05 ±0.07	-0.00 ±0.05	-0.05 ±0.04
Rearing Rank							
Single	0.04 ±0.06	0.23 ±0.06	0.05 ±0.07	-0.08 ±0.11	0.14 ±0.10	-0.06 ±0.05	0.04 ±0.04
Twin	-0.04 ±0.06	-0.23 ±0.06	-0.05 ±0.07	0.08 ±0.11	-0.14 ±0.10	0.06 ±0.05	-0.04 ±0.04
Age weaned (Units/day)	0.009±0.007	-0.003±0.006	0.004±0.004	0.003±0.006	-0.007±0.008	-0.004±0.004	0.004±0.004
General Mean - corrected to average age at weaning	5.00 ±0.62	5.20 ±0.48	5.53 ±0.39	5.70 ±0.55	5.28 ±0.73	5.15 ±0.37	5.24 ±0.33

Table 4.2.21: Least squares estimates and standard errors of environmental effects for ewe character grade

Factor	Sire group 1 1966/1967	Sire group 2 1968/1969	Sire group 3 1970/1971	Sire group 4 1972/1973	Sire group 5 1974/1975	Sire group 6 1977/1978
Age of Ewe						
2 years	-0.10±0.05	0.65±0.05	0.52±0.06	0.00±0.05	0.39±0.05	-0.05±0.05
3 years	0.11±0.05	0.30±0.05	-0.08±0.06	0.05±0.05	0.19±0.05	-0.06±0.05
4 years	0.29±0.05	0.08±0.05	-0.53±0.06	0.18±0.05	-0.14±0.05	-0.01±0.05
5 years	-0.29±0.05	-1.03±0.05	0.09±0.06	-0.23±0.05	-0.45±0.05	0.11±0.05
No of lambs Born/Weaned						
0 0	0.36±0.10	-0.04±0.10	0.18±0.10	0.03±0.09	0.16±0.07	0.00±0.07
1 0	0.22±0.11	0.00±0.10	-0.07±0.11	0.19±0.12	-0.03±0.09	-0.27±0.11
1 1	0.17±0.09	-0.19±0.07	0.04±0.08	0.08±0.07	0.03±0.05	-0.08±0.05
2 0	-1.03±0.33	0.21±0.22	0.11±0.26	-0.30±0.22	0.08±0.14	0.36±0.14
2 1	0.12±0.18	0.53±0.22	-0.11±0.17	0.22±0.11	0.04±0.10	0.03±0.09
2 2	0.16±0.11	-0.51±0.10	-0.14±0.11	-0.21±0.09	-0.28±0.07	-0.04±0.06
Stocking Rate						
Control	0.15±0.03	0.06±0.03	-0.08±0.04	-0.06±0.03	-0.02±0.03	-0.06±0.03
High	-0.15 ±0.03	-0.06±0.03	0.08±0.04	0.06±0.03	0.02±0.03	0.06±0.03
Rearing Rank						
Single	0.02±0.03	0.04±0.03	0.03±0.05	0.09±0.05	0.03±0.04	-0.03±0.03
Twin	-0.02±0.03	-0.04±0.03	-0.03±0.05	-0.09±0.05	-0.03±0.04	0.03±0.03
General Mean	4.78±0.08	5.10±0.07	4.60±0.07	4.78±0.07	4.80±0.05	4.88±0.04

Although Chopra found stocking rate to be highly significant, in this study it described only 0.1% of the total variance in the pooled analysis. However, stocking rate was a significant effect in 3 of the sire group period analyses. The least squares estimates in Table 4.2.20 indicated that CHG was lower in the HSR sheep. This agreed with results reported by Chopra (1978).

A stocking rate difference was found for sire group 7, even though the hoggets were then run together. Ryder and Stephenson (1968) pointed out that CHG seems to become worse only after prolonged and severe nutritional stress. In this study the nutritional stress on the lambs is not severe but there may have been some carry over effect on the HSR hoggets in sire group 7.

Year was the most important effect. This reflected the importance of climatic variation and as "wool character" may be interpreted differently by different observers, variations between observers may have contributed to year-to-year variation in this trait.

Year x stocking rate interactions were significant, indicating the different response of the stocking rates to the year-to-year variation in climate and other factors.

Ewe Character Grade

Stocking rate was also nonsignificant in the pooled analysis for ewe CHG. This contrasts with studies done by Bublath (1969), Sumner (1969), Langlands and Bennett (1973), Joyce *et al*. (1976) and Langlands *et al*. (1984), in which increased stocking levels led to poorer character, partly as a result of wool becoming more tippy.

CHG generally decreased steadily and significantly with age. Lewer *et al*. (1983) suggested this may have been caused by loss of crimp associated with the development of cysts on the follicles. This phenomenon (dogginess) increases with age (Chapman and Jackson, 1972).

Year effects accounted for 16% of the total variation in CHG. Year effects were also found to be significant by Langlands *et al*. (1984) and by Lewer (1978) who noted change in observers was probably the most important factor but climatic and nutritional differences were probably also involved.

Interactions were non significant except age x birth year x stocking rate. Most interactions were also found to be nonsignificant for character by Jackson and Roberts (1970).

4.1.2.11 Lustre Grade

Hogget Lustre Grade

Stocking rate, though significant in several of the separate sire group period analyses, controlled only 0.2% of the total variation in the pooled analysis. Estimated effects, in Table 4.2.22, were inconsistent. A similar result was obtained by Chopra (1978). From 1976, when the hoggets were run together, the stocking rate effects were reduced and did not differ significantly.

The year effect was significant. Variations in the standards of scoring by different observers was probably the major cause of this (Chopra, 1978). The year x stocking rate interaction was also significant.

Table 4.2.22: Least squares estimates and standard errors of environmental effects for hogget lustre grade

Factor	Sire group 1 1968/1967	Sire group 2 1968/1969	Sire group 3 1970/1971	Sire group 4 1972/1973	Sire group 5 1974/1975	Sire group 6 1977/1978	Sire group 7 1979/1980
Stocking Rate							
Control	0.09 ±0.06	-0.12 ±0.04	0.06 ±0.04	-0.07 ±0.07	-0.01 ±0.08	0.02 ±0.04	-0.03 ±0.03
High	-0.09 ±0.06	0.12 ±0.04	-0.06 ±0.04	0.07 ±0.07	0.01 ±0.08	-0.02 ±0.04	0.03 ±0.03
Rearing Rank							
Single	-0.03 ±0.06	0.09 ±0.04	0.04 ±0.05	-0.21 ±0.10	-0.15 ±0.11	-0.03 ±0.04	-0.05 ±0.03
Twin	0.03 ±0.06	-0.09 ±0.04	-0.04 ±0.05	0.21 ±0.10	0.15 ±0.11	0.03 ±0.04	0.05 ±0.03
Age weaned (units/day)	0.006±0.006	0.001±0.004	-0.003±0.003	-0.006±0.005	0.004±0.008	0.008±0.004	0.001±0.003
General Mean - corrected to average age at weaning	5.69 ±0.56	5.85 ±0.31	5.59 ±0.27	5.12 ±0.49	6.13 ±0.74	6.39 ±0.32	6.73 ±0.31

Table 4.2.23: Least squares estimates and standard errors of environmental effects for ewe lustre grade

Factor	Sire group 1 1966/1967	Sire group 2 1968/1969	Sire group 3 1970/1971	Sire group 4 1972/1973	Sire group 5 1974/1975	Sire group 6 1977/1978
Age of Ewe						
2 years	0.35±0.05	-0.16±0.05	0.19±0.06	-0.74±0.05	-0.64±0.04	0.29±0.04
3 years	0.05±0.05	0.08'0.05	-0.03±0.06	-0.32±0.05	0.02±0.04	0.25±0.04
4 years	-0.25±0.05	0.42±0.05	-0.18±0.06	0.25±0.05	0.17±0.04	0.03±0.04
5 years	-0.15±0.05	-0.33±0.05	0.02±0.06	0.81±0.05	0.45±0.04	-0.57±0.04
No of Lambs Born/Weaned						
0 0	0.31±0.09	0.24±0.09	0.03±0.10	0.23±0.09	0.13±0.06	-0.01±0.06
1 0	0.14±0.10	0.04±0.09	-0.13±0.10	-0.08±0.12	0.05±0.07	-0.10±0.09
1 1	0.11±0.08	-0.05±0.07	-0.17±0.07	-0.03±0.07	-0.01±0.04	-0.11±0.04
2 0	-0.51±0.30	0.48±0.20	0.30±0.25	0.00±0.23	-0.20±0.11	0.13±0.11
2 1	-0.10±0.16	-0.38±0.20	0.09±0.16	-0.19±0.12	0.02±0.08	0.11±0.07
2 2	0.04±0.10	-0.32±0.10	-0.11±0.11	0.07±0.09	0.01±0.05	-0.03±0.05
Stocking rate						
Control	0.06±0.03	0.13±0.03	0.09±0.04	0.13±0.03	0.05±0.02	0.07±0.02
High	-0.06±0.03	-0.13±0.03	-0.09±0.04	-0.13±0.03	-0.05±0.02	-0.07±0.02
Rearing Rank						
Single	0.04±0.0	0.04±0.03	0.06±0.05	0.03±0.05	-0.03±0.03	0.01±0.02
Twin	-0.04±0.03	-0.04±0.03	-0.06±0.05	-0.03±0.05	0.03±0.03	-0.01±0.02
General Mean	5.37±0.07	5.35±0.06	5.55±0.07	5.77±0.07	6.73±0.04	6.80±0.03

Ewe Lustre Grade

Lustre grade was higher in the CSR ewes than in the HSR ewes, with 1.3% of the total variation controlled by stocking rate. Sumner and Wickham (1969) noted that, although fleeces from the intensive sub-flock were measured finer, quality number appraisals indicated that the fleeces were judged to be coarser at the higher stocking rate. This contradiction may have been due to the wool being more lustrous at the higher stocking level.

Although age controlled 14.5% of the variation, age effects, in Table 4.2.23, were inconsistent. In sire group periods 1 and 6 LUS decreased with age, but in periods 4 and 5 it increased.

Birth year and age x birth year interactions controlled 3.4 and 14.5% of the total variation respectively. As with other assessed traits observer variation was probably an important source of year-to-year variation.

4.1.2.12 Tippiness Grade

TIP was subjectively assessed, with wool having a rather pointed 'tip' protruding beyond the bulk of the staple being graded low and wool with 'square tipped' staples getting high grades (Chopra, 1978). When it is present this fault becomes more evident in sheep with relatively low fibre number and little yolk. A thin and 'wispy' tip in the Merino can be caused by poor nutrition following shearing, whereas tippiness in British breeds is due to more rapid growth of the coarser fibres (Ryder and Stephenson, 1968).

Hogget Tippiness Grade

Although rearing rank controlled 4.9% of the total variation in the pooled analyses, the least squares estimates presented in Table 4.2.24 did not indicate any consistent difference in tippiness grade between hoggets reared as singles or those reared as twins.

Age weaned controlled 7.5% of the variation with earlier born hoggets having more tippy wool.

The between year effect was significant but contributed only a negligible fraction of the variation in the pooled anlayses. 'Year' differences could arise from differences in the climatic conditions, especially rainfall, as TIP may be affected by wetting and drying of the staple. Since this trait was subjectively graded, variations in scoring in different years or by different observers could also have contributed to the variation due to this source.

Ewe Tippiness Grade

Birth year, age and birth year x age interactions explained most of the model variation. TIP declined with increasing age, 2 or 3 year old ewes showing the highest grades.

'Year' effects, especially the age x birth year interactions which include a record year component, were highly significant. As noted for hoggets, yearly variations in climatic conditions, especially rainfall, or variation in the subjective grading by observers could have resulted in variation due to this source.

Stocking rate and stocking rate interaction effects were non-significant in the ewe analyses, as was found in the hogget analyses. Thus nutrition was not an important factor affecting

Table 4.2.24: Least squares estimates and standard errors of environmental effects for hogget tippiness grade

Factor	Sire group 1 1966/1967	Sire group 2 1968/1969	Sire group 3 1970/1971	Sire group 4 1972/1973	Sire group 5 1974/1975	Sire group 6 1977/1978	Sire group 7 1979/1980
Stocking Rate							
Control		-0.09 ±0.05	-0.24 ±0.07	0.10 ±0.06	-0.02 ±0.07	-0.00 ±0.04	0.07 ±0.04
High		0.09 ±0.05	0.24 ±0.07	-0.10 ±0.06	-0.02 ±0.07	0.00 ±0.04	-0.07 ±0.04
Rearing Rank							
Single		0.00 ±0.05	0.01 ±0.09	-0.22 ±0.09	0.09 ±0.10	-0.01 ±0.04	0.04 ±0.04
Twin		-0.00 ±0.05	-0.01 ±0.09	0.22 ±0.09	-0.09 ±0.10	0.01 ±0.04	-0.04 ±0.04
Age weaned (units/day)		0.003±0.005	0.011±0.005	0.011±0.005	-0.004±0.007	0.006±0.004	0.001±0.004
General Mean - corrected to average age at weaning		6.45 ±0.42	5.42 ±0.50	5.05 ±0.46	5.29 ±0.71	4.85 ±0.33	5.03 ±0.33

Table 4.2.25: Least squares estimates and standard errors of environmental effects for ewe tippiness grade

Factor	Sire group 1 1966/1967	Sire group 2 1968/1969	Sire group 3 1970/1971	Sire group 4 1972/1973	Sire group 5 1974/1975	Sire group 6 1977/1978
Age of Ewe						
2 years	0.39±0.05	0.82±0.05	0.04±0.05	0.38±0.05	0.21±0.04	0.03±0.05
3 years	0.51±0.05	-0.31±0.05	0.16±0.05	-0.04±0.05	0.03±0.04	-0.05±0.05
4 years	-0.08±0.05	-0.24±0.05	-0.07±0.05	-0.08±0.05	-0.07±0.04	-0.08±0.05
5 years	-0.83±0.05	-0.27±0.05	-0.13±0.05	-0.26±0.05	-0.17±0.04	0.10±0.05
No of Lambs Born/Weaned						
0 0	0.09±0.09	0.00±0.09	0.03±0.10	0.03±0.08	0.05±0.06	0.02±0.07
1 0	0.15±0.10	-0.05±0.10	0.05±0.10	0.18±0.11	-0.06±0.07	-0.09±0.10
1 1	0.09±0.08	-0.18±0.07	0.05±0.10	0.05±0.06	0.01±0.04	-0.12±0.05
2 0	-0.78±0.30	0.34±0.21	0.04±0.24	-0.28±0.20	-0.01±0.12	0.24±0.13
2 1	0.28±0.16	0.25±0.21	-0.14±0.16	0.22±0.10	0.16±0.09	-0.02±0.09
2 2	0.17±0.10	-0.37±0.10	-0.02±0.10	-0.20±0.08	-0.16±0.06	-0.02±0.06
Stocking Rate						
Control	-0.00±0.03	-0.04±0.03	0.07±0.03	0.06±0.03	-0.04±0.02	-0.05±0.03
High	0.00±0.03	0.04±0.03	-0.07±0.03	-0.06±0.03	0.04±0.02	0.05±0.03
Rearing Rank						
Single	0.07±0.03	0.01±0.03	-0.07±0.04	0.06±0.04	0.05±0.03	-0.02±0.03
Twin	-0.07±0.03	-0.01±0.03	0.07±0.04	-0.06±0.04	-0.05±0.03	0.02±0.03
General Mean	5.53±0.07	5.33±0.06	4.88±0.07	4.83±0.06	4.65±0.04	4.87±0.04

tippiness grade in this study. Chopra (1978) suggested TIP was better in the HSR group of sheep but noted that the between stocking rate effect, though significant contributed only a negligible fraction of the variation in the pooled variance components analyses. The unimportance of stocking rate in this study was supported by the non-significant stocking rate x age interaction. If nutrition was significant an interaction would be expected, as due to more rapid teeth wear and higher grazing pressure older ewes in the high stocking rate were generally under the greatest nutritional stress. A highly significant increase in rate of wear was recorded by Nolan and Black (1970) for each increase in stocking rate.

The reproductive rate effect was small but tippiness tended to increase with lambs born.

4.1.2.13 Cotting Grade

Wickham and Bigham (1973) attributed the cotting of the fleece mainly to two events; shedding of fine fibres and the migration of the shed fibres to entangle with other fibres in the fleece. Wetting and drying of the fleece may aid the process. They noted that cotting is seldom severe in hogget fleeces.

Differences in COT between stocking rates were highly significant in the separate sire group periods for both hoggets and ewes but controlled only 0.4 - 0.5% of the total variation in the combined analyses, with rankings inconsistent. Bublath (1969) and Langlands and Bennett (1973) reported that COT increased with stocking rate, while Joyce (1961) observed that a low plane nutrition more than doubled the incidence of COT. In an earlier study

Table 4.2.26: Least squares estimates and standard errors of environmental effects for hogget cotting grade

Factor	Sire group 1 1966/1967	Sire group 2 1968/1969	Sire group 3 1970/1971	Sire group 4 1972/1973	Sire group 5 1974/1975	Sire group 6 1977/1978	Sire group 6 1979/1980
Stocking Rate							
Control	-0.05 ±0.04	0.05 ±0.03	-0.12 ±0.03	0.12 ±0.05	-0.04 ±0.05	-0.01 ±0.04	-0.01 ±0.03
High	0.05 ±0.04	-0.05 ±0.03	0.12 ±0.03	-0.12 ±0.05	0.04 ±0.05	0.01 ±0.04	0.01 ±0.03
Rearing Rank							
Single	0.05 ±0.04	0.03 ±0.03	0.02 ±0.03	-0.02 ±0.07	0.14 ±0.07	-0.04 ±0.04	0.01 ±0.03
Twin	-0.05 ±0.04	-0.03 ±0.03	-0.02 ±0.03	0.02 ±0.07	-0.14 ±0.07	0.04 ±0.04	-0.01 ±0.03
Age weaned (units/day)	0.002±0.004	0.002±0.002	0.005±0.002	0.005±0.004	-0.000±0.005	-0.004±0.003	-0.004±0.003
General Mean - corrected to average age at weaning	6.89 ±0.43	6.91 ±0.20	6.02 ±0.20	6.53 ±0.36	6.09 ±0.52	6.26 ±0.30	6.65 ±0.30

Table 4.2.27: Least squares estimates and standard errors of environmental effects for ewe cotting grade

Factor	Sire group 1 1966/1967	Sire group 2 1968/1969	Sire group 3 1970/1971	Sire group 4 1972/1973	Sire group 5 1974/1975	Sire group 6 1977/1978
Age of Ewe						
2 years	0.08±0.05	0.54±0.05	-0.37±0.06	-0.25±0.07	-0.17±0.07	-0.40±0.07
3 years	0.75±0.05	-0.36±0.05	0.52±0.06	0.01±0.06	0.19±0.07	0.16±0.07
4 years	0.12±0.05	-0.23±0.05	-0.05±0.06	0.10±0.06	0.12±0.06	0.42±0.07
5 years	-0.95±0.05	0.05±0.05	-0.10±0.06	0.15±0.07	-0.13±0.07	-0.19±0.07
No of Lambs Born/Weaned						
0 0	0.06±0.09	-0.04±0.08	0.17±0.11	0.51±0.11	0.26±0.11	0.27±0.11
1 0	-0.00±0.09	-0.06±0.09	-0.09±0.12	-0.09±0.15	-0.09±0.12	-0.16±0.16
1 1	0.09±0.08	-0.03±0.06	0.01±0.09	0.08±0.08	-0.00±0.07	0.06±0.08
2 0	-0.28±0.29	0.25±0.19	0.17±0.29	-0.26±0.28	-0.11±0.20	0.01±0.21
2 1	0.10±0.16	0.17±0.19	0.01±0.19	-0.01±0.15	0.02±0.15	0.02±0.14
2 2	0.03±0.10	-0.29±0.09	-0.27±0.12	-0.23±0.11	-0.09±0.09	-0.20±0.09
Stocking Rate						
Control	-0.06±0.03	-0.01±0.03	0.07±0.04	0.20±0.04	-0.05±0.04	-0.03±0.04
High	0.6 ±0.03	0.01±0.03	-0.07±0.04	-0.20±0.04	0.05±0.04	0.03±0.04
Rearing Rank						
Single	0.11±0.03	-0.01±0.03	0.06±0.05	0.07±0.06	0.07±0.05	-0.10±0.05
Twin	-0.11±0.03	0.01±0.03	-0.06±0.05	-0.07±0.06	-0.07±0.05	0.10±0.05
General Mean	6.02±0.07	5.51±0.06	5.34±0.08	5.39±0.08	5.69±0.07	5.98±0.06

on this flock Sumner and Wickham (1969) noted that the intensively grazed ewes had a greater winter/spring depression of wool growth, associated with a greater thinning of the wool fibres and a higher incidence of cotting.

Climatic differences between the years, especially the rainfall, could be a major factor in the significant year effect. Joyce (1961) found that the incidence of COT was affected by season, breed, age, reproductive performance and nutrition. As in other subjectively graded traits, the observer variation could also have contributed to the 'year' effect in this trait.

In ewe fleeces 10.5% of the total variation in COT was controlled by age. 3 year old ewe fleeces were generally least cotted (higher COT grade).

Reproductive status was nonsignificant in the pooled analysis, although twin-bearing ewes generally produced more cotted fleeces.

4.1.2.14 Cotted Area Grade

In all fleeces there is some evidence of entanglement of wool fibres but it is only when it is severe enough to cause difficulty in dividing the fleece that a fleece is given the description "cotted" or "matted" (Henderson, 1968).

CAG was more severe in the HSR fleeces. These results are in agreement with Joyce (1961), Sumner (1969), Langlands and Bennett (1973) and Chopra (1978). Sumner and Wickham (1969) observed that increased stocking rate tends to result in a greater amplitude of the seasonal rhythm of wool growth

Table 4.2.28: Least squares estimates and standard errors of environmental effects for hogget cotted area grade

Factor	Sire Group 1 1966/1967	Sire Group 2 1968/1969	Sire Group 3 1970/1971	Sire Group 4 1972/1973	Sire Group 5 1974/1975	Sire Group 6 1977/1978	Sire Group 7 1979/1980
Stocking Rate							
Control	0.05 ±0.04	0.28 ±0.04	0.03 ±0.03	0.10 ±0.04	0.06 ±0.07	0.02 ±0.03	
High	-0.05 ±0.04	-0.28±0.04	-0.03 ±0.03	-0.10 ±0.04	-0.06 ±0.07	-0.02 ±0.03	
Rearing Rank							
Single	0.01 ±0.04	0.00 ±0.04	-0.01 ±0.04	-0.02 ±0.06	0.12 ±0.09	-0.06 ±0.03	
Twin	-0.01 ±0.04	-0.00 ±0.04	0.01 ±0.04	0.02 ±0.06	-0.12 ±0.09	0.06 ±0.03	
Age weaned (units/day)	0.005±0.004	0.002±0.003	-0.002±0.002	-0.002±0.003	-0.001±0.007	-0.003±0.003	
General Mean - corrected to average age at weaning	6.52 ±0.39	6.74 ±0.30	6.82 ±0.21	6.15 ±0.28	6.34 ±0.64	6.54 ±0.25	

Table 4.2.29: Least squares estimates and standard errors of environmental effects for ewe cotted area grade

Factor	Sire group 1 1966/1967	Sire group 2 1968/1969	Sire group 3 1970/1971	Sire group 4 1972/1973	Sire group 5 1974/1975	Sire group 6 1977/1978
Age of Ewe						
2 years	-0.14±0.09	0.03±0.06	-0.14±0.07	0.03±0.07	0.10±0.06	
3 years	0.17±0.07	0.24±0.06	0.27±0.07	0.25±0.07	0.33±0.06	
4 years	0.21±0.07	-0.25±0.06	0.28±0.07	-0.07±0.06	-0.04±0.06	
5 years	-0.23±0.07	-0.02±0.06	-0.41±0.07	-0.21±0.07	-0.40±0.06	
No of Lambs Born/Weaned						
0 0	0.28±0.14	0.10±0.11	0.37±0.12	0.54±0.12	0.34±0.10	
1 0	-0.10±0.14	-0.01±0.11	-0.02±0.12	0.08'0.16	-0.04±0.11	
1 1	-0.08±0.11	-0.02±0.08	0.02±0.09	0.09±0.09	-0.05±0.07	
2 0	-0.64±0.42	0.34±0.25	0.32±0.30	-0.01±0.29	-0.13±0.19	
2 1	0.61±0.25	0.06±-0.25	-0.18±0.20	-0.27±0.15	0.08±0.14	
2 2	-0.06±0.14	-0.47±0.12	-0.51±0.13	-0.43±0.11	-0.21±0.09	
Stocking Rate						
Control	-0.01±0.05	0.07±0.04	0.16±0.04	0.35±0.04	-0.06±0.04	
High	0.01±0.05	-0.07±0.04	-0.16±0.04	-0.35±0.04	0.06±0.04	
Rearing Rank						
Single	0.17±0.04	-0.02±0.04	0.04±0.05	-0.04±0.06	0.10±0.05	
Twin	-0.17±0.04	0.02±0.04	-0.04±0.05	0.04±0.06	-0.10±0.05	
General Mean	6.05±0.11	5.79±0.07	5.47±0.09	5.36±0.08	5.13±0.06	

and fibre diameter with the trough of the rhythm occuring later in the year. This can result in increased cotting. It is believed that poor feeding or any other stress which is likely to reinforce or prolong the normal winter depression will cause shedding of more fibres and may result in more cotting. Cotting tends to be more severe on the regions having the greatest variability of fibre diameter (Chopra, 1978).

The year effect was highly significant, controlling 5.8% of the total variation in hogget CAG and 3.6% in ewe CAG. However this was not as high as the 39% attributed to year for hogget CAG by Chopra (1978). Observer variation and climatic conditions are likely to contribute to this effect.

Age controlled 5.1% of the total variation in the ewe model. Maximum CAG occurred in the 3 year old ewes.

Reproductive status of the ewes controlled 2.7% of the total variation. Dry dry ewes had the highest CAG (least cotted), with CAG declining as number of lambs born and reared increased.

Stocking rate x age and stocking rate x age x birthyear interactions controlling significant amounts of the total variation.

4.1.2.15 Soundness Grade

Henderson (1968) attributed the unsoundness in wool to the decrease in cross-sectional area of a region of the fibres, shedding and the fundamental structural weakness of the fibres - these effects acting singly or in combination.

Hogget Soundness Grade

Stocking rate controlled 3.0% of the total variation in SOU and was generally lower in the HSR fleeces. These results agree with those found by Bublath (1969), Langlands and Bennett (1973) and Chopra (1978).

Although Chopra (1978) found that year effects explained 12.8% of the total variation, inclusion of more data and different analysis techniques meant that the year effect controlled none of the total variation in combined analyses in this study.

Year x stocking rate interactions controlled 15.5% of the total variation, indicating that although year effects were nonsignificant, within years the stocking rates were differentially influenced.

Ewe Soundness Grade

Stocking rate controlled the largest proportion of the total variation, with soundness grade lower in the high stocking rate ewe fleeces.

Effects of age were significant, although rankings were inconsistent (Table 4.2.31).

Significant birthyear, age x birthyear and age x birthyear x stocking rate interactions reflected the importance of year to year differences due to climatic conditions, parasitic infections or any other seasonal variations. Variations in the standards of scoring may also have contributed to this source of variation.

Table 4.2.30: Least squares estimates and standard errors of environmental effects for hogget soundness grade

Factor	Sire group 1 1966/1967	Sire group 2 1968/1969	Sire group 3 1970/1971	Sire group 4 1972/1973	Sire group 5 1974/1975	Sire group 6 1977/1978	Sire group 7 1979/1980
Stocking Rate							
Control	-0.32 ±0.07	0.31 ±0.08	-0.10 ±0.09	1.22 ±0.1	-0.11 ±0.08	0.09 ±0.06	-0.08 ±0.07
High	0.32 ±0.07	-0.31 ±0.08	0.10 ±0.09	-1.22 ±0.10	0.11 ±0.08	-0.09 ±0.06	0.08 ±0.07
Rearing Rank							
Single	-0.03 ±0.07	0.01 ±0.08	0.06 ±0.11	-0.03 ±0.15	0.13 ±0.11	0.07 ±0.07	-0.05 ±0.08
Twin	0.03 ±0.07	-0.01 ±0.08	-0.06 ±0.11	0.03 ±0.15	-0.13 ±0.11	-0.07 ±0.07	0.05 ±0.08
Age weaned (units/day)	0.01 ±0.007	0.02 ±0.007	-0.009±0.007	0.000±0.008	-0.001±0.008	-0.003±0.006	0.016±0.007
General Mean - corrected to average age at weaning	7.07 ±0.67	6.68 ±0.60	5.91 ±0.63	5.38 ±0.72	6.27 ±0.76	6.56 ±0.49	6.58 ±0.67

Table 4.2.31: Least squares estimates and standard errors of environmental effects for ewe soundness grade

Factor	Sire group 1 1966/1967	Sire group 2 1968/1969	Sire group 3 1970/1971	Sire group 4 1972/1973	Sire group 5 1974/1975	Sire group 6 1977/1978
Age of ewe						
2 years	-0.31±0.09	0.26±0.23	0.18±0.09	-1.59±0.09	0.17±0.09	-0.46±0.10
3 years	-0.06±0.09	0.16±0.18	0.01±0.09	-0.05±0.09	0.60±0.09	-0.01±0.10
4 years	-0.04±0.15	0.12±0.10	-0.50±0.09	0.69±0.09	-0.18±0.09	0.36±0.10
5 years	0.41±0.15	-0.54±0.10	0.31±0.09	0.95±0.09	-0.59±0.09	0.12±0.10
No of Lambs Born/Weaned						
0 0	0.75±0.27	0.52±0.21	0.95±0.17	0.56±0.16	0.65±0.15	0.78±0.15
1 0	0.45±0.28	0.14±0.21	-0.16±0.17	0.19±0.22	0.41±0.17	0.05±0.23
1 1	0.70±0.25	0.04±0.15	0.03±0.12	0.44±0.12	0.30±0.10	0.42±0.12
2 0	-2.58±1.14	-0.05±0.54	-0.05±0.42	0.54±0.40	-1.01±0.28	-0.37±0.30
2 1	0.28±0.38	-0.25±0.38	-0.33±0.27	-0.32±0.20	-0.26±0.21	-0.40±0.19
2 2	0.39±0.30	-0.40±0.21	-0.44±0.18	-0.32±0.15	-0.08±0.13	-0.48±0.13
Stocking Rate						
Control	0.27±0.06	0.52±0.08	0.36±0.06	0.15±0.06	0.27±0.05	1.18±0.06
High	-0.27±0.06	-0.52±0.08	-0.36±0.06	-0.15±0.06	-0.27±0.05	-1.18±0.06
Rearing Rank						
Single	0.02±0.06	0.07±0.06	-0.07±0.08	0.03±0.08	-0.20±0.08	-0.01±0.06
Twin	-0.02±0.06	-0.07±0.06	0.07±0.08	-0.03±0.08	0.20±0.08	0.01±0.06
General Mean	4.99±0.24	5.26±0.15	5.32±0.12	5.74±0.12	6.25±0.10	4.96±0.09

Wickham (1968) examined the various factors causing the lack of strength in the fibres and pointed out that increasing stocking rates can result in higher levels of unsoundness. Other possible causes were seasonal differences in wool growth rate, pregnancy, lactation, lambing and other stresses accentuating the fundamental seasonal effect.

There appeared to be little similarity between soundness grade and objectively measured staple strength for the hogget traits. In the ewes the trend in the means of both traits was to increase across the sire groups and then drop at the last sire group. Stocking rate and reproductive status effects were also consistent across both traits.

4.1.2.16 Handle Grade

Hogget Handle Grade

As noted by Chopra (1978), stocking rate effects were small and nonsignificant. HND tended to be higher (softer) in the HSR wools as compared to the CSR.

Between year effects were significant. Chopra (1978) noted that since weathering is one of the major causes of harshness, differences in the yearly environments because of climatic conditions may have contributed to this source of variation. Other factors such as variations in the standards of scoring and the subjective assessment of the trait might have also contributed to the 'year' effect.

Table 4.2.32: Least squares estimates and standard errors of environmental effects for hogget handle grade

Factor	Sire group 1 1966/1967	Sire group 2 1968/1969	Sire group 3 1970/1971	Sire group 4 1972/1973	Sire group 5 1974/1975	Sire group 6 1977/1978	Sire group 7 1979/1980
Stocking Rate							
Control	-0.08 ±0.06	-0.01 ±0.05	0.02 ±0.05	-0.13 ±0.06	0.01 ±0.05	0.03 ±0.03	0.03 ±0.03
High	0.08 ±0.06	0.01 ±0.05	-0.02 ±0.05	0.13 ±0.06	-0.01 ±0.05	-0.03 ±0.03	-0.03 ±0.03
Rearing Rank							
Single	-0.01 ±0.05	0.14 ±0.05	0.03 ±0.06	0.06 ±0.09	0.02 ±0.06	-0.00 ±0.03	0.03 ±0.03
Twin	0.01 ±0.05	-0.14 ±0.05	-0.03 ±0.06	-0.06 ±0.09	-0.02 ±0.06	0.00 ±0.03	-0.03 ±0.03
Age weaned (units/day)	0.003±0.006	-0.006±0.005	-0.005±0.004	-0.003±0.005	-0.001±0.005	-0.003±0.003	0.002±0.003
General Mean - corrected to average age at weaning	6.50 ±0.56	6.29 ±0.38	5.83 ±0.38	6.19 ±0.44	5.53 ±0.45	5.49 ±0.26	5.46 ±0.23

Table 4.2.33: Least squares estimates and standard errors of environmental effects for ewe handle grade

Factor	Sire group 1 1966/1967	Sire group 2 1968/1969	Sire group 3 1970/1971	Sire group 4 1972/1973	Sire group 5 1974/1975	Sire group 6 1977/1978
Age of Ewe						
2 years	-0.11±0.05	0.45±0.05	0.45±0.05	-0.31±0.04	0.03±0.04	-0.13±0.04
3 years	0.35±0.05	-0.13±0.05	-0.11±0.05	0.09±0.04	0.11±0.04	0.05±0.04
4 years	0.12±0.05	-0.03±0.05	-0.29±0.05	0.19±0.04	-0.02±0.04	0.18±0.04
5 years	-0.36±0.05	-0.29±0.05	-0.05±0.05	0.03±0.04	-0.13±0.04	-0.10±0.04
No of Lambs Born/Weaned						
0 0	0.22±0.10	0.04±0.09	0.14±0.09	0.05±0.08	0.20±0.06	0.14±0.06
1 0	0.23±0.10	0.02±0.09	-0.02±0.09	0.02±0.10	0.06±0.07	0.03±0.09
1 1	0.18±0.08	-0.02±0.07	-0.00±0.07	-0.04±0.06	-0.02±0.04	0.04±0.05
2 0	-0.50±0.31	-0.14±0.19	0.06±0.23	0.46±0.19	0.27±0.12	-0.04±0.12
2 1	-0.30±0.17	0.41±0.20	-0.04±0.15	-0.06±0.10	-0.16±0.09	0.02±0.08
2 2	0.16±0.10	-0.30±0.09	-0.13 ±0.10	-0.43±0.07	-0.35±0.06	-0.19±0.05
Stocking Rage						
Control	-0.18±0.03	-0.07±0.03	0.04±0.03	0.11±0.03	0.03±0.02	-0.00±0.02
High	0.18±0.03	0.07±0.03	-0.04±0.03	-0.11±0.03	-0.03±0.02	0.00±0.02
Rearing Rank						
Single	0.07±0.03	0.20±0.03	0.08±0.04	0.02±0.04	0.04±0.03	0.01±0.03
Twin	-0.07±0.03	-0.20±0.03	-0.08±0.04	-0.02±0.04	-0.04±0.03	-0.01±0.03
General Mean	5.81±0.07	5.64±0.06	5.15±0.06	5.25±0.06	5.17±0.04	5.16±0.04

Rearing rank effects were nonsignificant, although Chopra (1978) found the effect was highly significant with single-born hoggets displaying higher HND than the twin-borns.

Ewe Handle Grade

Stocking rate had a significant effect on handle grade of ewe fleeces, controlling 1.9% of the total variation. Where there were significant differences HSR fleeces had higher (softer) HND in two sire group periods, and lower HND in another sire group period.

Birthyear and age x birthyear interaction effects controlled 3.0% and 12.2% of the total variation, respectively. Thus the major proportion of the variation was due to climatic variation or observer differences between the years.

Age effects were significant but inconsistent. Langlands *et al.* (1984) found handle declined linearly with age.

Rearing rank was significant in this model, controlling 2.4% of the total variation. Single-born ewes had a lower handle grade than the twin-born ewes.

Reproductive status effects were significant, with 1.9% of the total variation explained. In general HND decreased as the number of lambs born and weaned increased.

4.1.2.17 Greasy Midside Colour Grade

Hogget Greasy Midside Colour Grade

GCM was better in the HSR wool. This was in agreement with findings by Bublath (1969), Sumner (1969), Langlands and Bennett (1973), Joyce *et al.* (1976) and Chopra (1978).

Year effects were significant, but not of as large a magnitude as determined by Chopra (1978). Variations in climatic conditions are important in causing year-to-year differences in wool colour, especially rainfall and temperature. Observer variation may also be an important effect.

Year x stocking rate interactions were significant, controlling 5.7% of the total variation.

Ewe Greasy Midside Colour Grade

Stocking rate effects controlled only 0.6% of the total variation. Rankings were inconsistent between the two stocking rates.

Birth year and age x birth year interactions controlled 2.8% and 8.5% of the variation, respectively. These equate with the year effects in hoggets.

Reproductive status effects were significant. Dry dry ewes had the whitest wool, with colour generally declining as number of lambs born and reared increased.

Age effects were the most important source of variation. Rankings varied across sire group periods but GCM tended to decline with increased age.

Table 4.2.34: Least squares estimates and standard errors of environmental effects for hogget greasy midside colour grade

Factor	Sire group 1 1966/1967	Sire group 2 1968/1969	Sire group 3 1970/1971	Sire group 4 1972/1973	Sire group 5 1974/1975	Sire group 6 1977/1978	Sire group 7 1979/1980
Stocking rate							
Control	-0.30 ±0.06	-0.23 ±0.04	-0.06 ±0.03	-0.00 ±0.04	-0.08 ±0.07	0.00 ±0.03	0.04 ±0.03
High	0.30 ±0.06	0.23 ±0.04	0.06 ±0.03	0.00 ±0.04	0.08 ±0.07	-0.00 ±0.03	-0.04 ±0.03
Rearing Rank							
Single	0.11 ±0.06	-0.02 ±0.03	0.04 ±0.04	0.07 ±0.06	-0.15 ±0.10	0.02 ±0.03	-0.00 ±0.03
Twin	-0.11 ±0.06	0.02 ±0.03	-0.04 ±0.04	-0.07 ±0.06	0.15 ±0.10	-0.02 ±0.03	0.00 ±0.03
Age weaned (units/day)	0.01 ±0.006	-0.002±0.003	0.001±0.002	0.003±0.003	-0.003±0.007	0.000±0.003	-0.005±0.003
General Mean - corrected to average age at weaning	6.41 ±0.56	6.40 ±0.28	6.10 ± 0.23	6.39 ±0.32	5.79 ±0.72	5.33 ±0.26	5.32 ±0.26

Table 4.2.35: Least squares estimates and standard errors of environmental effects for ewe greasy midside colour grade

Factor	Sire group 1 1966/1967	Sire group 2 1968/1969	Sire group 3 1970/1971	Sire group 4 1972/1973	Sire group 5 1974/1975	Sire group 6 1977/1978
Age of Ewe						
2 years	-0.08±0.04	-0.21±0.04	0.40±0.04	0.36±0.05	0.01±0.04	-0.20±0.05
3 years	0.15±0.04	-0.08±0.03	0.27±0.04	0.28±0.05	0.03±0.04	-0.04±0.04
4 years	-0.16±0.04	0.30±0.03	-0.13±0.04	-0.28±0.05	0.06±0.04	0.05±0.05
5 years	0.09±0.04	-0.01±0.03	-0.54±0.04	-0.37±0.05	-0.10±0.04	0.19±0.05
No of Lambs Born/Weaned						
0 0	0.06±0.08	0.10±0.06	0.25±0.08	0.14±0.08	0.27±0.07	0.39±0.07
1 0	-0.07±0.08	0.05±0.07	0.02±0.08	0.08±0.11	0.04±0.08	-0.07±0.10
1 1	-0.07±0.06	-0.00±0.05	0.02±0.06	-0.08±0.06	-0.19±0.05	-0.01±0.05
2 0	0.16±0.24	0.03±0.14	0.17±0.19	0.37±0.21	0.38±0.13	0.08±0.13
2 1	-0.11±0.13	-0.07±0.14	-0.26±0.12	-0.12±0.11	-0.09±0.09	-0.14±0.08
2 2	0.02±0.08	-0.11±0.07	-0.19±0.08	-0.39±0.08	-0.41±0.06	-0.25±0.06
Stocking Rate						
Control	-0.08±0.02	-0.01±0.02	0.09±0.03	0.06±0.03	-0.01±0.02	-0.04±0.03
High	0.08±0.02	0.01±0.02	-0.09±0.03	-0.06±0.03	0.01±0.02	0.04±0.03
Rearing Rank						
Single	0.02±0.02	-0.00±0.02	0.03±0.03	-0.00±0.04	-0.02±.03	-0.05±0.03
Twin	-0.02±0.02	0.00±0.02	-0.03±0.03	0.00±0.04	0.02±0.03	0.05±0.03
General Mean	5.71±0.06	5.89±0.04	5.61±0.05	5.06±0.06	4.70±0.04	4.85±0.04

4.1.2.18 Scoured Midside Colour Grade

Hogget Scoured Midside Colour Grade

As with other subjectively assessed traits in the hogget the model for SCM explained little of the total variation, accounting for only 11.8% with sire components contributing half the variation.

Stocking rate was not significant in the combined analyses, explaining only 0.9% of the variance. CSR fleeces had a lower scoured colour in the first three sire group periods but after the management change in 1976 there was no difference between the stocking rates.

Year effects explained none of the total variation, but year x stocking interactions contributed 5.8%.

Ewe Scoured Midside Colour Grade

Stocking rate effects controlled only 1.0% of the total variation, as was found in the hoggets. HSR fleeces had a higher SCM (whiter) compared to CSR fleeces.

Age effects were significant, with SCM tending to decline as ewe age increased. Stocking rate x age interactions approached significance, controlling 1.7% of the total variation, indicating the differential effect of age in the two stocking rates.

'Year' effects were the most important source of variation, probably reflecting climatic and grading variation.

Age x birthyear x stocking rate interactions controlled 11.2% of the total variation, indicating the different effects of year-to-year variation on the two stocking rates.

4.2.36: Least squares estimates and standard errors of environmental effects for hogget scoured midside colour grade

Factor	Sire group 1 1966/1967	Sire group 2 1968/1969	Sire group 3 1970/1971	Sire group 4 1972/1973	Sire group 5 1974/1975	Sire group 6 1977/1978	Sire group 7 1979/1980
Stocking Rate							
Control	-0.17 ±0.04	-0.09 ±0.04	-0.22 ±0.04	0.11 ±0.07	0.02 ±0.06	0.02 ±0.03	0.03 ±0.03
High	0.17 ±0.04	0.09 ±0.04	0.22 ±0.04	-0.11 ±0.07	-0.02 ±0.06	-0.02 ±0.03	-0.03 ±0.03
Rearing Rank							
Single	-0.02 ±0.04	-0.05 ±0.03	0.05 ±0.05	0.17 ±0.11	0.12 ±0.08	0.03 ±0.03	0.03 ±0.03
Twin	0.02 ±0.04	0.05 ±0.03	-0.05 ±0.05	-0.17 ±0.11	-0.12 ±0.08	-0.03 ±0.03	-0.03 ±0.03
Age weaned (Units/day)	-0.002±0.005	-0.002±0.003	0.008±0.003	0.005±0.006	-0.000±0.006	-0.001±0.003	0.002±0.003
General Mean - corrected to average age at weaning	6.20 ±0.43	6.13 ±0.28	6.11 ±0.28	5.59 ±0.52	5.45 ±0.56	5.12 ±0.26	5.07 ±0.28

Table 4.2.37: Least squares estimates and standard errors of environmental effects for ewe scoured midside colour grade

Factor	Sire group 1 1966/1967	Sire group 2 1968/1969	Sire group 3 1970/1971	Sire group 4 1972/1973	Sire group 5 1974/1975	Sire group 6 1977/1978
Age of Ewe						
2 years	0.52±0.04	-0.18±0.04	0.47±0.04	0.10±0.04	-0.14±0.04	-0.01±0.09
3 years	-0.18±0.04	-0.09±0.04	0.16±0.04	0.11±0.04	-0.15±0.04	0.24±0.10
4 years	-0.51±0.04	0.36±0.04	-0.30±0.04	-0.01±0.04	0.15±0.04	0.30±0.06
5 years	0.17±0.04	-0.09±0.04	-0.33±0.04	-0.19±0.04	0.13±0.04	-0.53±0.19
No of Lambs Born/Weaned						
0 0	-0.04±0.07	-0.11±0.08	0.01±0.08	-0.09±0.08	-0.05±0.07	-0.19±0.08
1 0	-0.03±0.07	-0.06±0.08	0.03±0.08	-0.02±0.10	-0.19±0.08	-0.05±0.11
1 1	0.08±0.06	-0.07±0.06	-0.02±0.06	0.01±0.06	-0.00±0.05	0.06±0.06
2 0	0.03±0.22	-0.08±0.17	0.24±0.20	-0.01±0.19	0.15±0.13	-0.01±0.15
2 1	-0.11±0.12	0.35±0.17	-0.15±0.13	0.06±0.10	0.12±0.10	0.12±0.09
2 2	0.07±0.07	-0.02±0.08	-0.11±0.08	0.06±0.07	-0.03±0.04	0.07±0.06
Stocking Rate						
Control	-0.04±0.02	-0.04±0.03	-0.02±0.03	-0.08±0.03	-0.03±0.03	-0.16±0.05
High	0.04±0.02	0.04±0.03	0.02±0.03	0.08±0.03	0.10±0.03	0.16±0.05
Rearing Rank						
Single	-0.00±0.02	0.08±0.03	-0.04±0.04	-0.03±0.04	0.05±0.03	-0.08±0.03
Twin	0.00±0.02	-0.08±0.03	0.04±0.04	0.03±0.04	-0.05±0.03	0.03±0.03
General Mean	5.48±0.05	5.59±0.05	5.41±0.06	5.06±0.06	4.89±0.04	4.72±0.09

4.1.2.19 Greasy Fleece Colour Grade

Effects of significance in discoloured area grade closely parallel those of greasy colour of midside samples, except year effects on GCF in the hogget model which are non-significant.

The estimated effects for each sire group period are presented in Table 4.2.38 and 4.2.39. GCF was better in the CSR in the hogget fleeces and in the first two ewe sire group periods. After the stocking rate decrease in 1976 and the rearing of the hoggets as one mob there was no difference between stocking rates in the GCF of the hogget fleeces and a major drop in magnitude of stocking rate effects in ewe fleece GCF. Wickham and Bigham (1973) suggested that the very high stocking rate appeared to result in increased discolouration perhaps as a result of increased dirt contamination or slower drying of more cotted wool.

Age effects were highly significant in the ewe analyses, controlling 5.9% of the total variation in the pooled analyses. The maximum GCF occurred at 3 or 4 years of age.

Table 4.2.38: Least squares estimates and standard errors of environmental effects for hogget greasy fleece colour grade

Factor	Sire group 1 1966/1967	Sire group 2 1968/1969	Sire group 3 1970/1971	Sire group 4 1972/1973	Sire group 5 1974/1975	Sire group 6 1977/1978	Sire group 7 1979/1980
Stocking rate							
Control	-0.02 ±0.04	0.06 ±0.05	0.09 ±0.04	0.15 ±0.05	-0.03 ±0.07	0.05 ±0.05	
High	0.02 ±0.04	-0.06 ±0.05	-0.09 ±0.04	-0.15 ±0.05	0.03 ±0.07	-0.05 ±0.05	
Rearing Rank							
Single	-0.12 ±0.04	-0.04 ±0.04	-0.04 ±0.05	0.03 ±0.08	0.04 ±0.10	-0.06 ±0.05	
Twin	0.12 ±0.04	0.04 ±0.04	0.04 ±0.05	-0.03 ±0.08	-0.04 ±0.10	0.06 ±0.05	
Age weaned (units/day)	0.001±0.004	0.000±0.004	0.000±0.003	-0.005±0.004	-0.005±0.007	-0.008±0.004	
General Mean - Corrected to average age at weaning	6.68 ±0.34	6.37 ±0.35	6.28 ±0.28	5.28 ±0.38	5.72 ±0.67	6.04 ±0.35	

Table 4.2.39: Least squares estimates and standard errors of environmental effects for ewe greasy fleece colour grade

Factor	Sire group 1 1966/1967	Sire group 2 1968/1969	Sire group 3 1970/1971	Sire group 4 1972/1973	Sire group 5 1974/1975	Sire group 6 1977/1978
Age of Ewe						
2 years	-0.21±0.07	-0.05±0.05	-0.01±0.05	0.12±0.05	0.10±0.04	
3 years	-0.14±0.05	0.39±0.04	0.09±0.05	0.19±0.05	0.18±0.04	
4 years	0.12±0.05	-0.12±0.04	0.30±0.05	-0.10±0.05	-0.09±0.04	
5 years	0.24±0.05	-0.22±0.04	-0.38±0.05	-0.20±0.05	-0.19±0.04	
No of Lambs Born/Weaned						
0 0	-0.05±0.10	0.12±0.08	0.05±0.09	0.03±0.09	0.17±0.06	
1 0	-0.06±0.10	0.06±0.08	0.17±0.10	0.00±0.13	0.00±0.07	
1 1	-0.12±0.08	-0.03±0.06	0.02±0.07	0.02±0.07	-0.08±0.04	
2 0	0.19±0.30	0.22±0.18	0.18±0.23	0.17±0.23	0.09±0.12	
2 1	0.10±0.18	-0.19±0.18	-0.18±0.15	0.01±0.12	0.02±0.09	
2 2	-0.07±0.10	-0.18±0.09	-0.24±0.10	-0.24±0.09	-0.22±0.06	
Stocking Rate						
Control	-0.24±0.03	-0.15±0.03	0.03±0.03	0.13±0.03	0.04±0.02	
High	0.24±0.03	0.15±0.03	-0.03±0.03	-0.13±0.03	-0.04±0.02	
Rearing Rank						
Single	0.06±0.03	-0.04±0.03	0.01±0.04	-0.09±0.05	0.02±0.03	
Twin	-0.06±0.03	0.04±0.03	-0.01±0.04	0.09±0.05	-0.02±0.03	
General Mean	6.32±0.08	5.90±0.05	5.47±0.07	5.34±0.07	4.93±0.04	

4.1.2.20 Number of Lambs Born Per Ewe Mated

Table 4.2.40 indicated that prior to the management change in 1976 the average number of lambs born was 1.00 - 1.01. After 1976 the average number of lambs born increased to 1.08 - 1.27.

Stocking rate effects were significant, contributing 3.3% of the total variation. The HSR ewes had a low number of lambs born per ewe lambing as compared with the CSR ewes, although this difference decreased in magnitude after 1976. Langlands *et al.* (1984b) also noted that the stocking rate at which the sheep grazed as adults had a major effect on number of lambs born per ewe lambing.

There was an increase in number of lambs born with age until 4 or 5 years of age or possibly later. The same trend was found in an early study of these ewes (Ch'ang and Rae, 1970). Results from the study of Langlands *et al.* (1984b) on Merino ewes indicated that peak fertility appeared to be reached at the 6th lambing or 7 years of age. Dalton and Rae (1978) concluded that peak fertility appeared to be reached around 5 years of age with a decline thereafter. A similar trend has been noted by Hight and Jury (1970) and Lundie (1971). Coop (1962) suggested that the increase in reproductive performance with age resulted from the greater liveweight of the older ewes, but Hight and Jury (1973) found that age differences could not be attributed to weight alone.

In this study liveweight was not a significant effect. However, some of the ewe liveweight effects may have been removed in the stocking rate effect since one stocking rate is heavier than the other (Table 4.2.3). Similarly, as liveweight trends paralleled age effects some of the variation due to liveweight may have been removed in the age effects.

Table 4.2.40: Least squares estimates and standard errors of environmental effects for number of lambs born

Factor	Sire group 1 1966/1967	Sire group 2 1968/1969	Sire group 3 1970/1971	Sire group 4 1972/1973	Sire group 5 1974/1975	Sire group 6 1977/1978
Age of Ewe						
2 years	-0.06'0.04	-0.21±0.03	-0.10±0.03	-0.31±0.04	-0.21±0.05	-0.43±0.05
3 years	0.06±0.04	0.08±0.03	0.04±0.03	-0.05±0.04	-0.01±0.05	-0.01±0.04
4 years	0.02±0.04	0.11±0.03	0.04±0.03	0.13±0.04	0.07±0.05	0.25±0.05
5 years	-0.01±0.04	0.02±0.03	0.02±0.03	0.23±0.04	0.14±0.05	0.19±0.04
Stocking Rate						
Control	0.23±0.03	0.16±0.03	0.18±0.02	0.15±0.03	0.11±0.03	0.14±0.03
High	-0.23±0.03	-0.16±0.03	-0.18±0.02	-0.15±0.03	-0.11±0.03	-0.14±0.03
Ewe Liveweight (NLB/kg)	-0.02±0.00	-0.01±0.00	-0.01±0.00	-0.01±0.00	-0.02±0.00	-0.03±0.00
General Mean - corrected to average ewe liveweight	1.00±0.02	1.00±0.02	1.01±0.02	1.10±0.02	1.08±0.03	1.27±0.02
HS effect on ewe l.w.:	-7.00	-7.07	-6.21	-5.59	-3.82	-4.62
Stocking rate effect ignoring ~~discounting~~ l.w.	0.09	0.09	0.12	0.09	0.03	-0.01
	1.09	1.09	1.13	1.17	1.11	1.26
LS – HS	.91	0.91	0.89	1.01	1.05	1.28
/ HS						

Table 4.2.41: Least squares estimates and standard errors of environmental effects for lifetime number of lambs born

Factor	Sire group 1 1066/1967	Sire group 2 1968/1969	Sire group 3 1970/1971	Sire group 4 1972/1973	Sire group 5 1974/1975	Sire group 6 1977/1978
Stocking Rate						
Control	0.36±0.18	0.16±0.14	0.38±0.14	0.18±0.18	0.41±0.18	0.84±0.17
High	-0.36±0.18	-0.16±0.14	-0.38±0.14	-0.18±0.18	-0.41±0.18	-0.84±0.17
Hogget liveweight (NLB/kg)	0.12±0.03	0.09±0.02	0.16±0.03	0.10±0.04	0.15±0.05	0.20±0.04
Average liveweight (NLB/kg)	-0.02±0.01	-0.01±0.01	-0.02±0.01	-0.01±0.01	-0.03±0.01	-0.04±0.01
General Mean - corrected to average ewe liveweight	3.96±0.09	3.88±0.09	4.04±0.09	4.36±0.12	4.33±0.14	5.08±0.12

'Year' effects reflect annual differences in various aspects of management and climate, which affect ovulation rate, fertilisation, embryo and pre-natal lamb survival.

Ch'ang and Rae (1970) found that the effects of type of birth and rearing on fertility were consistent and indicated that the twins, on average, were more fertile than the singles. The estimates showed that the value of additive genetic variance of fertility was underestimated by using the data adjusted for difference, among others, in type of birth and rearing. Their results implied that the estimates of the effects of type of birth and rearing on a ewe's fertility contain a genetic component in addition to the environmental difference between those born and reared as singles or twins. They concluded it would therefore appear reasonable that adjustment should not be made for this effect as was done in this study.

Lifetime Number of Lambs Born

Due to the large chance element in whether a ewe bears 0, 1 or 2 lambs a year, the number of lambs born over the ewe's lifetime was calculated. The model described only a little more variation than the number of lambs born model, 21.1% compared to 17.2%.

As ewes were not culled once they entered a sub-flock, persistently dry ewes were retained which would not be the case in most flocks. The lifetime number of lambs born per ewe ranged from 0 to 8, with most producing 3-5 lambs.

Mean lifetime number of lambs born followed the same trends as number of lambs born, with an increase after the stocking rate decrease in 1976.

Stocking rate effects increased, rather than decreased as for number of lambs born, in the last two sire group periods. Coop and Clark (1955) found lifetime reproductive rate appeared to be adversely affected by low-plane levels of nutrition at rearing even when ewes were then given a high plane of nutrition for the rest of their lives. Increased barrenness and decreased twinning rates were observed.

4.1.2.21 Number of Lambs Weaned per Ewe Mated

Average number of lambs weaned are presented in Table 4.2.42. Trends are similar to number of lambs born, except for a large drop in average number of lambs weaned in sire group 5.

Stocking rate effects were significant. The CSR ewes weaned 0.26 - 0.42 more lambs per ewe lambing than the HSR ewes. The magnitude of the stocking rate differences declined after the stocking rate decrease but were still highly significant.

Generally age effects were maximum at 4 years of age, as was found by Hight and Jury (1970), and Lundie (1971) for New Zealand Romney ewes and by Rendel (1985) for Coopworth ewes.

'Year' effects were significant, reflecting annual differences in climate, management, rainfall, etc which affect post-natal lamb survival.

Table 4.2.42: Least squares estimates and standard errors of environmental effects for number of lambs weaned

Factor	Sire group 1 1966/1967	Sire group 2 1968/1969	Sire group 3 1970/1971	Sire group 4 1972/1973	Sire group 5 1974/1975	Sire group 6 1977/1978
Age of Ewe						
2 years	-0.07±0.04	-0.28±0.04	-0.11±0.04	-0.30±0.05	-0.18±0.05	-0.48±0.06
3 years	0.12±0.04	0.11±0.03	0.02±0.04	-0.06±0.04	-0.02±0.06	0.06±0.05
4 years	0.02±0.04	0.14±0.04	0.13±0.04	0.09±0.05	0.06±0.05	0.31±0.05
5 years	-0.08±0.04	0.02±0.03	-0.04±0.04	0.27±0.04	0.10±0.06	0.11±0.05
Stocking Rate						
Control	0.21±0.04	0.20±0.03	0.20±0.03	0.19±0.03	0.13±0.03	0.16±0.03
High	-0.21±0.04	-0.20±0.03	-0.20±0.03	-0.19±0.03	-0.13±0.03	-0.16±0.03
Ewe Liveweight (NLB/kg)	-0.01±0.00	-0.02±0.00	-0.02±0.00	-0.03±0.00	-0.03±0.00	-0.04±0.00
General Mean - corrected to average ewe liveweight	0.94±0.04	0.88±0.03	0.87±0.03	0.99±0.03	0.87±0.04	1.04±0.03

Table 4.2.43: Least squares estimates and standard errors of environmental effects for lifetime numbers of lambs weaned

Factor	Sire group 1 1966/1967	Sire group 2 1968/1969	Sire group 3 1970/1971	Sire group 4 1972/1973	Sire group 5 1974/1975	Sire group 6 1977/1978
Stocking rate						
Control	0.37±0.22	0.13±0.15	0.46±0.14	0.22±0.17	0.41±0.17	0.76±0.16
High	-0.37±0.22	-0.13±0.15	-0.46±0.14	-0.22±0.17	-0.41±0.17	-0.76±0.16
Hogget liveweight (NLB/kg)	0.13±0.03	0.13±0.02	0.16±0.03	0.11±0.04	0.20±0.05	0.18±0.03
Average liveweight (NLB/kg)	-0.02±0.01	-0.02±0.01	-0.02±0.01	-0.02±0.01	-0.03±0.01	-0.04±0.01
General Mean - corrected to average ewe liveweight	3.25±0.11	3.15±0.09	3.35±0.09	3.80±0.11	3.68±0.13	4.32±0.11

Lifetime Number of Lambs Weaned

Utilising the lifetime number of lambs weaned led to a decrease in the proportion of total variation explained by the model (Table 4.1.3).

The lifetime number of lambs weaned per ewe ranged between 0 and 7 in all sire groups.

4.1.2.22 Weight of Lamb Weaned Per Ewe

Mean values for weight of lamb weaned are presented in Table 4.2.44. There was an increase in the average weight of lamb weaned per ewe over the first three sire group periods, which was not due to an increasing number of lambs weaned (Table 4.2.42). As number of lambs weaned had decreased over these periods the increased lamb weight was due to a greater weight per lamb weaned, as was shown in Table 4.2.46.

After the stocking rate decrease in the HSR the mean weight of lamb weaned increased, except in sire group period 5 which reflected the low NLB and NLW in that period.

Stocking rate effects were highly significant, controlling 8.5% of the total variation. Ewes of the HSR weaned 7.2 - 11.6 kg less of lamb as compared to the CSR, with no change in magnitude after 1976.

'Year' effects were significant reflecting the effects of year-to-year variations in climate, rainfall, nutrition, etc which affect the ewe's ability to provide milk for the lamb and which influence the lamb's growth rate. If feed supply was affected then it would be expected that the HSR would be most affected. This is indicated to some extent with age x birthyear x stocking rate controlling 1.3% of the variation.

Age effects were also highly significant. Three or four year old ewes weaned the highest weight of lambs weaned in most sire groups. This was a function of both higher number of lambs weaned and of a greater weight per lamb weaned. Rendel (1985) found the 4 year old ewes had the greatest WLW but the mature age group in that study included very old ewes which were past their peak production. Lundie (1971) and Dalton and Rae (1978) found the peak occurred at a later age.

Ewe liveweight contributed only 1.2% of the total variation but may have been partially removed by stocking rate or age effects. The estimates of liveweight effects indicate a consistent negative influence, which increased when the high stocking rate pressure was reduced.

Age of lambs at weaning did not contribute to the variation in the combined analyses but was significant in the separate sire group analyses. Estimates in Table 4.2.44 were consistent although in sire group period 5 there was a decrease in the regression coefficient.

Table 4.2.44: Least squares estimates and standard errors of environmental effects for weight of lamb weaned (kg)

Factor	Sire group 1 1966/1967	Sire group 2 1968/1969	Sire group 3 1970/1971	Sire group 4 1972/1973	Sire group 5 1974/1975	Sire group 6 1977/1978
Age of Ewe						
2 years	-1.92±0.96	-6.28±0.74	-4.55±0.83	-5.99±1.17	-3.09±1.26	-12.93±1.36
3 years	5.72±0.86	2.68±0.73	1.69±0.84	-1.37±1.12	2.26±1.38	1.45±1.07
4 years	-2.63±0.94	3.33±0.75	4.31±0.85	2.43±1.12	0.98±1.22	8.44±1.10
5 years	-1.17±0.87	0.27±0.75	-1.44±0.88	4.93±1.11	-0.15±1.35	3.03±1.08
Stocking rate						
Control	5.45±0.84	4.26±0.62	5.32±0.64	4.94±0.77	3.61±0.81	5.78±0.66
High	-5.45±0.84	-4.26±0.62	-5.32±0.64	-4.94±0.77	-3.61±0.81	-5.78±0.66
Ewe liveweight (WLW/kg)	-0.24±0.09	-0.19±0.07	-0.37±0.07	-0.54±0.10	-0.60±0.11	-0.75±0.08
Age lambs at wean (WLW/day)	0.20±0.05	0.23±0.04	0.21±0.05	0.22±0.06	0.19±0.08	0.27±0.07
Age weaned.sr (WLW/day))						
CSR	0.05±0.05	0.13±0.04	-0.03±0.05	0.09±0.06	-0.04±0.08	0.04±0.07
HSR	-0.05±0.05	-0.13±0.04	0.03±0.05	-0.09±0.06	0.04±0.08	-0.04±0.07
Age weaned.age (WLW/day)						
2 years	-0.58±0.08	-0.09±0.07	-0.36±0.08	-0.07±0.11	0.05±0.14	0.16±0.11
3 years	-0.07±0.08	0.04±0.07	0.11±0.09	0.09±0.11	-0.07±0.15	-0.04±0.11
4 years	0.54±0.09	-0.08±0.08	0.12±0.09	0.25±0.11	-0.07±0.14	-0.19±0.11
5 years	0.11±0.08	0.12±0.08	0.13±0.08	-0.27±0.10	0.09±0.13	0.07±0.14
General Mean - corrected to average ewe liveweight and average age of lambs at weaning	17.87±0.89	18.90±0.63	20.66±0.67	24.97±0.80	20.33±0.84	24.36±0.76

Table 4.2.45: Least squares estimates and standard errors of environmental effects for lifetime weight of lamb weaned (kg)

Factor	Sire group 1 1966/1967	Sire group 2 1968/1969	Sire group 3 1970/1971	Sire group 4 1972/1973	Sire group 5 1974/1975	Sire group 6 1977/1978
Stocking rate						
Control	4.29±2.28	2.69±1.48	6.62±1.78	3.92±2.06	5.08±2.17	11.16±2.15
High	-4.29±2.28	-2.69±1.48	-6.62±1.78	-3.92±2.06	-5.08±2.17	-11.16±2.15
Hogget liveweight (WLW/kg)	0.01±0.35	0.25±0.25	0.87±0.41	0.56±0.48	1.36±0.61	1.16±0.46
Average ewe liveweight (WLW/kg)	0.16±0.08	0.21±0.05	0.09±0.07	0.10±0.08	0.01±0.11	-0.12±0.08
Average age of lambs at wean (WLW/day)	0.28±0.01	0.27±0.01	0.28±0.01	0.33±0.02	0.30±0.02	0.32±0.02
Age Wean.SR (WLW/day)						
CSR	0.05±0.01	0.03±0.01	0.04±0.01	0.04±0.02	0.00±0.01	0.03±0.02
HSR	-0.05±0.01	-0.03±0.01	-0.04±0.01	-0.04±0.02	-0.00±0.01	-0.03±0.02
General Mean - corrected to average ewe liveweight and average age of lamb at weaning	69.75±1.11	72.48±0.91	80.02±1.15	97.22±1.37	85.71±1.66	99.11±1.47

Lifetime Weight of Lamb Weaned

Trends were similar for lifetime weight of lamb weaned as for weight of lamb weaned. The exception was liveweight effects.

Unlike in the individual records, the average liveweight of the ewe over her lifetime was positively related to lifetime WLW and the lifetime weight of lamb weaned increased as the average ewe liveweight increased. After the management change in 1976 the liveweight effect was insignificant.

4.1.2.23 Weight Per Lamb Weaned

Least squares estimates and standard errors of the environmental effects for weight per lamb weaned are presented in Table 4.2.46.

The number of lambs reared by a ewe has a large influence on the weight of lamb weaned by a ewe. Lambs that were reared as twins were 3.8 - 6.2 kg lighter than those reared as singles.

Weight per lamb weaned increased before 1976, but the mean weight per lamb weaned was the same for sire group periods 4 - 6.

Table 4.2.46: Least squares estimates and standard errors of environmental effects for weight per lamb weaned (kg)

Factor	Sire group 1 1966/1967	Sire group 2 1968/1969	Sire group 3 1970/1971	Sire group 4 1972/1973	Sire group 5 1974/1975	Sire group 6 1977/1978
Age of Ewe						
2 years	1.29±0.43	-0.69±0.32	-1.09±0.32	0.30±0.45	1.01±0.35	-3.57±0.36
3 years	1.47±0.34	0.62±0.27	0.71±0.30	0.57±0.49	1.46±0.37	0.35±0.28
4 years	-1.09±0.44	0.28±0.27	1.09±0.28	-0.38±0.44	-0.51±0.32	2.37±0.30
5 years	-1.66±0.38	-0.22±0.27	-0.70±0.29	-0.49±0.38	-1.96±0.36	0.85±0.31
Stocking Rate						
Control	1.80±0.35	0.85±0.25	1.56±0.23	0.59±0.23	0.51±0.24	2.35±0.20
High	-1.80±0.35	-0.85±0.25	-1.56±0.23	-0.59±0.23	-0.51±0.24	-2.35±0.20
Ewe liveweight (WPL/kg)	0.12±0.04	0.20±0.03	0.10±0.03	0.14±0.03	0.12±0.03	0.03±0.02
Age of lamb at wean (WPL/day)	0.13±0.04	0.14±0.01	0.14±0.02	0.16±0.02	0.16±0.02	0.16±0.02
Age weaned.age (WPL/day)						
2 years	-0.10±0.03	0.01±0.02	0.03±0.03	-0.02±0.03	-0.03±0.03	-0.02±0.03
3 years	0.04±0.03	0.01±0.02	0.03±0.03	-0.04±0.03	0.04±0.04	-0.05±0.03
4 years	0.06±0.04	0.04±0.02	-0.05±0.03	0.02±0.03	-0.03±0.03	0.04±0.03
5 years	-0.01±0.03	-0.06±0.02	-0.01±0.03	0.04±0.03	0.02±0.03	0.04±0.04
No lambs reared						
Single	2.64±0.30	3.13±0.26	2.83±0.25	2.13±0.25	1.92±0.23	2.35±0.17
Twin	-2.64±0.30	-3.13±0.26	-2.83±0.25	-2.13±0.25	-1.92±0.23	-2.35±0.17
General Mean - corrected to average ewe liveweight and average age of lamb at weaning	19.46±0.33	19.87±0.25	22.17±0.27	23.11±0.30	23.02±0.23	23.21±0.18

4.1.2.24 Lamb Survival

The model fitted to lamb survival percentage accounted for little of the total variation. In 5 of the separate sire group period analyses less than 5% of the variation was explained by the model. The least squares estimates and associated standard errors of the main environmental effects are presented in Table 4.2.47.

In the first two sire groups periods the high stocking rate ewes had significantly lower lamb survival percentages, however in sire group period 3 there was no difference between the stocking rates. After the stocking rate decrease there were no significant differences between the stocking rates, though the high stocking rate tended to have the better survival percentage. The reversal of stocking rate effects on lamb survival was probably attributable in part to the effects of natural selection occurring at the high stocking rate. Coop and Clark (1955) noted that lamb mortality was slightly increased by low-plane rearing nutrition levels but this was not statistically significant. Langlands *et al.* (1984b) reported that approximately 10 more lambs survived / 100 lambs born at the low than at the high stocking rate, the difference was significant at the first three and sixth lambings.

Rearing rank effects were non-significant, however as for stocking rate, the effect was reversed after the first 2 sire group periods. Initially ewes reared as twins had a lower offspring survival rate but in later sire group periods these ewes had the higher offspring survival rate.

Age effects were inconsistent, with large standard errors which meant few differences between age levels were significant. Birth year effects, age x birthyear, stocking rate x birthyear and age x birthyear x stocking rate interactions were nonsignificant for this trait.

Table 4.2.47: Least squares estimates and standard errors of environmental effects for lamb survival percentage

Factor	Sire group 1 1966/1967	Sire group 2 1968/1969	Sire group 3 1970/1971	Sire group 4 1972/1973	Sire group 5 1974/1975	Sire group 6 1977/1978
Age of Ewe						
2 years	0.19±2.85	-8.44±2.54	-3.36±2.47	4.57±2.40	1.43±3.27	-1.20±2.34
3 years	10.65±2.78	3.50±2.38	-4.43±2.42	-0.63±2.30	-1.09±3.15	3.12±2.27
4 years	-2.05±2.86	2.80±2.34	7.57±2.39	-1.88±2.30	-1.51±3.05	3.71±2.22
5 years	-8.79±2.83	2.15±2.40	0.22±0.42	-2.06±2.32	1.17±3.06	-5.63±2.27
Stocking Rate						
Control	4.09±1.63	3.13±1.46	-0.74±1.54	-1.04±1.45	-1.04±1.89	-1.30±1.34
High	-4.09±1.63	-3.13±1.46	0.74±1.54	1.04±1.45	1.04±1.89	1.30±1.34
Rearing Rank						
Single	2.71±1.67	2.77±1.50	-2.72±1.96	-1.65±2.04	-2.88±2.45	1.04±1.41
Twin	-2.71±1.67	-2.78±1.50	2.72±1.96	1.65±2.04	2.88±2.45	-1.04±1.41
General Mean	81.92±1.65	81.92±1.44	85.25±1.74	89.97±1.95	87.54±2.36	85.34±1.33

4.2 GENOTYPE X ENVIRONMENT INTERACTIONS AND INTRA-TRAIT GENETIC CORRELATIONS

The variance components estimates for sire, sire x birth-year interactions, sire x stocking rate interactions and error are presented in table 4.3.

As noted in the methods section the relative magnitudes of the sire x stocking rate and sire x year or birth year variance components to the total variance and genetic variance were computed to assess the importance of genotype x environment interactions in the traits under investigation.

Intra-trait genetic correlation estimates and associated standard errors are presented in table 4.4. The genetic correlations of each trait between the two stocking rates was a measure of the practical importance of sire x stocking rate interactions in selection. Where sire x stocking rate interactions are non-significant, intra-trait genetic correlations are expected to be 0.9 or greater. Hence an intra-trait genetic correlation indicates greater genotype x environmental interaction the further it deviates from 1.0. Robertson (1959) suggested that an estimate of r_g around 0.6 would be of consequence in selection.

Table 4.3: Pooled estimates of sire, sire x year, sire x stocking rate and error variance components in the hogget combined stocking rate analysis

Trait	σ^2_{sire}	$\sigma^2_{sire\ x\ year}$	$\sigma^2_{sire\ x\ sr}$	σ^2_{error}
WWT				
- both sexes	0.252	0.105	-	10.483
- ewe lambs	0.339	0.214	-	9.282
LW	0.293	0.922	0.267	15.366
GFW	0.015	0.013	0.003	0.229
CFW	0.013	0.007	0.003	0.155
Y	0.876	0.104	0.475	16.905
QN	0.266	-	0.042	3.481
MFD	0.541	0.135	0.075	5.853
SL	0.329	0.048	-	2.578
TCN	1.186	0.026	0.167	8.383
CF	0.056	-	-	0.512
SST	4.167	0.902	-	95.817
CHG	0.044	-	0.015	0.715
LUS	0.033	-	0.005	0.516
TIP	0.027	0.005	-	0.658
COT	0.021	-	-	0.312
CAG	0.015	0.004	-	0.332
SOU	0.046	0.016	-	1.486
HND	0.019	0.014	0.008	0.463
GCM	0.011	0.020	0.015	0.392
SCM	0.005	0.010	0.008	0.397
GCF	0.012	-	-	0.450

Table 4.3: Pooled estimates of sire, sire x year, sire x stocking rate and error variance components in the hogget control stocking rate analysis.

Trait	σ^2_{sire}	$\sigma^2_{sire \times year}$	σ^2_{error}
WWT			
- both sexes	0.272	0.219	10.378
- ewe lambs	0.463	0.033	9.290
LW	0.796	1.422	17.213
GFW	0.027	0.001	0.276
CFW	0.024	-	0.183
Y	1.347	-	16.427
QN	0.294	-	3.303
MFD	0.751	0.372	6.172
SL	0.256	0.043	2.715
TCN	1.231	0.182	8.147
CF	0.047	-	0.494
SST	1.800	-	81.743
CHG	0.045	0.023	0.706
LUS	0.047	-	0.506
TIP	0.019	0.009	0.703
COT	0.021	0.008	0.331
CAG	0.008	0.015	0.299
SOU	0.020	0.093	1.592
HND	0.014	0.047	0.461
GCM	0.045	0.006	0.445
SCM	0.015	0.011	0.388
GCF	0.008	-	0.418

Table 4.3: Pooled estimates of sire, sire x year, sire x stocking rate and error variance components in the hogget high stocking rate analysis.

Trait	σ^2_{sire}	$\sigma^2_{sire\ x\ year}$	σ^2_{error}
WWT			
- both sexes	0.153	0.089	10.060
- ewe lambs	0.090	-	8.715
LW	0.176	0.659	13.219
GFW	0.018	0.011	0.181
CFW	0.010	0.009	0.125
Y	1.458	0.003	17.693
QN	0.321	-	3.680
MFD	0.433	0.056	5.309
SL	0.392	-	2.447
TCN	1.302	-	8.537
CF	0.062	-	0.532
SST	4.907	4.076	110.731
CHG	0.053	0.008	0.704
LUS	0.029	-	0.527
TIP	0.034	0.004	0.670
COT	0.015	-	0.353
CAG	0.015	-	0.368
SOU	0.018	0.038	1.337
HND	0.035	0.002	0.450
GCM	0.024	0.010	0.342
SCM	0.004	0.021	0.405
GCF	0.008	-	0.492

Table 4.3: Pooled estimates of sire, sire x year, sire x stocking rate and error variance components in the ewe combined stocking rate analysis.

Trait	σ^2 sire	σ^2 sire x byr	σ^2 sire x sr	σ^2 error
LW	0.900	1.361	2.734	30.490
GFW	0.026	0.020	0.011	0.283
CFW	0.018	0.011	0.008	0.195
Y	0.485	0.641	0.401	16.761
QN	0.117	0.101	0.067	2.428
MFD	0.663	0.366	0.250	5.018
SL	0.227	0.160	0.127	2.897
TCN	0.370	0.179	0.233	6.675
CF	0.013	0.012	0.006	0.274
SST	0.859	1.314	1.780	45.885
CHG	0.017	0.018	0.009	0.645
LUS	0.004	0.009	0.008	0.543
TIP	0.031	0.006	0.006	0.548
COT	0.022	0.043	0.018	0.869
CAG	0.056	0.025	0.026	0.939
SOU	0.024	-	0.049	2.106
HND	0.023	0.016	0.003	0.498
GCM	-	0.014	0.001	0.413
SCM	-	0.002	0.011	0.425
GCF	0.003	0.008	0.003	0.554
NLB	-	0.008	0.001	0.274
NLW	-	0.006	0.008	0.301
WLW	-	2.663	4.750	145.002
WPL	0.101	-	0.447	12.126
LS	2.610	16.976	-	1123.605
LNLB	0.011	-	-	1.660
LNLW	0.053	-	-	1.736
LWLW	7.118	-	-	222.127

Table 4.3: Pooled estimates of sire, sire x year, sire x stocking rate and error variance components in the ewe control stocking rate analysis.

Trait	σ^2 sire	σ^2 sire x byr	σ^2 error
LW	4.642	2.873	31.135
GFW	0.029	0.047	0.291
CFW	0.027	0.022	0.204
Y	0.642	1.106	16.147
QN	0.188	0.152	2.635
MFD	0.978	0.728	0.467
SL	0.328	0.182	2.806
TCN	0.493	0.580	6.580
CF	0.013	0.023	0.260
SST	3.233	1.832	50.720
CHG	0.015	0.046	0.684
LUS	0.017	0.016	0.544
TIP	0.041	0.008	0.596
COT	0.036	0.039	0.843
CAG	0.051	0.079	0.967
SOU	0.057	0.040	2.008
HND	0.028	0.015	0.491
GCM	0.001	0.022	0.415
SCM	0.009	0.009	0.440
GCF	-	0.019	0.523
NLB	0.001	0.024	0.297
NLW	0.009	0.017	0.329
WLW	1.038	0.981	58.122
WPL	2.407	-	35.071
LS	-	35.151	1032.127
LNLB	0.028	0.066	1.657
LNLW	0.085	0.014	1.737
LWLW	5.180	-	318.652

Table 4.3: Pooled estimates of sire, sire x year, sire x stocking rate and error variance components in the ewe high stocking rate analysis.

Trait	σ^2 sire	σ^2 sire x byr	σ^2 error
LW	1.717	2.215	28.568
GFW	0.032	0.021	0.262
CFW	0.019	0.016	0.178
Y	0.844	0.658	17.154
QN	0.104	0.179	2.180
MFD	0.606	0.494	5.136
SL	0.356	0.203	2.946
TCN	0.451	0.359	6.513
CF	0.017	0.021	0.279
SST	1.560	1.322	40.777
CHG	0.025	0.014	0.599
LUS	-	0.013	0.536
TIP	0.024	0.011	0.500
COT	0.014	0.096	0.881
CAG	0.071	0.044	0.885
SOU	0.034	0.070	2.150
HND	0.021	0.029	0.501
GCM	0.005	0.007	0.402
SCM	0.008	0.002	0.408
GCF	0.001	0.025	0.570
NLB	-	0.003	0.241
NLW	-	0.009	0.270
WLW	-	0.486	26.594
WPL	0.297	0.101	9.835
LS	-	24.543	1202.456
LNLB	-	-	1.282
LNLW	-	-	1.501
LWLW	-	1.994	130.143

Table 4.3: Pooled estimates of sire, sire x year, sire x stocking rate and error variance components in the two year old ewe combined stocking rate analysis.

Trait	σ^2 sire	σ^2 sire x yr	σ^2 sire x sr	σ^2 error
LW	0.694	0.985	1.136	24.875
GFW	0.018	0.027	0.015	0.318
CFW	0.017	0.021	0.007	0.223
Y	0.071	0.927	0.560	14.968
QN	0.099	0.126	0.063	2.066
MFD	0.895	-	0.050	5.206
SL	0.310	0.014	0.067	3.278
TCN	1.003	-	-	8.494
CF	0.020	-	-	0.257
SST	-	0.277	0.870	45.537
CHG	0.038	-	-	0.532
LUS	-	0.013	0.007	0.553
TIP	0.015	0.018	0.001	0.491
COT	0.044	0.036	-	0.819
CAG	0.020	0.021	0.025	1.057
SOU	0.006	-	0.027	1.842
HND	0.014	0.016	-	0.494
GCM	-	0.004	-	0.409
SCM	0.003	-	0.008	0.370
GCF	0.011	-	-	0.646
NLB	-	0.012	-	0.253
NLW	-	0.009	0.010	0.266
WLW	0.079	0.269	0.501	26.833
WPL	0.015	-	0.493	10.392
LS	-	39.841	-	1286.094

Table 4.3: Pooled estimates of sire, sire x year, sire x stocking rate and error variance components in the three year old ewe combined stocking rate analysis.

Trait	σ^2 sire	σ^2 sire x yr	σ^2 sire x sr	σ^2 error
LW	1.711	0.529	0.771	31.172
GFW	0.023	0.016	-	0.302
CFW	0.017	0.008	0.002	0.216
Y	0.807	-	0.337	16.273
QN	0.159	-	-	2.627
MFD	0.531	0.206	0.036	5.369
SL	0.191	0.066	0.039	2.624
TCN	0.329	-	0.032	6.738
CF	0.020	-	-	0.280
SST	1.075	-	-	48.815
CHG	0.015	-	0.023	0.679
LUS	0.006	0.010	-	0.508
TIP	0.030	-	-	0.574
COT	0.030	0.005	-	0.837
CAG	0.047	-	-	0.846
SOU	0.087	-	0.037	1.949
HND	0.031	0.003	0.010	0.497
GCM	-	0.010	-	0.430
SCM	0.003	0.005	-	0.435
GCF	0.002	0.005	0.006	0.553
NLB	-	-	-	0.264
NLW	0.003	-	-	0.285
WLW	-	-	1.078	34.682
WPL	-	-	0.906	12.751
LS	-	6.247	-	1010.766

Table 4.3: Pooled estimates of sire, sire x year, sire x stocking rate and error variance components in the four year old ewe combined stocking rate analysis.

Trait	σ^2 sire	σ^2 sire x yr	σ^2 sire x sr	σ^2 error
LW	1.733	-	2.345	34.383
GFW	0.037	-	-	0.280
CFW	0.021	-	-	0.189
Y	0.808	0.561	-	16.978
QN	0.181	0.046	-	2.893
MFD	0.835	0.001	-	5.614
SL	0.443	0.069	0.008	3.095
TCN	0.254	-	-	6.536
CF	0.021	0.001	-	0.310
SST	2.298	-	-	42.996
CHG	0.020	0.044	-	0.659
LUS	0.020	-	-	0.557
TIP	0.046	-	-	0.538
COT	0.007	0.051	0.045	0.886
CAG	0.075	0.004	-	0.951
SOU	-	-	-	2.226
HND	0.024	0.023	-	0.478
GCM	-	0.018	0.010	0.380
SCM	0.004	-	-	0.430
GCF	0.027	-	-	0.497
NLB	-	0.001	0.003	0.263
NLW	-	-	0.008	0.313
WLW	0.141	-	2.645	49.525
WPL	0.219	-	-	13.461
LS	18.429	-	-	992.435

Table 4.3: Pooled estimates of sire, sire x year, sire x stocking rate and error variance components in the five year old ewe combined stocking rate analysis.

Trait	σ^2_{sire}	$\sigma^2_{\text{sire x yr}}$	$\sigma^2_{\text{sire x sr}}$	σ^2_{error}
LW	2.192	-	0.868	37.173
GFW	0.039	-	0.002	0.277
CFW	0.024	-	-	0.181
Y	0.261	0.358	-	19.980
QN	0.077	0.024	-	2.513
MFD	0.739	0.066	-	5.551
SL	0.275	0.118	-	3.075
TCN	0.374	-	-	6.278
CF	0.004	0.007	-	0.308
SST	2.705	0.284	-	47.160
CHG	0.021	-	0.001	0.719
LUS	0.004	-	0.017	0.569
TIP	0.016	-	0.012	0.622
COT	0.021	0.052	0.007	0.961
CAG	0.085	0.026	0.004	0.981
SOU	0.009	-	-	2.581
HND	0.023	0.011	-	0.550
GCM	0.004	0.008	-	0.424
SCM	-	-	0.030	0.474
GCF	-	0.011	-	0.536
NLB	-	0.004	0.003	0.319
NLW	-	0.003	0.003	0.364
WLW	-	-	-	52.434
WPL	0.095	-	0.516	11.449
LS	-	33.995	7.521	1208.217

Table 4.4: Intra-trait genetic correlations and standard errors of traits in two stocking rates for hoggets.

Trait	r_g	SE	Trait	r_g	SE
LWT	0.51	0.04	CHG	0.71	0.03
GFW	0.84	0.02	LUS	0.89	0.03
CFW	0.89	0.02	TIP	1.04	0.05
Y	0.57	0.17	COT	1.01	0.05
QN	0.85	0.03	CAG	1.04	0.05
MFD	0.90	0.02	SOU	1.00	0.09
SL	1.02	0.02	HND	0.73	0.03
TCN	0.87	0.01	GCM	0.21	0.08
CF	1.01	0.01	SCM	0.14	0.09
SST	1.10	0.12	GCF	1.00	0.29

Table 4.4: Intra-trait genetic correlations and standard errors of traits in two stocking rates for ewes

Trait	r_g	SE	Trait	r_g	SE
LWT	-0.24	0.03	CHG	0.60	0.03
GFW	0.65	0.01	LUS	0.00	0.07
CFW	0.65	0.01	TIP	0.85	0.02
Y	0.42	0.04	COT	0.46	0.04
QN	0.58	0.02	CAG	0.63	0.02
MFD	0.70	0.01	SOU	-0.01	0.11
SL	0.56	0.02	HND	0.89	0.01
TCN	0.52	0.02	GCM	1.89	0.14
CF	0.63	0.02	SCM	-1.00	0.06
SST	-0.02	0.05	GCF	0.38	0.14

4.2.1 LIVEWEIGHT

Weaning Weight

Sire and sire interactions controlled little of the total variation in the weaning weight model (Table 4.1), reflecting the greater importance of the dam on lamb weight to weaning as compared to the sire of the lamb.

The sire x year interaction variance components accounted for only 2.2% of the total variance (1.0% for both sexes combined). Sire x stocking rate interactions did not explain any of the variation in the model and accounted for none of the total variance. Sire x year interactions were unimportant in the separate stocking rates also. Thus random interactions were not important for this trait.

The low proportion of total variance accounted for by sire was reflected in the heritability estimates calculated by the EI method, especially in the HSR (sire only 1.0% of total variance).

Hogget Liveweight

Sire and sire stocking rate interaction effects were of little importance in the hogget liveweight model (table 4.1), and although Morley (1956) reported highly significant sire x nutrition interactions for 12 and 17 months body weight, the difference between the planes of nutrition in his experiment was more extreme than usually found.

Sire x year interactions contributed 1.4% of the total model variability. Rae (1958) discussed possible causes of sire x year interactions. Other researchers found sire x year interactions to be a nonsignificant or negligible source of variation in hoggets (Ch'ang, 1967;

King and Young, 1955) and in adults (Dunlop, 1963; Rae, 1958). Chopra (1978) noted that even though small, significant sire x year interactions could have considerable selection implications.

Sire x year interactions contributed 5.5, 7.3 and 4.7% of the total variance in the combined, control and high stocking rates respectively and 62.2, 64.1 and 78.9% of the genetic variance. Sire x stocking rate interactions accounted for 1.6% of the total variance and 18.0% of the genetic variance in the combined stocking rate analyses.

The ratio of sire x stocking rate and sire x year interactions to the between sire variances was 4:1, indicating the importance of the GxE interactions in this trait. Most variation was attributable to sire x year interactions, with the ratio of sire x year to between sire variances being 3.4, 1.8 and 3.7 in the combined, control and high stocking rates respectively.

The intra-trait genetic correlation for hogget liveweight was 0.51 ± 0.04, supporting the observation that the sire x stocking rate interactions, though small, were real. The presence of the sire x year and sire x stocking rate interactions in SLW, will have implications in commercial breeding. Chopra (1978) obtained a similar estimate for the intra-trait genetic correlation, 0.58 ± 0.20.

Ewe Liveweight

Sire and sire interactions controlled little of the total variation explained by the model for ewe liveweight. However, unlike hoggets where sire x year interactions controlled the most of the three sources of variation, in the ewe analyses sire x stocking rate interactions were most important (table 4.1).

In the pooled data analysis sire x birthyear and sire x stocking rate interactions contributed 3.8 and 7.7% of the total variance and accounted for 27.2 and 54.7% of the genetic variance. Sire x birthyear interactions contributed 7.4 and 6.8% of the total variance and 38.2 and 56.3% of the genetic variance in the control and high stocking rates respectively. The effects of sire x birthyear interactions were greater in the high stocking rate than in the control stocking rate. These observations were supported by the relative magnitudes of the two parts of the genetic variance, the ratio was 4.6 in the combined stocking rate and 0.6 and 1.3 in the control and high stocking rates.

Similar trends were observed in the separate age analyses. Effects of sire x year interactions declined, with 35.0 and 17.6% of the genetic variance due to sire x year interactions at 2 and 3 years of age and none at 4 and 5 years of age. Sire x stocking rate interactions contributed 4.1, 2.3, 6.1 and 2.2% of the total variance and accounted for 40.4, 25.6, 57.5 and 28.4% of the genetic variance in the respective age classes.

The estimated intra-trait genetic correlation was -0.24 ± 0.03. This implied that the genes controlling liveweight in one of the stocking rates had the opposite effect in the other stocking rate. Similar effects were observed by Falconer (1960) in his experiment on selection of mice for growth on high and low planes of nutrition. However, it implies that if, in this flock, sires were selected at a stocking rate other than that in which their progeny were to perform then selection of the 'worst' sires would be required to obtain any genetic improvement in liveweight in the other environment.

4.2.2 GREASY AND CLEAN FLEECE WEIGHT

Because clean fleece weight was derived from greasy fleece weight and yield some association with these traits was expected. CFW variance components were found to be close to those for GFW (see Table 4.3) such that trends and conclusions are applicable to both traits. Hence fleece weight in general will be discussed, except if any important deviations occur.

Hogget Fleece Weight

In the combined stocking rate analysis, sire x stocking rate interactions contributed only 1.2% to the total variance and 9.7% to the genetic variance. Other studies (Morley, 1956; Rae, 1958; King *et al*. 1959; Dunlop, 1962; Osman and Bradford, 1965; Carter *et al*. 1971a) have also noted that genotype x nutrition interactions are of little importance in GFW.

Sire x year interactions were significant, contributing 5.0 and 3.9% of the total variance and 41.9 and 30.4% of the genetic variance in GFW and CFW respectively in the combined data analysis. In the control stocking rate sire x year interactions were nonsignificant but in the high stocking rate they contributed similar amounts to in the combined data analysis. Such interactions however, were non-significant for GFW in the studies by Rae (1958) and Dunlop (1962).

The intra-trait genetic correlations calculated were 0.84 ± 0.02 for GFW and 0.89 ± 0.02 for CFW. As the sire x stocking interactions were nonsignificant in the combined data analysis, the high values for the intra-trait genetic correlation indicated that the sire x nutrition interactions would have little effect on hogget GFW and CFW selection.

Ewe Fleece Weight

As found by other researchers and as noted for hogget fleece weight sire x stocking rate interactions were nonsignificant for GFW and CFW. The same occurred in the separate age analyses, with sire x stocking rate interactions contributing only 4.0% of the total variance in GFW and 2.6% in CFW for age 2 ewes and zero or less than 1% for the older ages.

Sire x birth year interactions contributed 5.9% (4.7%) and 35.1% (29.7%) of the total and genetic variances respectively for GFW (CFW) in the combined data analysis. Proportions of variance were similar in the HSR but twice as large in the CSR. In the separate age analyses importance of sire x year interactions declined for GFW from 7.1% of the total variance in age 2, 4.7% in age 3 to nil at 4 and 5 years of age. Similar trends occurred for CFW.

For many of the traits sire x environment interactions declined in significance as age increased. Possible explanations of this include a decline in the influence of birth year as the ewe becomes older or, as the year interaction was solely due to the record year component in the separate age analyses, the older ewes may be less sensitive to year-to-year variations.

Estimated intra-trait genetic correlations for GFW and CFW were 0.65 ± 0.01 and 0.65 ± 0.01, respectively. Thus the genes controlling fleece weight in the control stocking rate have a different effect in part in the high stocking rate.

4.2.3 CLEAN SCOURED YIELD

Hogget Clean Scoured Yield

As noted by Chopra (1978) sire x year interactions were small and formed less than 1% of the total variance in any of the hogget analyses.

In the combined data analysis sire x stocking rate contributed 2.6% of the total variance and accounted for 32.6% of the genetic variance. Similar results were obtained by Chopra (1978). Morley (1956) reported that sire x nutrition interactions were non-significant in yield data. Although the interaction term was not large, Dunlop (1962) observed significant strain x environment interactions.

The estimated intra-trait genetic correlation was 0.57 ± 0.17.

Ewe Clean Scoured Yield

Sire x environment interactions were important sources of variation in ewe yield analyses. Sire x birthyear and sire x stocking rate interactions controlled 3.5% and 2.2% of the total and 42.0% and 26.3% of the genetic variances respectively in the combined data analysis. Sire x birthyear interactions controlled 6.2% and 63.3% of the total and genetic variances in the CSR and 3.5% and 43.8% in the HSR.

The ratio of the sire interactions to between sire variances was 2.1 in the pooled data analysis indicating that the sire x environment interactions were important sources of variation in this trait. However, in the separate ages the ratio decreased from 20.9 in the 2 year olds to 0.4, 0.7 and 1.3 in the older ages.

In the separate age analyses the importance of interactions declined as age increased. Sire x stocking rate interactions contributed no variance at 4 and 5 years of age and sire x year interactions were less important at older ages also.

The estimated intra-trait genetic correlation was 0.42 ± 0.04.

4.2.4 QUALITY NUMBER

Hogget Quality Number

In the hogget analyses sire x year and sire x stocking rate interactions were nonsignificant, with sire x year interactions controlling zero variance in all analyses and sire x stocking rate interactions controlling > 1.1% of the total variance in the combined data analysis. Other researchers have also found that sire x environment interactions were nonsignificant (Rae, 1958; Osman and Bradford, 1965) or negligible (Dunlop, 1962) sources of variation in quality number.

The intra-trait genetic correlation between the two stocking rates was 0.85 ± 0.03.

The lack of sire x environment interactions and high intra-trait genetic correlation indicated that genotype×environment interactions were not important for hogget QN in this flock.

Ewe Quality Number

In the combined data and separate stocking rate analyses sire x birth year and sire x stocking rate interactions were significant. Sire x birthyear controlled 3.7, 5.1 and 7.3% of the total variance and 35.4, 44.7 and 63.3% of the genetic variance in the combined, control and high stocking rates respectively. Sire x stocking rate interactions were less important, controlling 2.5% of the total and 23.5% of the genetic variance in the combined data analysis.

In the separate age analyses sire x stocking rate controlled part of the total variation (2.7%) in the 2 year old ewes only. Sire x year interactions contributed 5.4, 0.0, 1.5 and 0.9% at 2, 3, 4 and 5 years of age. Hence sire x environment interactions were present at 2 years of age but were negligible at later ages. The ratio of sire interaction to between sire variance was 1.9 in the 2 year old ewe analysis.

The intra-trait genetic correlation estimate was 0.58 ± 0.02, significantly lower than in the hogget analyses (0.85 ± 0.03).

4.2.5 MEAN FIBRE DIAMETER

Hogget Mean Fibre Diameter

When fitting models to hogget MFD there was much unexplained variation, the model accounting for only 19.5% (Table 4.1). Sire accounted for the largest proportion of variation in the model (7.4%), with sire interactions contributing a further 2.9%. Dunlop (1962) reported significant strain x location interactions, of moderate size, in MFD. Flocks x level of nutrition interactions were found to be significant for fibre cross-sectional area by Williams (1966). King and Young (1955), however, did not observe any significant breed x nutrition interactions for fibre diameter.

Sire x year interactions contributed 2.0% of the total variance and 18.0% of the genetic variance in the combined data analyses. Sire x stocking rate interactions contributed 1.1 and 10.0% of the total and genetic variances. In the separate stocking rates sire x year interactions contributed 5.1 and 1.0% of the total variance and accounted for 33.1 and 11.5% of the genetic variance in the CSR and HSR respectively.

The ratio of sire interactions to between sire variance components was less than 0.5 in all hogget MFD analyses, demonstrating that these interactions were not important in this trait. Similarly, the estimated intra-trait genetic correlation was high (0.90 ± 0.02). This was comparable to the estimate by Chopra (1978) of 0.93 ± 0.09.

Ewe Mean Fibre Diameter

Sire x birth year and sire x stocking rate interactions controlled 5.8 and 4.0% of the total variance and 28.6 and 19.5% of the genetic variance in the combined stocking rate analysis. Sire x year interactions controlled 33.5 and 7.9% of the total variance in CSR and HSR respectively and 42.7 and 44.9% of the genetic variance. The ratio of sire interaction to between sire variance thus approached 1.0 in the combined and separate stocking rate analyses, such that GxE interactions could be of importance in genetic parameters for ewe MFD.

In separate age analyses interactions were of less importance, controlling less than 1.0% of the total variance (except sire x year in 3 year old ewes which controlled 3.4% of total variance).

The intra-trait genetic correlation between the two stocking rates was estimated as 0.70 ± 0.01. This was significantly lower than for hoggets. It should be noted that the hogget measurements were by the projection microscope and only a small number of fibres were measured for each sample (150) while the ewe measurements were by airflow. It is unlikely that this would have influenced the relative sizes of the intra-trait genetic correlations but it may have been a factor in the high unexplained variation in the hogget model.

4.2.6 STAPLE LENGTH

Hogget Staple Length

When fitting models to hogget staple length data it was observed that sire x stocking rate and sire x year interactions were nonsignificant. This was confirmed with sire x stocking rate interactions contributing nothing to the total variance, while sire x year interactions accounted for only 1.6% of the total variance in the combined data analysis and 1.4 and 0.0% in the control and high stocking rates.

These results are in agreement with other studies. Morley (1956) reported non-significant sire x nutrition interactions for SL, while King and Young (1955) and King *et al.* (1959) reported similar results for average fibre length. Dunlop (1962) indicated small significant strain x location interactions, however the interactions accounted for only a minor (less than 1%) fraction of the variation. Sire x year interactions were found to control little of the variation in this trait by Rae (1958), Dunlop (1962) and Chopra (1978).

The intra-trait genetic correlation estimate for staple length in hoggets in this study was 1.02 ± 0.02. Thus, as genotype x environment interactions are of no importance in this trait and the intratrait genetic correlation is equal to 1.0, selection for SL in one environment will be equally effective in changing performance in another environment and maximum progress would be made in the environment demonstrating the greatest heritability.

Ewe Staple Length

Sire x birth year interactions were significant for ewe staple length in the combined data, CSR and HSR analyses contributing 4.7, 5.5 and 5.8% of the total variance, and 31.1, 35.7 and 36.3% of the genetic variance, respectively. In the separate age analyses sire x birth year interactions were less important, controlling an increasing percentage of the total variance with increasing age (0.4, 2.2, 1.9 and 3.4 for 2, 3, 4 and 5 year old ewe analyses).

Sire x stocking rate interactions controlled 3.7% of the total variance and 24.7% of the genetic variance in the combined data analysis, but less than 2% in the separate age analyses.

Except in the combined data analysis the ratio of the sire interaction to the between sire variances was less than 1.0, in the combined analysis the ratio was 1.3.

The estimate of the intra-trait genetic correlation between the two stocking rates was 0.56 ± 0.02, significantly lower than for the hogget analysis. The intra-trait genetic correlation indicated that the sire x stocking rate interactions, while small, were of importance.

4.2.7 TOTAL CRIMP NUMBER

Hogget Total Crimp Number

Sire x environment interactions contributed less than 2% of the total variance in all the hogget analyses. In the combined data analysis sire x stocking rate interactions accounted for 12.1% of the genetic variance, while sire x year interactions contributed only 1.9%. In the CSR sire x year interactions accounted for 12.9% of the genetic variance, but were not present in the HSR.

The intra-class genetic correlation estimate was 0.87 ± 0.01. Thus in general sire x environment interactions were unimportant in hogget total crimp number in this flock.

Ewe Total Crimp Number

Sire x stocking rate interactions contributed a significant proportion of the variance in the combined data, accounting for 3.1% of the total variance and 29.8% of the genetic variance. In the separate age analyses however, the sire x stocking rate interactions did not account for any of the variance.

Similarly, sire x birthyear interactions contributed 2.4% of the total variance in the combined data analysis and 7.6 and 4.9% in the CSR and HSR, but none were present in the separate age analyses. Sire x birth year interactions accounted for 22.9, 54.1 and 44.3% of the genetic variance in the combined, control and high stocking rates respectively.

The estimated intra-class genetic correlation was 0.52 ± 0.02. This was lower than the hogget intra-trait correlation for TCN (0.87 ± 0.01).

4.2.8 CRIMP FREQUENCY

Hogget Crimp Frequency

No sire x stocking rate or sire x year interactions were present in this trait. Morley (1956) and Dunlop (1962) also reported such interactions to be of no consequence in this trait.

The intra-trait genetic correlation was estimated as 1.01 ± 0.01. Hence, as for SL and TCN, genotype x environment interactions are not present for CF in hoggets in this flock.

Ewe Crimp Frequency

Sire x birth year interactions accounted for 3.9, 7.8 and 6.6% of the total variance and 38.7, 63.9 and 55.3% of the genetic variance in the combined data, control and high stocking rates respectively.

Sire x stocking rate interactions contributed 2.0% of the total variance and 19.4% of the genetic variance.

Sire x environment interactions were not present in the separate age analyses, except for 2.2% of the total variation contributed by sire x birth year interactions in the 5 year old ewe analysis.

The intra-trait genetic correlation was estimated as 0.63 ± 0.02.

4.2.9 STAPLE STRENGTH

Hogget Staple Strength

Sire x stocking rate interactions were non-significant for staple strength in hoggets, contributing nothing to the total variance.

Sire x year interactions accounted for only 0.9% of the total variance, which equated to 17.8% of the genetic variance. This was due to the presence of sire x year interactions in the HSR, controlling 3.4% of the total variance. Sire x year interactions were not present in the CSR.

The intra-trait genetic correlation was estimated as 1.10 ± 0.12. With the low importance of genotype x environment interactions and the high intra-trait genetic correlation, selection for hogget staple strength would be most effective when carried out in the stocking rate with the highest heritability (HSR). Gains made in one stocking rate would still be present in the other stocking rate.

Ewe Staple Strength

Sire x birth year interactions controlled 2.6% of the total variation in the combined data analysis, 3.3 and 3.0% in the CSR and HSR respectively, but less than 1% in the separate age analyses. Where significant, sire x birth year interactions controlled about 33-46% of the genetic variance.

Sire x stocking rate interactions controlled 3.6% of the total variance and 45.0% of the genetic variance in the combined data analysis but were non significant in the separate age analyses.

The intra-trait genetic correlation was estimated as -0.02 ± 0.05.

Therefore, in this trait the presence of genotype x environment interactions and very low intra-trait genetic correlation and low heritabilities means that little progress would result from indirect selection.

4.2.10 CHARACTER GRADE

Hogget Character Grade

Sire x year interactions contributed nothing to the total variance in the combined data analysis. In the separate stocking rates they contributed 3.0 and 1.0% of the total variance in the CSR and HSR respectively, accounting for 33.8 and 13.1% of the genetic variance. Rae (1958) reported significant sire x year interactions in this trait; however Dunlop (1962) reported that sire x year interactions accounted for a negligible percentage of the total variation.

In the combined data analyses sire x stocking rate interactions contributed 1.9% to the total variance, accounting for 25.4% of the genetic variance.

The intra-trait genetic correlation between the two stocking rates was estimated to be 0.71 ± 0.03.

Ewe Character Grade

Sire x birth year interactions accounted for 2.6 and 40.9% of the total and genetic variance respectively in the combined data analysis, 6.2 and 75.4% in the CSR and 2.2 and 35.9% in the HSR.

In the control stocking rate the presence of highly significant sire x birth year interactions, with the ratio of sire interaction to between sire variance being 3.1, would mean that the ranking of sires would change across years.

Sire x stocking rate interactions were less important contributing 1.3% of the total variance and 20.5% of the genetic variance in the combined data analysis.

In the separate age analyses genotype x environment interactions did not contribute to the total variance, with the exceptions of sire x stocking rate interactions in the 3 year old ewe analysis (accounted for 3.2% of the total variance) and sire x year interactions in the 4 year old ewe analysis (accounted for 6.1% of the total variance).

The estimated intra-trait genetic correlation was 0.60 ± 0.03.

4.2.11 LUSTRE GRADE

Hogget Lustre Grade

Sire x year interactions were not present in the hogget lustre grade analyses. Sire x stocking rate interactions contributed less than 1% of the total variation in the combined stocking rate analysis.

The intra-trait genetic correlation estimate was 0.89 ± 0.03. Thus GxE interactions were unimportant in hogget lustre grade.

Ewe Lustre Grade

Unlike in the hoggets, genotype x environment interactions were important in ewe lustre grade analyses. Sire x birth year and sire x stocking rate interactions controlled 1.6 and 1.4% of the total variance and 42.9 and 38.1% of the genetic variance, respectively in the combined age analysis. The ratio of sire interactions to between-sire variance was 4.25, reflecting the importance of GxE interactions in ewe lustre grade.

Sire x birth year interactions contributed 2.8 and 2.4% of the total variance in the CSR and HSR, respectively, accounting for 48.5 and 100.0% of the genetic variance.

In the separate age analyses the importance of sire x year interactions declined as age increased (2.3, 1.9, 0 and 0% of the total variance controlled in consecutive age classes). Sire x stocking rate interactions accounted for 1.2 and 2.9 of the total variance in the 2 and 5 year old ewe analyses respectively.

The intra-trait genetic correlation between the two stocking rates was 0.00 ± 0.07. Selection response in one environment would therefore carry no advantage in the other environment.

4.2.12 TIPPINESS GRADE

Hogget Tippiness Grade

Genotype x environment interactions were non-significant for hogget tippiness grade. Sire x stocking rate interaction accounted for none of the total variance and sire x year interactions contributed less than 1.5% in any of the analyses.

The intra-trait genetic correlation was estimated as 1.04 ± 0.05.

Ewe Tippiness Grade

Sire x birth year interactions contributed 1.0, 1.2 and 2.1% of the total variance in the pooled data, CSR and HSR analyses, accounting for 14.0, 16.3 and 31.4% of the genetic variance respectively. Sire x stocking rate interactions were nonsignificant, contributing only 1% to the total variance, in the pooled analyses.

In the separate age analyses sire x stocking rate interactions contributed less than 0.5% except in the 5 year old ewe analysis where they accounted for 1.8% of the total variance. Sire x year interactions contributed to the 2 year old ewe analysis only, accounting for 3.4% of the total variance and 52.9% of the genetic variance.

The estimated intra-trait genetic correlation between the two environments was 0.85 ± 0.02. As sire x stocking rate and sire x birth year interactions were generally nonsignificant and the intra-trait genetic correlation is high it can be concluded that GxE interactions are not important for this trait in this flock.

4.2.13 COTTING GRADE

Hogget Cotting Grade

Genotype x environment interactions contributed none of the variance in the combined data and high stocking rate analyses. In the CSR sire x year interactions contributed 2.2% of the total variance, accounting for 27.5% of the genetic variance.

The intra-trait genetic correlation estimate was 1.01 ± 0.05. Hence genotype x environment interactions are unimportant for hogget cotting grade in this flock.

Ewe Cotting Grade

Sire x birth year interactions contributed significant amounts to the variation in ewe cotting grade in most analyses, accounting for greater than 4% of the total variance and more than 45.0% of the genetic variance, except in the 3 year old ewe analysis.

Sire x stocking rate interactions controlled 1.9% of the total variance and 21.7% of the genetic variance in the pooled analysis. They were not significant in the first two age classes, controlled 4.6% of the total variance in the 4 year old ewes and only 0.7% of the total variance in the last age class.

The ratio of sire interactions to between sire variance was high for most analyses, being 2.8, 1.1 and 6.9 in the pooled data, CSR and HSR respectively and 0.8, 0.2, 13.7 and 2.8 in the respective age classes.

The estimated intra-trait genetic correlation was 0.46 ± 0.04. This was significantly lower than the estimate for hogget COT (1.01 ± 0.05). The low intra-trait genetic correlation estimate and high variance ratios reflected the importance of genotype x environment interactions in this trait in this flock.

4.2.14 COTTED AREA GRADE

Hogget Cotted Area Grade

Sire x year interactions contributed only 1.1% of the total variance in the pooled analysis. In the separate stocking rates sire x year interactions were not present in the HSR and contributed 4.7% of the total variance in the CSR, accounting for 65.2% of the genetic variance.

No sire x stocking rate interactions were present in the pooled analysis.

The intratrait genetic correlation for hogget CAG was estimated as 1.04 ± 0.05. Although there was a significant sire x year interaction in the CSR, heritability estimates by the EI and II methods (Table 4.5) were not significantly different and with the other interactions being unimportant and the high intra-trait genetic correlation it was concluded that GxE interactions are not important for hogget cotted area grade in this flock.

Ewe Cotted Area Grade

Sire x birth year interactions contributed 2.4, 7.2 and 4.4% of the total variance in the pooled, CSR and HSR respectively, accounting for 23.4, 60.8 and 38.3% of genetic variance respectively. In the separate age analyses sire x year interactions controlled 1.9, 0, 0.4 and 2.4% of the total variance in respective age classes.

Sire x stocking rate interactions contributed 2.5 and 24.3% of the total and genetic variance respectively in the pooled analysis. In the separate age analyses sire x stocking rate interactions contributed 2.2% of the total variance in the 2 year old ewe analysis but less than 0.5% in the older ewe analyses.

The intra-trait genetic correlation was estimated as 0.63 ± 0.02.

4.2.15 SOUNDNESS GRADE

Hogget Soundness Grade

No sire x stocking rate interactions were present in the combined data analysis. Sire x year interactions were non-significant in the combined data analysis, but contributed 5.5 and 2.7% of the total variance, accounting for 82.3 and 67.8% of the genetic variance, in the CSR and HSR respectively.

Dunlop (1962) reported that strain x location and strain x year interactions were not significant for soundness, as found in the combined data analysis in this study.

The estimate of the intra-trait genetic correlation between the two stocking rates was 1.00 ± 0.09.

Ewe Soundness Grade

In the combined data analysis sire x birthyear interactions were unimportant. Sire x stocking rate interactions contributed 2.2% of the total variance, accounting for 67.1% of the genetic variance.

In the separate stocking rate analyses sire x birth year interactions contributed 1.9 and 3.1% of the total variance, accounting for 41.2 and 67.4% of the genetic variance, in the CSR and HSR respectively.

Sire x year interactions did not contribute to the variance in the separate age analyses. Sire x stocking rate interactions were only present in the first 2 age classes, contributing 1.4 and 1.8% of the total variance. Although controlling a low percentage of the total variance the sire x stocking rate interactions accounted for a large proportion (81.8%) of the genetic variance in the 2 year old ewe analysis. It was less important in the 3 year old ewe analysis, accounting for 29.8% of the genetic variance.

The intra-trait genetic correlation was estimated as -0.01 ± 0.11. This implied that the genes controlling soundness in one stocking rate had no influence in the other stocking rate.

4.2.16 HANDLE GRADE

Hogget Handle Grade

Sire x stocking rate interactions in the combined data analysis were non-significant, controlling only 1.6% of the total variance. Sire x year interactions were significant in the combined and CSR analyses, contributing 2.8 and 9.0% of the total variance and 34.1 and 77.0% of the genetic variance, respectively. In the HSR, sire x year interactions only accounted for 0.4% of the total variance. Dunlop (1962) reported that strain x location interactions were a negligible source of variation for this trait.

The intra-trait genetic correlation estimate was 0.73 ± 0.03.

Ewe Handle Grade

Sire x stocking rate interactions were non-significant in this trait, controlling 0.6% of the total variance in the pooled data analysis. The only other stocking rate interaction, in the second age class, controlled only 1.8% of the total variance and was also non-significant.

Sire x birth year interactions were important, controlling 3.0, 2.8 and 5.3% of the total variance in the pooled, CSR and HSR analyses respectively, accounting for 38.1, 34.9 and 58.0% of the genetic variance. In the separate age analyses sire x year interactions contributed 3.1, 0.6, 4.4 and 1.9% of the total variance in the four age classes respectively.

The ratio of sire interactions to between sire variances was 0.8, 0.54 and 1.2 in the pooled data, CSR and HSR respectively. The intra-trait genetic correlation between the two stocking rates was estimated as 0.89 ± 0.01. The paternal half-sib estimates of heritability calculated by the EI and II methods were not significantly different (Table 4.5) and as sire x stocking rate interactions were nonsignificant and sire x birth year interactions generally unimportant it could be concluded that genotype x environment interactions were not very important for ewe handle grade in this flock.

4.2.17 GREASY MIDSIDE COLOUR GRADE

Hogget Greasy Midside Colour Grade

Sire x stocking rate interactions controlled 3.4 and 32.6% of the total and genetic variance in the combined data analysis. Sire x year interactions were significant in the combined data analysis, contributing 4.6% of the total variance and 43.5% of the genetic variance, but were less important in the separate stocking rate analyses, contributing 1.2 and 2.7% of the total variance in the CSR and HSR respectively.

Dunlop (1962) reported that sire x year interactions were non-significant in this trait. He noted that though strain x station interactions were significant, the average size of the interaction term was small.

The intra-trait genetic correlation was estimated as 0.21 ± 0.08. Therefore genes controlling GCM in one stocking rate in the hoggets in this flock did not have the same effect in the other stocking rate.

Ewe Greasy Midside Colour Grade

Sire x stocking rate interactions were unimportant. In the pooled data analysis sire x stocking rate interactions contributed 0.2% of the total variance, a result of the presence of an interaction in the 4 year old ewe analysis where it controlled 2.5% of the total variance. No sire x stocking rate interactions were present in the other age analyses.

Sire x birth year interactions contributed 3.3, 5.0 and 1.7% of the total variance, accounting for 93.3, 95.7 and 58.3% of the genetic variance in the pooled data, CSR and HSR analyses respectively. In the separate age analyses sire x year interactions controlled 1.0, 2.3, 4.4 and 1.8% of the total variance respectively. Because sire variance was absent or of very low magnitude and sire x stocking rate interactions were nonsignificant the sire x birth year interactions contributed most of the genetic variance.

The low sire variance estimates, 0.000, 0.001 and 0.005 in the pooled data, CSR and HSR respectively, contributing only 0.0, 0.2 and 1.2% of the total variance, resulted in an estimated intra-trait genetic correlation estimate of 1.89 ± 0.14.

4.2.18 SCOURED MIDSIDE COLOUR GRADE

Hogget Scoured Midside Colour Grade

Sire x stocking rate interactions contributed 1.9 and 34.8% of the total and genetic variance in the combined data analysis. Sire x year interactions contributed 2.4 and 43.5% of the total and genetic variance. In the separate stocking rate analyses sire x year interactions contributed 2.7 and 4.9% of the total variance in the

CSR and HSR respectively, accounting for 42.3 and 84.0% of the genetic variance.

The ratio of sire interactions to between sire variances was 3.6, 0.7 and 5.25 in the combined, HSR and CSR respectively.

The estimated intra-trait genetic correlation was 0.14 ± 0.09. Chopra (1978) obtained an estimate of 0.57 ± 0.37. The ratio of variance components and low intra-trait genetic correlation indicated the importance of genotype x environment interactions on hogget scoured midside colour.

Ewe Scoured Midside Colour Grade

Sire x birth year interactions contributed less than 2.0% of the total variance in analyses of ewe SCM. Sire x stocking rate interactions contributed 2.5% of the total variance, accounting for 84.6% of the genetic variance, in the pooled data analysis. In the separate age analyses sire x stocking rate interactions controlled 2.1, 0.0 and 6% of the total variance in the respective age classes.

Although sire interactions were not significant in terms of the total variance, the low sire variances resulted in interactions controlling most of the genetic variance. The intra-trait genetic correlation was estimated as -1.00 ± 0.06. This resulted from the lack of sire variance.

4.2.19 GREASY FLEECE COLOUR GRADE

Hogget Greasy Fleece Colour Grade

No genotype x environment interactions were present in this trait. The intra-trait genetic correlation was estimated as 1.00 ± 0.29.

Ewe Greasy Fleece Colour Grade

Genotype x environment interactions were of little importance in the ewe GCF analyses. Sire x stocking rate interactions controlled only 0.5% of the total variance in the pooled analysis. The 1.1% of the total variance controlled in the 3 year old ewe analysis was the only sire x stocking rate interaction present in the separate age analyses.

Sire x birth year interactions contributed 1.4, 3.5 and 4.2% of the total variance in the pooled, CSR and HSR analyses respectively. Less than 2% of the total variance was contributed by sire x year interactions in the separate age analyses.

Lack of sire variance meant that the sire x environment interactions accounted for most of the genetic variance when present. In the pooled analyses sire x environment interactions accounted for 78.5% of the genetic variance, with 100.0 and 96.2% of the genetic variance controlled in the CSR and HSR respectively.

The intratrait genetic correlation estimate was 0.63 ± 0.02.

4.2.20 NUMBER OF LAMBS BORN AND WEANED

Sire explained none of the total variation in the models fitted for number of lambs born and number of lambs weaned (Table 4.1), hence sire interactions controlled all the genetic variance. The sire variance also accounted for none of the variance in the separate stocking rate and separate age analyses, except in the control stocking rate where it still explained little of the variance (3% of the total and 4% of the genetic variance for NLB and 2.5% of the total and 34.6% of the genetic variance for NLW).

Sire interactions were also unimportant, generally explaining less than 5% of the total variation. The greatest amount of variation was explained in the CSR model where they accounted for 7.5 and 7.3% of the total variance for NLB and NLW respectively.

Low or zero values for sire and interaction variance components resulted in meaningless intra-trait genetic correlation values for reproductive traits so these were not presented.

Lifetime Number of Lambs Born and Weaned

No sire interactions were identifiable in the ewe combined or high stocking rate analyses for lifetime number of lambs born. In the control stocking rate sire x birthyear accounted for 3.8% of the total variance.

Similar trends occurred for lifetime number of lambs weaned. Sire x birthyear interactions were nonsignificant, accounting for 0, 0.8 and 0% of the total variance in the combined, control and high stocking rates respectively. No sire x stocking rate interactions were present in the combined stocking rate analyses.

4.2.21 WEIGHT OF LAMB WEANED

Sire x birth year interactions controlled 1.8, 1.6 and 1.8% of the total variance in the combined, control and high stocking rates respectively. In the separate age analyses sire x year interactions were present in the two year old ewe analysis only, where it only controlled 1.0% of the total variance.

Sire x stocking interactions controlled 3.1% of the total variance in the combined stocking rate analysis and 1.8, 3.0, 5.1 and 0% of the total variance in the separate age analyses.

Lifetime Weight of Lamb Weaned

As for weight of lamb weaned, sire and sire interactions were generally unimportant as sources of variance in lifetime weight of lamb weaned models.

Sire x birthyear interactions were present only in the control stocking rate analysis, where it accounted for only 1.6% of the total variance. Sire x stocking rate interactions controlled 1.5% of the total variance in the combined stocking rate analysis.

4.2.22 WEIGHT PER LAMB WEANED

Sire x birthyear interactions were non-significant sources of variance for weight per lamb weaned, occurring only in the high stocking rate where it accounted for 1.0% of the total variance.

Sire x stocking rate interactions controlled 3.5% of the total variance in the combined analysis, which corresponded to 81.6% of the genetic variance.

4.2.23 LAMB SURVIVAL

Sire and sire interactions were non-significant in the lamb survival analyses, demonstrating the importance of environmental effects on this trait.

Sire x year interactions controlled 1-3% of the total variation in the analyses. Sire x stocking rate interactions accounted for none of the variation except in the 5 year old ewe analyses where it was still non-significant, contributing 0.6% of the total variance.

As the sire variance estimates were so low the interactions, although nonsignificant, controlled 77-100% of the genetic variance.

4.2.24 EFFECT OF THE HSR MANAGEMENT CHANGE

After 1976 hoggets from the HSR treatment were no longer grazed on the same block as the ewes but were removed to graze with the CSR hoggets. This would have eliminated the stocking rate difference for this period of time until they were returned to the HSR as ewes. However there would still have been a carryover effect from the lamb stocking rate environment so that some differences would still be expected in the hoggets. From the estimates of environmental effects in Table 4.2 it could be seen that the stocking rates effects generally diminished in sire groups 6 and 7, when the hoggets were grazed together. The traits most obviously affected were LW, GFW, CFW, Y, SL, LUS, COT, SOU, SCM.

To quantify the effect the management change had on the HSR hoggets the variance components were calculated before and after the change in the HSR. As shown in table 4.5 the change in the HSR hogget management did not affect most traits. These can be compared to the values for the combined analyses (Table 4.3). Traits where there were significant changes included QN, TCN, CF and LUS. Heritability estimates of traits were reduced after the management change (Table 4.5.2). However as these were only based on two siregroup periods the resultant large standard errors meant these differences were generally not significant.

Although there was a slight reduction in the high stocking rate ewe intensity the effect was less than in the hoggets so ewe data was not subdivided.

Table 4.5.1: Pooled estimates of variance components of hogget HSR traits before and after the HSR management change

TRAIT	σ^2 sire		σ^2 sire x year		σ^2 error	
	before	after	before	after	before	after
LW	0.093	0.291	0.674	0.891	11.215	15.375
GFW	0.024	0.009	0.009	0.016	0.176	0.187
CFW	0.012	0.008	0.009	0.009	0.119	0.131
Y	1.620	1.119	-	-	19.248	15.973
QN	0.437	0.102	0.120	-	2.785	4.626
MFD	0.516	0.260	-	0.231	5.606	5.025
SL	0.483	0.251	-	-	2.497	2.387
TCN	1.555	0.852	0.314	-	6.384	10.611
CF	0.087	0.029	0.005	-	0.416	0.649
SST	na	3.377	na	5.768	na	111.169
CHG	0.062	0.038	0.010	-	0.803	0.597
LUS	0.051	-	-	-	0.534	0.517
TIP	0.045	0.014	0.005	-	0.815	0.551
COT	0.013	0.014	-	0.010	0.311	0.397
CAG	0.019	-	-	0.022	0.336	0.427
SOU	0.033	-	0.004	0.099	1.201	1.483
HND	0.049	0.004	-	0.004	0.614	0.271
GCM	0.037	0.002	-	0.029	0.316	0.369
SCM	0.004	0.003	0.026	0.009	0.439	0.368
GCF	0.011	-	-	0.012	0.429	0.614

Table 4.5.2: Heritability estimates and standard errors of hogget HSR traits before and after the HSR management change

TRAIT	H^2 EI		H^2 II	
	before	after	before	after
LW	0.03 ± 0.14	0.07 ± 0.17	0.26 ± 0.14	0.29 ± 0.16
GFW	0.46 ± 0.20	0.16 ± 0.21	0.63 ± 0.19	0.47 ± 0.19
CFW	0.34 ± 0.20	0.21 ± 0.21	0.60 ± 0.18	0.45 ± 0.19
Y	0.31 ± 0.15	0.26 ± 0.17	0.31 ± 0.15	0.26 ± 0.16
QN	0.52 ± 0.20	0.09 ± 0.12	0.67 ± 0.20	0.09 ± 0.12
MFD	0.34 ± 0.17	0.19 ± 0.19	0.34 ± 0.17	0.36 ± 0.18
SL	0.65 ± 0.20	0.38 ± 0.20	0.65 ± 0.20	0.38 ± 0.20
TCN	0.75 ± 0.24	0.30 ± 0.18	0.91 ± 0.23	0.30 ± 0.17
CF	0.69 ± 0.22	0.17 ± 0.14	0.73 ± 0.22	0.17 ± 0.14
SST		0.11 ± 0.17		0.30 ± 0.16
CHG	0.28 ± 0.16	0.24 ± 0.16	0.33 ± 0.15	0.24 ± 0.16
LUS	0.35 ± 0.16	0.00 ± 0.10	0.35 ± 0.16	0.00 ± 0.09
TIP	0.21 ± 0.16	0.10 ± 0.12	0.23 ± 0.16	0.10 ± 0.12
COT	0.16 ± 0.13	0.13 ± 0.15	0.16 ± 0.13	0.22 ± 0.15
CAG	0.21 ± 0.14	0.00 ± 0.18	0.21 ± 0.14	0.20 ± 0.17
SOU	0.11 ± 0.12	0.00 ± 0.16	0.12 ± 0.12	0.25 ± 0.15
HND	0.29 ± 0.15	0.06 ± 0.12	0.29 ± 0.15	0.11 ± 0.12
GCM	0.42 ± 0.17	0.02 ± 0.18	0.42 ± 0.17	0.32 ± 0.16
SCM	0.04 ± 0.14	0.04 ± 0.13	0.25 ± 0.14	0.13 ± 0.12
GCF	0.10 ± 0.12	0.00 ± 0.15	0.10 ± 0.12	0.08 ± 0.14

4.3 HERITABILITY ESTIMATES

The heritability estimates obtained from daughter-dam regression analysis and from sire intra-class correlation are presented with standard errors in Table 4.6. Estimates were calculated from the combined data (across both stocking rates) and within each stocking rate.

Two methods were used to estimate heritability by sire intra-class correlation, one including (II) and the other omitting (EI) interaction variance components in the numerator of the heritability expression. Chopra (1978) assessed the significance of differences between the various heritability estimates by calculating the standard error of the difference and examining the change in the estimates in terms of that standard error.

Comparison of heritability estimates obtained in this study with those obtained from other studies may be difficult as different models are frequently used. Most studies are carried out on a single stocking rate, within year basis so that estimates of heritability are similar to those including sire interactions in this study. When interactions are important sources of variance, selection responses calculated from these types of estimates may be higher than the responses likely to be achieved in practise.

Daughter-dam (DD) regression estimates of heritability should be relatively free of genotype x year effects (Rae, 1958). Hence they would be expected to be lower than paternal half-sib (PHS) II estimates, but higher than the EI estimates as they still contain the stocking rate interaction. However the daughter-dam estimates may be biased upward by maternal effects (Ch'ang and Rae, 1970, 1972).

TABLE 4.6: Heritability estimates and standard errors of various traits

TRAIT	Dtr-Dam Regression ± Std Err			Sire Intraclass Correlation* ± Std Err		
	Combined	CSR	HSR	Combined SR	CSR	HSR
$LW_{weaning}$				0.14 ± 0.11 0.22 ± 0.11	0.19 ± 0.17 0.20 ± 0.17	0.04 ± 0.15
SLW_1	0.07 ± 0.09	0.10 ± 0.13	0.05 ± 0.13	0.07 ± 0.09 0.35 ± 0.08	0.16 ± 0.13 0.46 ± 0.12	0.05 ± 0.11 0.24 ± 0.10
ALW_2	0.34 ± 0.07	0.14 ± 0.12	0.65 ± 0.10	0.10 ± 0.13 0.41 ± 0.13	0.41 ± 0.19	0.32 ± 0.18 0.34 ± 0.18
ALW_3	0.37 ± 0.08	0.30 ± 0.10	0.47 ± 0.11	0.20 ± 0.13 0.35 ± 0.13	0.56 ± 0.21	0.16 ± 0.16
ALW_4	0.39 ± 0.09	0.36 ± 0.12	0.47 ± 0.12	0.14 ± 0.13 0.39 ± 0.13	0.52 ± 0.20	0.28 ± 0.18
ALW_5	0.45 ± 0.08	0.40 ± 0.13	0.50 ± 0.12	0.22 ± 0.12 0.30 ± 0.12	0.46 ± 0.20	0.15 ± 0.16
ALW_{2-5}	0.54 ± 0.08	0.43 ± 0.12	0.68 ± 0.11	0.10 ± 0.10 0.56 ± 0.09	0.48 ± 0.15 0.78 ± 0.14	0.21 ± 0.11 0.48 ± 0.10

* Upper Value - sire interactions not included
Lower Value - interactions included

TABLE 4.6: CONTINUED

TRAIT	Dtr-Dam Regression ± Std Err			Sire Intraclass Correlation* ± Std Err		
	Combined	CSR	HSR	Combined SR	CSR	HSR
GFW$_1$	0.07 ± 0.06	0.00 ± 0.08	0.46 ± 0.11	0.23 ± 0.11 0.48 ± 0.10	0.36 ± 0.12	0.34 ± 0.15 0.56 ± 0.14
GFW$_2$	0.57 ± 0.07	0.57 ± 0.11	0.62 ± 0.10	0.19 ± 0.16 0.64 ± 0.15	0.14 ± 0.22 0.62 ± 0.20	0.57 ± 0.23 0.74 ± 0.22
GFW$_3$	0.62 ± 0.07	0.70 ± 0.10	0.55 ± 0.10	0.26 ± 0.14 0.46 ± 0.14	0.20 ± 0.21 0.52 ± 0.20	0.38 ± 0.19
GFW$_4$	0.54 ± 0.07	0.70 ± 0.11	0.38 ± 0.10	0.47 ± 0.15	0.50 ± 0.20	0.40 ± 0.19
GFW$_5$	0.49 ± 0.07	0.68 ± 0.11	0.34 ± 0.11	0.49 ± 0.15 0.51 ± 0.15	0.47 ± 0.22 0.60 ± 0.21	0.51 ± 0.20
GFW$_{2-5}$	0.51 ± 0.07	0.62 ± 0.10	0.43 ± 0.09	0.30 ± 0.12 0.67 ± 0.11	0.31 ± 0.16 0.82 ± 0.13	0.41 ± 0.14 0.68 ± 0.13
CFW$_1$	0.14 ± 0.07	0.10 ± 0.08	0.25 ± 0.13	0.29 ± 0.11 0.51 ± 0.10	0.47 ± 0.13	0.29 ± 0.15 0.53 ± 0.14
CFW$_2$	0.31 ± 0.22	0.14 ± 0.27	0.47 ± 0.40	0.25 ± 0.17 0.67 ± 0.15	0.16 ± 0.23 0.64 ± 0.21	0.47 ± 0.24 0.79 ± 0.22
CFW$_3$	0.43 ± 0.28	0.96 ± 0.36	0.09 ± 0.45	0.28 ± 0.14 0.44 ± 0.14	0.36 ± 0.21 0.50 ± 0.20	0.38 ± 0.19
CFW$_4$	0.32 ± 0.27	0.73 ± 0.30	0.00 ± 0.46	0.40 ± 0.14 0.41 ± 0.14	0.50 ± 0.20	0.29 ± 0.18
CFW$_5$	0.21 ± 0.31	0.33 ± 0.43	0.11 ± 0.47	0.47 ± 0.15	0.50 ± 0.20	0.43 ± 0.20
CFW$_{2-5}$	0.00 ± 0.17	0.00 ± 0.21	0.00 ± 0.29	0.32 ± 0.12 0.65 ± 0.11	0.42 ± 0.15 0.78 ± 0.14	0.36 ± 0.14 0.66 ± 0.12

TABLE 4.6: CONTINUED

	Dtr-Dam Regression ± Std Err			Sire Intraclass Correlation* ± Std Err		
TRAIT	Combined	CSR	HSR	Combined SR	CSR	HSR
Y_1	0.31 ± 0.07	0.29 ± 0.12	0.34 ± 0.10	0.19 ± 0.09 0.32 ± 0.08	0.30 ± 0.11	0.30 ± 0.12
Y_2	0.40 ± 0.07	0.44 ± 0.10	0.38 ± 0.12	0.02 ± 0.13 0.38 ± 0.12	0.06 ± 0.20 0.39 ± 0.19	0.27 ± 0.19 0.35 ± 0.18
Y_3	0.42 ± 0.07	0.32 ± 0.09	0.57 ± 0.11	0.19 ± 0.12 0.26 ± 0.12	0.25 ± 0.18 0.26 ± 0.18	0.28 ± 0.18
Y_4	0.37 ± 0.07	0.40 ± 0.10	0.33 ± 0.11	0.18 ± 0.12 0.30 ± 0.12	0.13 ± 0.18 0.26 ± 0.18	0.16 ± 0.16 0.18 ± 0.17
Y_5	0.21 ± 0.07	0.38 ± 0.12	0.12 ± 0.10	0.05 ± 0.10 0.12 ± 0.10	0.04 ± 0.15	0.00 ± 0.15 0.04 ± 0.16
Y_{2-5}	0.62 ± 0.06	0.61 ± 0.08	0.62 ± 0.09	0.11 ± 0.07 0.33 ± 0.06	0.14 ± 0.10 0.39 ± 0.09	0.18 ± 0.09 0.32 ± 0.08
QN_1	0.48 ± 0.07	0.54 ± 0.10	0.39 ± 0.10	0.28 ± 0.10 0.33 ± 0.09	0.33 ± 0.11	0.32 ± 0.12
QN_2	0.41 ± 0.07	0.42 ± 0.10	0.36 ± 0.09	0.17 ± 0.14 0.49 ± 0.13	0.36 ± 0.23 0.70 ± 0.21	0.13 ± 0.18 0.31 ± 0.18
QN_3	0.44 ± 0.08	0.48 ± 0.10	0.43 ± 0.12	0.23 ± 0.12	0.13 ± 0.16	0.23 ± 0.17
QN_4	0.48 ± 0.08	0.43 ± 0.11	0.49 ± 0.11	0.23 ± 0.29 0.29 ± 0.12	0.12 ± 0.17 0.23 ± 0.18	0.16 ± 0.16
QN_5	0.20 ± 0.06	0.44 ± 0.12	0.09 ± 0.07	0.12 ± 0.11 0.15 ± 0.11	0.03 ± 0.15	0.05 ± 0.17 0.21 ± 0.17
QN_{2-5}	0.51 ± 0.06	0.56 ± 0.09	0.41 ± 0.09	0.17 ± 0.08 0.42 ± 0.07	0.25 ± 0.11 0.46 ± 0.10	0.17 ± 0.11 0.50 ± 0.10

TABLE 4.6: CONTINUED

	Dtr-Dam Regression ± Std Err			Sire Intraclass Correlation* ± Std Err		
TRAIT	Combined	CSR	HSR	Combined SR	CSR	HSR
MFD_1	0.44 ± 0.10	0.54 ± 0.15	0.26 ± 0.15	0.33 ± 0.11 0.46 ± 0.11	0.41 ± 0.16 0.62 ± 0.15	0.30 ± 0.13 0.34 ± 0.13
MFD_2	0.76 ± 0.07	0.96 ± 0.10	0.50 ± 0.11	0.58 ± 0.18 0.61 ± 0.18	0.71 ± 0.25 0.75 ± 0.25	0.46 ± 0.21
MFD_3	0.59 ± 0.08	0.53 ± 0.11	0.65 ± 0.12	0.35 ± 0.16 0.50 ± 0.16	0.50 ± 0.26 0.77 ± 0.24	0.27 ± 0.19
MFD_4	0.65 ± 0.07	0.75 ± 0.10	0.56 ± 0.11	0.52 ± 0.15	0.53 ± 0.23	0.37 ± 0.19
MFD_5	0.50 ± 0.07	0.58 ± 0.10	0.45 ± 0.10	0.47 ± 0.15 0.51 ± 0.15	0.42 ± 0.21	0.39 ± 0.19
MFD_{2-5}	0.38 ± 0.04	0.36 ± 0.06	0.38 ± 0.07	0.42 ± 0.14 0.81 ± 0.12	0.61 ± 0.20 1.07 ± 0.16	0.39 ± 0.15 0.71 ± 0.13
SL_1	0.51 ± 0.07	0.49 ± 0.10	0.57 ± 0.10	0.45 ± 0.12 0.51 ± 0.11	0.34 ± 0.12 0.40 ± 0.12	0.55 ± 0.15
SL_2	0.49 ± 0.07	0.42 ± 0.10	0.54 ± 0.09	0.34 ± 0.14 0.43 ± 0.14	0.26 ± 0.17	0.55 ± 0.21
SL_3	0.53 ± 0.07	0.57 ± 0.11	0.52 ± 0.10	0.26 ± 0.14 0.41 ± 0.13	0.30 ± 0.18	0.44 ± 0.19
SL_4	0.38 ± 0.07	0.37 ± 0.10	0.40 ± 0.09	0.49 ± 0.16 0.58 ± 0.16	0.57 ± 0.22 0.63 ± 0.22	0.46 ± 0.20
SL_5	0.39 ± 0.07	0.53 ± 0.10	0.32 ± 0.10	0.32 ± 0.14 0.45 ± 0.14	0.33 ± 0.19	0.17 ± 0.21 0.51 ± 0.19
SL_{2-5}	0.14 ± 0.03	0.11 ± 0.05	0.19 ± 0.05	0.27 ± 0.11 0.60 ± 0.10	0.40 ± 0.13 0.62 ± 0.12	0.41 ± 0.13 0.64 ± 0.12

TABLE 4.6: CONTINUED

	Dtr-Dam Regression ± Std Err			Sire Intraclass Correlation* ± Std Err		
TRAIT	Combined	CSR	HSR	Combined SR	CSR	HSR
TCN_1	0.50 ± 0.08	0.55 ± 0.13	0.50 ± 0.11	0.49 ± 0.13 0.56 ± 0.12	0.51 ± 0.15 0.59 ± 0.15	0.53 ± 0.15
TCN_2	0.51 ± 0.07	0.48 ± 0.11	0.55 ± 0.10	0.42 ± 0.14	0.48 ± 0.20	0.29 ± 0.18
TCN_3	0.59 ± 0.07	0.66 ± 0.09	0.51 ± 0.11	0.19 ± 0.11 0.20 ± 0.11	0.00 ± 0.16 0.11 ± 0.16	0.37 ± 0.19
TCN_4	0.56 ± 0.08	0.52 ± 0.11	0.56 ± 0.12	0.15 ± 0.10	0.21 ± 0.17	0.10 ± 0.15
TCN_5	0.28 ± 0.08	0.50 ± 0.12	0.11 ± 0.10	0.23 ± 0.12	0.26 ± 0.20 0.43 ± 0.19	0.04 ± 0.15
TCN_{2-5}	0.13 ± 0.05	0.05 ± 0.07	0.19 ± 0.08	0.20 ± 0.08 0.42 ± 0.08	0.26 ± 0.12 0.56 ± 0.11	0.25 ± 0.11 0.44 ± 0.10
CF_1	0.59 ± 0.08	0.54 ± 0.13	0.66 ± 0.12	0.39 ± 0.10 0.40 ± 0.10	0.35 ± 0.12	0.42 ± 0.13
CF_2	0.60 ± 0.07	0.63 ± 0.10	0.57 ± 0.09	0.29 ± 0.12	0.38 ± 0.19 0.40 ± 0.19	0.16 ± 0.16
CF_3	0.65 ± 0.07	0.73 ± 0.10	0.56 ± 0.11	0.27 ± 0.12	0.00 ± 0.16 0.09 ± 0.16	0.46 ± 0.20
CF_4	0.53 ± 0.07	0.49 ± 0.10	0.54 ± 0.10	0.25 ± 0.12 0.26 ± 0.12	0.21 ± 0.17	0.24 ± 0.17
CF_5	0.38 ± 0.07	0.60 ± 0.11	0.21 ± 0.10	0.05 ± 0.10 0.14 ± 0.10	0.05 ± 0.15	0.00 ± 0.15
CF_{2-5}	0.63 ± 0.07	0.71 ± 0.11	0.60 ± 0.10	0.17 ± 0.08 0.42 ± 0.08	0.18 ± 0.11 0.49 ± 0.10	0.21 ± 0.11 0.48 ± 0.10

TABLE 4.6: CONTINUED

	Dtr-Dam Regression ± Std Err			Sire Intraclass Correlation* ± Std Err		
TRAIT	Combined	CSR	HSR	Combined SR	CSR	HSR
SST_1	0.03 ± 0.02	0.03 ± 0.03	0.03 ± 0.02	0.17 ± 0.09 0.20 ± 0.09	0.09 ± 0.10	0.16 ± 0.15 0.30 ± 0.14
SST_2	0.39 ± 0.09	0.41 ± 0.14	0.35 ± 0.12	0.00 ± 0.12 0.10 ± 0.12	0.23 ± 0.19 0.25 ± 0.20	0.04 ± 0.19
SST_3	0.43 ± 0.08	0.39 ± 0.13	0.47 ± 0.12	0.09 ± 0.12	0.00 ± 0.18	0.16 ± 0.21
SST_4	0.40 ± 0.07	0.51 ± 0.11	0.24 ± 0.09	0.20 ± 0.11	0.02 ± 0.16	0.00 ± 0.15
SST_5	0.38 ± 0.09	0.58 ± 0.13	0.15 ± 0.12	0.22 ± 0.12 0.24 ± 0.12	0.01 ± 0.16	0.16 ± 0.17
SST_{2-5}	0.23 ± 0.04	0.22 ± 0.06	0.26 ± 0.06	0.07 ± 0.07 0.32 ± 0.06	0.23 ± 0.10 0.36 ± 0.09	0.14 ± 0.08 0.26 ± 0.08
CHG_1	0.22 ± 0.07	0.21 ± 0.10	0.29 ± 0.10	0.23 ± 0.09 0.31 ± 0.08	0.23 ± 0.12 0.35 ± 0.11	0.28 ± 0.12 0.32 ± 0.12
CHG_2	0.13 ± 0.07	0.21 ± 0.10	0.05 ± 0.09	0.27 ± 0.12	0.32 ± 0.18 0.33 ± 0.19	0.14 ± 0.16
CHG_3	0.15 ± 0.07	0.07 ± 0.11	0.26 ± 0.10	0.09 ± 0.11 0.21 ± 0.11	0.18 ± 0.17 0.23 ± 0.17	0.14 ± 0.18 0.30 ± 0.18
CHG_4	0.10 ± 0.07	0.03 ± 0.10	0.18 ± 0.10	0.11 ± 0.13 0.35 ± 0.12	0.00 ± 0.19 0.34 ± 0.18	0.00 ± 0.19 0.37 ± 0.18
CHG_5	0.13 ± 0.08	0.13 ± 0.10	0.16 ± 0.12	0.11 ± 0.10 0.12 ± 0.10	0.20 ± 0.17	0.01 ± 0.14
CHG_{2-5}	0.47 ± 0.07	0.30 ± 0.09	0.64 ± 0.11	0.10 ± 0.06 0.26 ± 0.06	0.08 ± 0.08 0.32 ± 0.08	0.16 ± 0.07 0.25 ± 0.07

TABLE 4.6: CONTINUED

	Dtr-Dam Regression ± Std Err			Sire Intraclass Correlation* ± Std Err		
TRAIT	Combined	CSR	HSR	Combined SR	CSR	HSR
LUS$_1$	0.24 ± 0.07	0.20 ± 0.11	0.28 ± 0.11	0.24 ± 0.08 0.27 ± 0.08	0.34 ± 0.12	0.21 ± 0.10
LUS$_2$	0.14 ± 0.06	0.15 ± 0.09	0.09 ± 0.08	0.00 ± 0.10 0.14 ± 0.10	0.00 ± 0.23 0.65 ± 0.20	0.00 ± 0.15 0.10 ± 0.16
LUS$_3$	0.05 ± 0.07	0.00 ± 0.10	0.19 ± 0.10	0.05 ± 0.10 0.12 ± 0.10	0.12 ± 0.16	0.00 ± 0.17 0.23 ± 0.17
LUS$_4$	0.05 ± 0.06	0.15 ± 0.09	0.00 ± 0.10	0.14 ± 0.10	0.17 ± 0.17 0.22 ± 0.17	0.00 ± 0.14
LUS$_5$	0.26 ± 0.07	0.26 ± 0.10	0.25 ± 0.09	0.03 ± 0.10 0.14 ± 0.14	0.10 ± 0.18 0.29 ± 0.18	0.07 ± 0.15
LUS$_{2-5}$	0.35 ± 0.08	0.23 ± 0.10	0.50 ± 0.12	0.03 ± 0.04 0.14 ± 0.04	0.12 ± 0.07 0.22 ± 0.07	0.00 ± 0.05 0.09 ± 0.05
TIP$_1$	0.26 ± 0.08	0.23 ± 0.12	0.26 ± 0.10	0.16 ± 0.07 0.19 ± 0.07	0.10 ± 0.09 0.15 ± 0.09	0.19 ± 0.11 0.21 ± 0.11
TIP$_2$	0.33 ± 0.06	0.47 ± 0.09	0.19 ± 0.10	0.11 ± 0.11 0.26 ± 0.11	0.26 ± 0.17 0.28 ± 0.18	0.18 ± 0.16
TIP$_3$	0.32 ± 0.07	0.36 ± 0.10	0.31 ± 0.11	0.20 ± 0.11	0.06 ± 0.15	0.18 ± 0.16
TIP$_4$	0.27 ± 0.07	0.23 ± 0.11	0.30 ± 0.10	0.32 ± 0.12	0.32 ± 0.18	0.17 ± 0.16
TIP$_5$	0.18 ± 0.07	0.30 ± 0.11	0.00 ± 0.10	0.10 ± 0.10 0.17 ± 0.17	0.19 ± 0.17	0.05 ± 0.15
TIP$_{2-5}$	0.34 ± 0.06	0.39 ± 0.09	0.29 ± 0.08	0.21 ± 0.07 0.29 ± 0.07	0.25 ± 0.08 0.30 ± 0.08	0.18 ± 0.08 0.26 ± 0.07

TABLE 4.6: CONTINUED

TRAIT	Dtr-Dam REgression ± Std Err Combined	CSR	HSR	Sire Intraclass Correlation* ± Std Err Combined SR	CSR	HSR
COT$_1$	0.23 ± 0.07	0.04 ± 0.11	0.40 ± 0.11	0.23 ± 0.08	0.24 ± 0.11 0.32 ± 0.11	0.16 ± 0.10
COT$_2$	0.50 ± 0.09	0.50 ± 0.14	0.50 ± 0.11	0.20 ± 0.13 0.36 ± 0.12	0.10 ± 0.15	0.09 ± 0.15
COT$_3$	0.45 ± 0.09	0.26 ± 0.12	0.63 ± 0.14	0.14 ± 0.10 0.16 ± 0.10	0.15 ± 0.17	0.09 ± 0.20 0.47 ± 0.19
COT$_4$	0.41 ± 0.09	0.43 ± 0.13	0.39 ± 0.13	0.03 ± 0.13 0.42 ± 0.12	0.22 ± 0.20 0.50 ± 0.19	0.11 ± 0.19 0.38 ± 0.18
COT$_5$	0.23 ± 0.09	0.06 ± 0.12	0.41 ± 0.14	0.08 ± 0.12 0.31 ± 0.12	0.09 ± 0.17 0.21 ± 0.17	0.00 ± 0.22 0.59 ± 0.20
COT$_{2-5}$	0.14 ± 0.04	0.12 ± 0.05	0.18 ± 0.06	0.09 ± 0.07 0.35 ± 0.06	0.16 ± 0.09 0.33 ± 0.08	0.06 ± 0.10 0.44 ± 0.09
CAG$_1$	0.06 ± 0.08	0.14 ± 0.13	0.00 ± 0.11	0.17 ± 0.08 0.22 ± 0.08	0.10 ± 0.11 0.28 ± 0.11	0.15 ± 0.10
CAG$_2$	0.35 ± 0.10	0.17 ± 0.16	0.48 ± 0.14	0.07 ± 0.14 0.24 ± 0.13	0.07 ± 0.25 0.50 ± 0.24	0.14 ± 0.20
CAG$_3$	0.20 ± 0.10	0.23 ± 0.16	0.15 ± 0.15	0.21 ± 0.12	0.08 ± 0.17	0.21 ± 0.19
CAG$_4$	0.28 ± 0.10	0.32 ± 0.15	0.27 ± 0.17	0.29 ± 0.13 0.31 ± 0.14	0.19 ± 0.18	0.30 ± 0.20
CAG$_5$	0.10 ± 0.10	0.03 ± 0.13	0.27 ± 0.18	0.31 ± 0.15 0.42 ± 0.15	0.30 ± 0.20 0.33 ± 0.21	0.38 ± 0.23 0.50 ± 0.22
CAG$_{2-5}$	0.10 ± 0.05	0.12 ± 0.06	0.08 ± 0.07	0.21 ± 0.09 0.41 ± 0.08	0.18 ± 0.12 0.47 ± 0.11	0.28 ± 0.12 0.46 ± 0.11

TABLE 4.6: CONTINUED

TRAIT	Dtr-DAM Regression ± Std Err Combined	 CSR	 HSR	Sire Intraclass Correlation* ± Std Err Combined SR	 CSR	 HSR
SOU_1	0.23 ± 0.07	0.32 ± 0.10	0.18 ± 0.10	0.12 ± 0.06 0.16 ± 0.06	0.05 ± 0.10 0.26 ± 0.10	0.05 ± 0.10 0.16 ± 0.09
SOU_2	0.23 ± 0.08	0.21 ± 0.12	0.23 ± 0.11	0.01 ± 0.10 0.07 ± 0.10	0.10 ± 0.17	0.04 ± 0.17
SOU_3	0.18 ± 0.09	0.16 ± 0.13	0.15 ± 0.12	0.17 ± 0.13 0.24 ± 0.12	0.15 ± 0.18	0.32 ± 0.22 0.35 ± 0.22
SOU_4	0.32 ± 0.09	0.56 ± 0.12	0.12 ± 0.14	0.00 ± 0.09	0.01 ± 0.15	0.00 ± 0.17 0.90 ± 0.17
SOU_5	0.22 ± 0.08	0.36 ± 0.12	0.15 ± 0.12	0.01 ± 0.09	0.00 ± 0.16	0.00 ± 0.20 0.31 ± 0.19
SOU_{2-5}	0.09 ± 0.05	0.15 ± 0.07	0.00 ± 0.07	0.04 ± 0.04 0.13 ± 0.04	0.11 ± 0.07 0.18 ± 0.06	0.06 ± 0.07 0.18 ± 0.06
HND_1	0.22 ± 0.06	0.31 ± 0.09	0.14 ± 0.09	0.15 ± 0.08 0.33 ± 0.08	0.11 ± 0.13 0.47 ± 0.12	0.29 ± 0.12 0.30 ± 0.12
HND_2	0.00 ± 0.06	0.00 ± 0.10	0.04 ± 0.09	0.11 ± 0.11 0.23 ± 0.11	0.00 ± 0.19 0.36 ± 0.18	0.06 ± 0.15
HND_3	0.17 ± 0.07	0.15 ± 0.09	0.17 ± 0.10	0.23 ± 0.12 0.33 ± 0.12	0.58 ± 0.21 0.61 ± 0.21	0.11 ± 0.16 0.16 ± 0.16
HND_4	0.13 ± 0.07	0.65 ± 0.10	0.18 ± 0.09	0.18 ± 0.13 0.36 ± 0.12	0.21 ± 0.17	0.27 ± 0.18 0.34 ± 0.18
HND_5	0.22 ± 0.07	0.12 ± 0.10	0.27 ± 0.09	0.16 ± 0.11 0.23 ± 0.11	0.18 ± 0.17 0.20 ± 0.17	0.19 ± 0.17
HND_{2-5}	0.18 ± 0.06	0.15 ± 0.07	0.20 ± 0.10	0.17 ± 0.07 0.32 ± 0.07	0.21 ± 0.09 0.32 ± 0.08	0.15 ± 0.09 0.36 ± 0.08

TABLE 4.6: CONTINUED

TRAIT	Dtr-DAM Regression ± Std Err			Sire Intraclass Correlation* ± Std Err		
	Combined	CSR	HSR	Combined SR	CSR	HSR
GCM_1	0.25 ± 0.07	0.24 ± 0.10	0.26 ± 0.11	0.10 ± 0.10 0.42 ± 0.09	0.36 ± 0.12 0.41 ± 0.12	0.25 ± 0.12 0.36 ± 0.12
GCM_2	0.12 ± 0.07	0.24 ± 0.10	0.04 ± 0.09	0.00 ± 0.09 0.04 ± 0.09	0.07 ± 0.17 0.19 ± 0.17	0.00 ± 0.14
GCM_3	0.20 ± 0.08	0.11 ± 0.11	0.32 ± 0.11	0.00 ± 0.09 0.09 ± 0.09	0.00 ± 0.14	0.10 ± 0.15
GCM_4	0.06 ± 0.08	0.04 ± 0.13	0.10 ± 0.11	0.00 ± 0.11 0.27 ± 0.11	0.09 ± 0.19 0.38 ± 0.18	0.00 ± 0.21 0.56 ± 0.19
GCM_5	0.00 ± 0.08	0.06 ± 0.12	0.00 ± 0.12	0.03 ± 0.10 0.11 ± 0.10	0.12 ± 0.16	0.02 ± 0.15
GCM_{2-5}	0.56 ± 0.06	0.54 ± 0.09	0.60 ± 0.10	0.00 ± 0.04 0.14 ± 0.04	0.01 ± 0.07 0.21 ± 0.06	0.05 ± 0.05 0.11 ± 0.05
SCM_1	0.11 ± 0.07	0.09 ± 0.11	0.14 ± 0.10	0.05 ± 0.07 0.22 ± 0.07	0.14 ± 0.10 0.25 ± 0.10	0.04 ± 0.11 0.23 ± 0.10
SCM_2	0.23 ± 0.07	0.44 ± 0.11	0.00 ± 0.10	0.03 ± 0.09 0.11 ± 0.10	0.15 ± 0.17	0.00 ± 0.15 0.07 ± 0.15
SCM_3	0.01 ± 0.07	0.07 ± 0.10	0.00 ± 0.10	0.02 ± 0.09 0.07 ± 0.09	0.00 ± 0.15	0.12 ± 0.16
SCM_4	0.00 ± 0.09	0.10 ± 0.13	0.00 ± 0.12	0.04 ± 0.10	0.20 ± 0.19	0.00 ± 0.14
SCM_5	0.05 ± 0.08	0.03 ± 0.12	0.11 ± 0.12	0.00 ± 0.12 0.23 ± 0.12	0.36 ± 0.21	0.10 ± 0.18
SCM_{2-5}	0.68 ± 0.07	0.80 ± 0.10	0.58 ± 0.10	0.00 ± 0.04 0.12 ± 0.04	0.08 ± 0.06 0.16 ± 0.06	0.08 ± 0.05 0.10 ± 0.05

TABLE 4.6: CONTINUED

	Dtr-DAM Regression ± Std Err			Sire Intraclass Correlation* ± Std Err		
TRAIT	Combined	CSR	HSR	Combined SR	CSR	HSR
GCF_1	0.07 ± 0.09	0.08 ± 0.13	0.15 ± 0.12	0.10 ± 0.06	0.08 ± 0.09	0.06 ± 0.09
GCF_2	0.39 ± 0.10	0.29 ± 0.14	0.48 ± 0.14	0.07 ± 0.12	0.00 ± 0.19	0.12 ± 0.20
GCF_3	0.18 ± 0.09	0.30 ± 0.14	0.05 ± 0.14	0.01 ± 0.10 0.09 ± 0.11	0.00 ± 0.17 0.02 ± 0.18	0.01 ± 0.18 0.14 ± 0.18
GCF_4	0.05 ± 0.09	0.00 ± 0.13	0.21 ± 0.14	0.21 ± 0.12	0.00 ± 0.18 0.14 ± 0.18	0.07 ± 0.25 0.60 ± 0.22
GCF_5	0.11 ± 0.09	0.02 ± 0.12	0.23 ± 0.13	0.00 ± 0.10 0.08 ± 0.11	0.00 ± 0.18 0.15 ± 0.19	0.00 ± 0.18 0.08 ± 0.18
GCF_{2-5}	0.61 ± 0.07	0.77 ± 0.11	0.48 ± 0.09	0.02 ± 0.04 0.10 ± 0.04	0.00 ± 0.06 0.14 ± 0.06	0.01 ± 0.07 0.17 ± 0.06
NLB_2	0.02 ± 0.08	0.08 ± 0.11	0.00 ± 0.12	0.00 ± 0.10 0.17 ± 0.10	0.00 ± 0.16 0.19 ± 0.16	0.00 ± 0.15 0.14 ± 0.15
NLB_3	0.06 ± 0.09	0.07 ± 0.13	0.08 ± 0.13	0.00 ± 0.08 0.01 ± 0.08	0.15 ± 0.16	0.00 ± 0.14
NLB_4	0.13 ± 0.09	0.09 ± 0.12	0.23 ± 0.13	0.00 ± 0.09 0.06 ± 0.09	0.15 ± 0.18 0.30 ± 0.17	0.00 ± 0.14
NLB_5	0.12 ± 0.09	0.18 ± 0.12	0.12 ± 0.13	0.00 ± 0.09 0.08 ± 0.09	0.00 ± 0.20 0.48 ± 0.19	0.00 ± 0.14
NLB_{2-5}	0.09 ± 0.05	0.08 ± 0.08	0.12 ± 0.08	0.00 ± 0.04 0.13 ± 0.04	0.01 ± 0.08 0.31 ± 0.07	0.00 ± 0.04 0.05 ± 0.04
Life NLB				0.03 ± 0.05	0.06 ± 0.17 0.21 ± 0.17	0.00 ± 0.14

TABLE 4.6: CONTINUED

	Dtr-DAM Regression ± Std Err			Sire Intraclass Correlation* ± Std Err		
TRAIT	Combined	CSR	HSR	Combined SR	CSR	HSR
NLW_2	0.08 ± 0.09	0.09 ± 0.13	0.02 ± 0.16	0.00 ± 0.11 0.25 ± 0.11	0.20 ± 0.16	0.03 ± 0.16 0.16 ± 0.16
NLW_3	0.15 ± 0.09	0.41 ± 0.14	0.00 ± 0.13	0.05 ± 0.09	0.08 ± 0.15	0.00 ± 0.15 0.08 ± 0.15
NLW_4	0.19 ± 0.08	0.30 ± 0.12	0.02 ± 0.13	0.00 ± 0.09 0.09 ± 0.09	0.29 ± 0.17	0.00 ± 0.14
NLW_5	0.00 ± 0.09	0.09 ± 0.13	0.00 ± 0.15	0.00 ± 0.09 0.07 ± 0.09	0.00 ± 0.17 0.26 ± 0.17	0.00 ± 0.14 0.01 ± 0.14
NLW_{2-5}	0.00 ± 0.04	0.00 ± 0.07	0.02 ± 0.06	0.00 ± 0.04 0.18 ± 0.04	0.10 ± 0.08 0.29 ± 0.07	0.00 ± 0.05 0.13 ± 0.05
Life NLW				0.12 ± 0.07	0.19 ± 0.17 0.21 ± 0.17	0.00 ± 0.14
WLW_2	0.08 ± 0.10	0.01 ± 0.14	0.28 ± 0.15	0.01 ± 0.10 0.12 ± 0.10	0.11 ± 0.15	0.00 ± 0.14
WLW_3	0.27 ± 0.10	0.43 ± 0.13	0.00 ± 0.17	0.00 ± 0.10 0.12 ± 0.10	0.05 ± 0.15	0.00 ± 0.14
WLW_4	0.06 ± 0.09	0.09 ± 0.13	0.00 ± 0.16	0.01 ± 0.11 0.21 ± 0.11	0.34 ± 0.18	0.12 ± 0.15 0.11 ± 0.16
WLW_5	0.08 ± 0.11	0.14 ± 0.14	0.03 ± 0.19	0.00 ± 0.08	0.00 ± 0.15	0.00 ± 0.14
WLW_{2-5}	0.22 ± 0.08	0.29 ± 0.11	0.14 ± 0.12	0.00 ± 0.05 0.19 ± 0.05	0.07 ± 0.06 0.13 ± 0.05	0.00 ± 0.05 0.07 ± 0.04
Life WLW				0.12 ± 0.06	0.06 ± 0.15	0.00 ± 0.15 0.06 ± 0.15

TABLE 4.6: CONTINUED

	Dtr-DAM Regression ± Std Err			Sire Intraclass Correlation* ± Std Err		
TRAIT	Combined	CSR	HSR	Combined SR	CSR	HSR
WPL$_{2}$	0.16 ± 0.10	0.14 ± 0.15	0.18 ± 0.14	0.01 ± 0.15 0.19 ± 0.15	0.21 ± 0.24	0.07 ± 0.24 0.15 ± 0.25
WPL$_{3}$	0.13 ± 0.08	0.11 ± 0.11	0.15 ± 0.13	0.00 ± 0.14 0.27 ± 0.14	0.25 ± 0.24 0.44 ± 0.23	0.07 ± 0.20
WPL$_{4}$	0.00 ± 0.08	0.08 ± 0.12	0.00 ± 0.12	0.06 ± 0.11	0.10 ± 0.19	0.00 ± 0.19
WPL$_{5}$	0.14 ± 0.09	0.32 ± 0.12	0.00 ± 0.13	0.03 ± 0.14 0.20 ± 0.14	0.11 ± 0.21	0.52 ± 0.25
WPL$_{2-5}$	0.20 ± 0.07	0.30 ± 0.10	0.13 ± 0.09	0.03 ± 0.05 0.17 ± 0.05	0.26 ± 0.09	0.12 ± 0.07 0.16 ± 0.07
LSP$_{2}$	0.00 ± 0.10	0.00 ± 0.20	0.09 ± 0.17	0.00 ± 0.11 0.12 ± 0.12	0.00 ± 0.17	0.00 ± 0.21 0.30 ± 0.20
LSP$_{3}$	0.09 ± 0.09	0.00 ± 0.14	0.24 ± 0.13	0.00 ± 0.09 0.02 ± 0.10	0.00 ± 0.16 0.09 ± 0.17	0.00 ± 0.18 0.25 ± 0.18
LSP$_{4}$	0.00 ± 0.13	0.00 ± 0.19	0.00 ± 0.21	0.07 ± 0.10	0.18 ± 0.18 0.26 ± 0.18	0.00 ± 0.15
LSP$_{5}$	0.04 ± 0.11	0.01 ± 0.16	0.06 ± 0.16	0.00 ± 0.11 0.13 ± 0.11	0.01 ± 0.18 0.18 ± 0.17	0.10 ± 0.17 0.11 ± 0.17
LSP$_{2-5}$	0.00 ± 0.08	0.00 ± 0.13	0.04 ± 0.10	0.01 ± 0.03 0.07 ± 0.03	0.00 ± 0.06 0.13 ± 0.06	0.00 ± 0.05 0.08 ± 0.05

4.3.1 LIVEWEIGHT

Weaning Weight

The heritability estimates of WWT, 0.04-0.22, were within the range of other published estimates. In the pooled analyses the II estimates were in the middle of the range of estimates of heritability of WWT in the New Zealand Romney (0.35 Ch'ang and Rae, 1961; 0.23, 0.30 Ch'ang and Rae, 1970; 0.35 Lundie, 1971; -0.05, 0.18 Baker *et al.* 1974; -0.06-0.22 Baker *et al.* 1979; 0.19-0.35 Blair, 1981; 0.10 Tait 1983; 0.20 Wewala, 1985). The estimates by the EI method were at the lower limit, although still well within the range of values as Baker *et al.* (1974, 1979) reported two negative estimates of heritability.

The heritabilities calculated from the CSR data were higher than those for the HSR, but the large standard errors meant there was no significant difference.

Similarly the large standard errors mean there was no significant difference between the estimates by EI and II methods.

As in other studies (Eikje, 1978; Baker *et al.* 1979) it was found that the heritability of weaning weight of the ewe lambs was higher than that of the ram lambs (0.03 - 0.10 higher).

Hogget Spring Liveweight

The estimated hogget spring liveweight heritability was 0.05 - 0.46 (Table 4.6). The estimates by the II method were within the range of published heritabilities for hogget SLW in New Zealand Romneys (0.46 Tripathy, 1966;

0.46, 0.51 Ch'ang and Rae, 1970; 0.22 Baker *et al.* 1974; 0.23-0.31 Baker *et al.* 1979; 0.06-0.52 Blair, 1981; 0.25 Tait, 1983). The EI and daughter-dam estimates were lower than the usual range, although Blair (1981) reported an estimate of 0.06 in a group of Romneys selected for open faces.

The daughter-dam regression estimates of heritability were very close to those obtained by the EI method. This was expected as sire x stocking rate interactions were nonsignificant for hogget SLW and the DD estimates are free of sire x year interactions.

Paternal half-sib estimates calculated by the EI and II methods were significantly different in the pooled data and CSR and approached a significant difference in the HSR.

CSR heritability estimates were higher than those of the HSR, but differences were not significant for the EI and daughter-dam estimates and only marginally significant for the II estimates.

Estimates obtained in this study were lower than estimates reported by Chopra (1978), 0.21-0.72, although these were only outside the standard error range in the combined stocking rate. Inclusion of more data in this study might have resulted in different genetic variance estimates; however an important cause of the variation was the different analysis techniques used, when heritability estimates were recalculated on the sire group periods involved in Chopra's study, the estimates were lower than those obtained by Chopra (1978) and almost identical to the SLW heritabilities reported earlier.

Ewe Autumn Liveweight

Ewe liveweight heritabilities ranged from 0.05 to 0.56 for paternal half-sib EI estimates, from 0.15 to 0.78 for paternal half-sib II estimates and from 0.05-0.68 for daughter-dam estimates. No other estimates have been published for autumn liveweight in New Zealand Romney ewes. There are few estimates of the heritability of liveweight for other breeds (0.33 Nelson and Venkatachalam, 1949; 0.22 Hazel and Terrill, 1946; 0.36 Morley, 1951, 1955; 0.34 Karam, Chapman and Pope, 1953; 0.54 Beattie, 1962; 0.65 Brown and Turner, 1968; -0.01-0.30 Vesely and Robison, 1970; 0.27 Watson *et al.* 1977; 0.32, 0.44 Gregory, 1977).

Paternal half-sib CSR estimates were higher than HSR estimates, however large standard errors meant the differences were not significant. In the daughter-dam estimates the opposite was true with CSR heritabilities being lower than those for the HSR.

Heritabilities calculated for individual ages reflected the absence of a sire x year interaction in the separate stocking rate estimates, while the presence of a sire x stocking rate interaction was indicated by the difference between EI and II methods in the combined stocking rate estimates in separate ages.

Daughter-dam estimates were very similar to the paternal half-sib II estimates in the combined stocking rate analyses. The CSR DD estimates were lower than paternal half-sib estimates while the opposite occurred at the HSR. However few of the differences were significant.

4.3.2 GREASY AND CLEAN FLEECE WEIGHT

Hogget Greasy Fleece Weight

The calculated heritabilities of hogget greasy fleece weight were 0.23-0.56 for paternal half-sib estimates and 0.00-0.46 for daughter-dam estimates. The paternal half-sib estimates in this study agreed well with other published estimates of the heritability of GFW in NZ Romney hoggets (0.31 Rae, 1957; 0.43 Tripathy, 1966; 0.29, 0.57 Baker *et al.* 1974a; 0.33-0.43 Eijke, 1978; 0.29-0.41 Baker *et al.* 1979; 0.28-0.34 Blair, 1981; 0.30 Tait, 1983).

The paternal half-sib II estimates were higher than the EI estimates in the combined and high stocking rates reflecting the significant sire x year interactions in those analyses. However the EI and II estimates were not significantly different.

The daughter-dam heritability estimates in the combined and control stocking rates were not significantly different from zero and were significantly lower than the PHS estimates. In the HSR the DD estimate was not different from the paternal half-sib estimates.

Hogget Clean Fleece Weight

Heritability of hogget clean fleece weight was 0.29-0.53 for the PHS estimates and 0.10-0.25 by DD method. Blair (1981) reported the only other Romney hogget estimates of the heritability of CFW; his estimates (0.11-0.36) agreed well with those found in this study. Estimates reported for hoggets of other breeds were also similar (0.37, 0.45 Young *et al.* 1960; 0.23, 0.27 Botkin *et al*, 1969; 0.16-0.26 Gregory, 1982).

Trends for CFW heritabilities were the same as GFW.

Ewe Greasy Fleece Weight

Estimates of ewe greasy fleece weight heritability ranged from 0.14 to 0.82. These estimates are in good agreement with others published for Romney ewes (0.20, 0.35 Rae, 1946; 0.15 Rae, 1948; 0.11, 0.32 Rae, 1957; 0.45 Builov, 1970; 0.23 Lundie 1971; 0.32, 0.37 Radomska and Tyszka, 1972) and in other breeds (0.28-0.37 Doney, 1957; 0.45 Young *et al.* 1960; 0.14-0.51 Mullaney *et al.* 1970; 0.25-0.51 Eijke, 1975; 0.39-0.56 Gregory, 1977; 0.24-0.62 Lewer, 1978).

No age trends or differences between the control and high stocking rates were observed in the PHS estimates. The II estimates were significantly higher than the EI estimates in the combined age analyses reflecting the importance of sire x birth year interactions on ewe GFW. Differences between the EI and II estimates declined as age increased in the separate age analyses, as did the importance of sire x birth year interactions. The large standard errors in the separate age analyses meant differences between the EI and II estimates were not significant.

DD estimates were similar to PHS II estimates. There were no significant differences between the DD and II estimates but some occurred between the DD and EI estimates.

Ewe Clean Fleece Weight

The estimates of heritability of ewe CFW were 0.16-0.78 for PHS analyses. Only one other estimate has been published for Romney ewe CFW heritability (0.41 Builov, 1970), but estimates in this study are in good agreement with those of other breeds (0.47 Morley, 1955; 0.28 Schinckel, 1958; 0.24-0.50 Mullaney *et al.* 1970; 0.28-0.46 Vesely and Robison, 1970; 0.06-0.65 Pattie and Barlow, 1974; 0.07-0.41 (Realized h^2) Heydenrych *et al.* 1977; 0.39 Watson *et al.* 1977).

As for ewe GFW DD estimates were not significantly different to PHS estimates in the separate age classes. However, in the combined age analyses the DD heritabilities were estimated as 0.00, significantly lower than the PHS estimates.

4.3.3 CLEAN SCOURED YIELD

Hogget Clean Scoured Yield

No significant differences were found between the different estimates of heritability of clean scoured yield in hoggets. All were in the range 0.29-0.34 except the EI combined data paternal half-sib estimate of 0.19. Estimates in this study fall within the range of the only other observations reported for New Zealand Romney hoggets (0.19-0.53 Chopra, 1978; 0.04-0.40 Blair, 1981). Estimates in the New Zealand Romney are lower than those of the same age in other breeds (0.39 Morley, 1955; 0.44, 0.49 Young *et al.* 1960; 0.32-0.56 Vesely and Robison 1970; 0.39, 0.65 Vesely *et al.* 1970; 0.59-0.69 Ozcan 1971; 0.47 0.59 Gregory, 1982).

As sire x year interactions were unimportant in this trait there were no differences between the EI and II PHS heritability estimates in the control and high stocking rates. The difference (non-significant) in the EI and II estimates in the combined data analysis was largely attributable to the sire x stocking rate interactions. Chopra (1978), despite non-significant sire interactions, found the heritability estimate was considerably lower in the HSR (0.19 ± 0.11) when compared to the estimates in the CSR (0.53 ± 0.19), although no significant difference was observed between the two estimates.

DD estimates were similar to the PHS estimates, as might be expected since genotype x year interactions were not important in the PHS analyses.

Ewe Clean Scoured Yield

Estimates of the heritability of clean scoured yield in ewes ranged from 0.00-0.30 by the EI calculation method, 0.04-0.39 by the II calculation method and 0.12-0.62 by DD techniques. As in the hoggets, PHS estimates of heritability in this study were generally lower than those published for ewes of other breeds (0.49 Brown and Turner, 1968; 0.43, 0.54 Gjedrem, 1969; 0.28-0.59 Mullaney *et al.* 1970; 0.33 Nawara, 1971; 0.60 Watson *et al.* 1977).

CSR and HSR PHS estimates were similar and although DD heritability estimates for the two stocking rates tended to vary in the separate age analyses differences were not significant. Differences between EI and II methods were greatest in the two year old ewe estimates, reflecting the large sire interaction to between sire variance ratio (20.9), however no differences were significant. The magnitude of the II heritability estimates tended to decline with age, with 5 year old heritabilities not being significantly different from zero.

DD estimates of heritability were generally significantly higher than the EI PHS estimates. They were higher, though not significantly, than the separate age estimates by the II method and significantly higher than the combined data II estimates.

4.3.4 QUALITY NUMBER

Hogget Quality number

Heritability estimates for quality number varied from 0.28-0.54. These values are lower than those reported by Chopra (1978) of 0.46 to 0.72 but are similar to other published estimates for New Zealand Romney hoggets (0.35-0.40 McMahon, 1943; 0.34 Rae, 1957; 0.34-10.47 Rae, 1958; 0.31-0.58 Blair 1981; 0.55-0.56 Tait, 1983).

PHS estimates by the EI and II methods were the same in the separate stocking rate and very close in the combined stocking rates, as expected since no sire x year interactions were present and sire x stocking rate interactions were nonsignificant for this trait. The heritability estimates in the separate and combined stocking rates were very similar.

The DD estimates of heritability were higher, although not significantly, than the PHS estimates.

Ewe Quality Number

Heritability estimates for quality number in ewes ranged from 0.12-0.51 in combined data analyses, within the range of published estimates, although as in this study, most tend to be greater than 0.20 (0.25-0.47 Rae, 1957; 0.32-0.60 Mullaney *et al.* 1970; 0.11, 0.28 Gregory, 1977; 0.22-0.66 Lewer 1978; 0.21-0.30 Gregory, 1982). In the separate stocking rates estimates varied from 0.03-0.56.

There were no significant differences between PHS estimates calculated by EI and II methods, due to large standard errors in some of the subclasses.

No consistent trends were identifiable in either separate age or separate stocking rate analyses. Lewer *et al.* (1983) failed to find an age trend in the PHS estimates but the DD estimates increased with age in their study.

Heritability estimates computed by the DD method were generally larger than the PHS estimates. Similar results were reported by Lewer *et al.* (1983) who could suggest no adequate explanation for the difference.

4.3.5 MEAN FIBRE DIAMETER

Hogget Mean Fibre Diameter

Heritability estimates for mean fibre diameter in hoggets ranged from 0.26 to 0.62. These estimates were similar to those reported in New Zealand Romney hoggets (0.34-0.81 Chopra, 1978; 0.49-0.64 Blair, 1981), although Blair (1981) also reported two lower estimates (0.18, 0.21) which were close to the 0.17 reported by Tripathy (1966). The values derived in this study are comparable to those found in hoggets of other breeds (0.12-0.45 Young *et al.* 1960; 0.38-0.53 Gjedrem, 1969; 0.52-0.65 Ozcan, 1971; 0.47, 0.54 Elliott, 1975; 0.42-0.88 Gregory, 1982).

Lack of significant GxE interaction in the HSR meant the EI and II estimates were very similar. The presence of significant interactions in the CSR and combined analysis meant the II estimates were higher than the EI estimates, however the difference was not significant.

The heritability estimates were higher in the CSR as compared with the HSR, however no significant differences were found. DD estimates were not significantly different from the PHS estimates.

Generally MFD heritability estimates are higher than quality number heritabilities. In this study no significant differences were observed, although the combined and CSR MFD estimates were higher. Thus although heritabilities of the two traits are similar greater accuracy in determining MFD would enable greater progress to be made in that trait, especially as the genetic correlation of MFD and QN is less than 1.0.

Ewe Mean Fibre Diameter

Estimates of heritability of ewe mean fibre diameter were very high in general, ranging from 0.26-1.07, and compare well with other published estimates based on ewe records (0.52 Schnickel, 1958; 0.47 Brown and Turner, 1968; 0.53 Gjedrem, 1969; 0.30-0.70 Mullaney *et al.* 1970; 0.83, 0.84 Watson *et al.* 1977; 0.24-0.60 Lewer, 1978).

Estimates of heritability in the combined data analyses by the EI and II methods were significantly different, reflecting the significant genotype x environment interactions.

However, due to the large standard errors there were no significant differences between the two methods of calculation in the separate stocking rates.

Although no significant differences existed between heritability estimates at the separate ages, the estimates were higher in the 2 year old ewes than in the hoggets. However, as hogget MFD measurement was done by projection microscope and ewe MFD by airflow techniques this may contribute somewhat to the difference. Mullaney *et al.* (1970) found that values for 18 month ewes were always lower than those for 30 month ewes in their analysis of 3 breeds. As in this study Lewer *et al.* (1983) could find no age pattern in 2-5 year old ewe MFD heritabilities.

Heritability estimates were higher in the CSR as compared to the HSR, but the difference was significant in the combined age analyses only.

DD estimates of heritability were generally higher than either PHS estimates in the separate age analyses, but were lower in the combined age analyses although few differences were significant.

As anticipated ewe MFD heritability estimates were higher than ewe QN heritabilities. Hence, as well as greater accuracy of measurement and direct selection on trait required (correlation of ewe QN to MFD was -0.5), use of MFD as a selection criterion would result in faster genetic progress due to higher heritabilities.

4.3.6 STAPLE LENGTH

Hogget Staple Length

The heritability estimates of SL ranged from 0.34 to 0.57. These estimates compare well with the estimates of SL heritability in New Zealand Romney hoggets in other studies (0.35 Rae, 1950; 0.50 Rae, 1957; 0.35, 0.48 Rae, 1958; 0.54-0.63 Chopra, 1978; 0.09-0.47 Blair, 1981; 0.37-0.38 Tait, 1983).

DD estimates of heritability were similar to those calculated by the II PHS method. However, there were no significant differences between any of the estimates, reflecting the lack of important genotype x environment interactions for this trait.

Heritability estimates tended to be higher in the high stocking rate as compared to the control stocking rate, though the differences were not significant. Chopra (1978) noted that the estimates in the CSR and in the HSR were almost identical. Osman and Bradford (1965) examined genotype x location interactions in SL but did not observe any significant difference in the heritability estimates at two locations.

Ewe Staple Length

Estimates of the heritability of ewe staple length ranged from 0.11-0.57 for daughter-dam regression estimates and 0.17-0.63 for paternal half-sib estimates. Few estimates are available for mature New Zealand Romney staple length heritabilities, however estimates in this study were in good agreement with those available and with other breed estimates (0.29-0.48 Rae, 1957; 0.35, 0.48 Rae, 1958; 0.42, 0.53 Osman and Bradford, 1965; 0.46 Tripathy, 1966; 0.31-0.59 Mullaney *et al.* 1970; 0.19-0.36 Vesely and Robison, 1970; 0.25-0.71 Lewer, 1978).

Large standard errors associated with the PHS estimates of heritability meant no differences existed between the combined data or separate stocking rate estimates.

Estimates calculated by the EI and II methods were not significantly different in the combined data analysis due to high standard errors. As the sire x environment (year) interactions were unimportant in the separate stocking rate analyses of individual ages the estimates by the EI and II methods were very similar except for estimates of 0.17 by the EI and 0.51 by the II methods in the HSR 5 year old ewe analysis. However with these the standard errors were large.

DD regression estimates were generally high, 0.32-0.57, except in the combined age analysis where the estimates were 0.14 ± 0.13 in the combined stocking rate, 0.11 ± 0.05 in the CSR and 0.19 ± 0.05 in the HSR.

4.3.7 TOTAL CRIMP NUMBER

Hogget Total Crimp Number

Estimated heritabilities for total crimp number in hoggets were 0.49 - 0.59. Few other studies have reported on heritability of TCN except Chopra (1978) and Blair (1981). Blair (1981) obtained estimates of 0.27 - 0.50 for 12 month old Romney ewes and rams. Using the same data as that in the early years of this study Chopra (1978) obtained estimates of 0.65 - 1.09. These are higher than those estimated in this study and those reported by Blair (1981). Recalculation of heritabilities using the same data as Chopra (1978) obtained estimates of 0.38 - 0.59.

There were no significant differences between heritability estimates in the separate stocking rates or between DD and PHS estimates. PHS EI and II estimates were very similar, since sire x environment interactions contributed less than 2% of the total variance in all hogget analyses.

Ewe Total Crimp Number

Estimates of the heritability of total crimp number in ewes ranged from 0.00 to 0.66. No other estimates have been published for total crimp number in ewes.

The presence of significant GxE interactions in the combined age analyses was reflected in the significant difference between the EI and II PHS estimates in the combined and control stocking rates. Lack of GxE interactions in the separate age analyses resulted in no or non-significant differences between estimates calculated by the EI or II methods.

Heritability estimates in the CSR were higher than in the HSR but large standard errors meant that differences were rarely significant. Age trends were unclear, though hoggets had the highest heritability estimates in the paternal half-sib estimates.

DD estimates were higher than PHS estimates in the separate age analyses, although differences were only significant in the 3 and 4 year old ewe classes. In the combined data analyses the DD estimates were lower than the PHS estimates but no significant differences occurred.

When examined by half-sib analyses of variance, Jackson and Chapman (1975) found the heritability of abnormal crimp scored at ages less than 4.5 years was low (0.10-0.19), whereas abnormality at 5.5 years and older was highly inherited (0.35-0.60). Heritabilities estimated by intra-sire dam-daughter regression analyses did not show such a clear-cut pattern, although the estimates tended to increase with age.

4.3.8 CRIMP FREQUENCY

Hogget Crimp Frequency

Heritabilities of crimp frequency in hoggets were 0.35-0.42 for paternal half-sib estimates and 0.54-0.66 for daughter-dam estimates. Chopra (1978) and Blair (1981) reported the only other estimates of crimp frequency in New Zealand Romney hoggets. Estimates reported by Blair (1981), 0.26-0.59, agreed with those obtained in this study; however heritabilities reported by Chopra (1978) were higher (0.48-0.78). Estimates in other breeds tended to be similar to those of Blair (1981) (0.36, 0.51 Young *et al*. 1960; 0.19-0.46 Gregory, 1982).

As noted by Chopra (1978), heritability estimates in the HSR were higher as compared to those in the CSR but the differences between the estimates were non-significant.

PHS estimates calculated by the EI and II methods were identical since there was no genotype x environment interactions present in this trait.

DD regression estimates were higher than those calculated by the PHS method. However the difference was only significant in the combined data analysis between the EI estimate of heritability and the daughter-dam regression estimate.

Ewe Crimp Frequency

Estimated heritability of ewe crimp frequency ranged from 0.00 - 0.49 for paternal half-sib estimates and from 0.21 - 0.73 for daughter-dam regression estimates. No other estimates of ewe crimp frequency heritability have been reported for New Zealand Romney's, except 0.72 reported by Tripathy (1966). However, estimates in ewes of other breeds agree well with those obtained in this study (0.28, 0.40 Morley, 1950; 0.47 Morley, 1955; 0.40 Schinckel, 1958; 0.38, 0.46 Robards and Pattie, 1967; 0.45 Brown and Turner, 1968; 0.09 - 0.40 Mullaney *et al.* 1970).

As for TCN, the difference in PHS estimates calculated by the EI and II methods was only significant for the combined age estimates.

Except in the 3 year old ewe estimates, heritabilities tended to be lower in the HSR as compared to the CSR. But large standard errors meant none of the differences were significant.

Heritability estimates tended to decrease with age, but there were no significant differences except 5 year old ewes as compared to hoggets.

DD regression estimates were higher than PHS estimates. The difference between the estimates was significant in most of the subclasses.

4.3.9 STAPLE STRENGTH

Hogget Staple Strength

Estimates of the heritability of hogget staple strength were 0.09 - 0.30 for PHS estimates and 0.03 for DD regression estimates. Few other estimates are available for comparison, Bigham *et al.* (1983) estimated heritability of staple strength in Romney ewe hoggets as 0.48 ± 0.15, which was considerably higher than in this study.

Differences in estimates between the EI and II methods occurred in the HSR and combined data analysis only and were due to the presence of a sire x year interaction in the HSR. Differences between the estimates were non-significant.

Heritability estimates in the HSR were higher than those in CSR; however large standard errors resulted in no significant differences between the estimates.

DD estimates were considerably lower than PHS estimates of heritability. As noted by Rae (1958), estimates by the DD method should be relatively free of genotype x year effects. This was probably reflected in this trait where there was no significant difference between the DD and PHS estimates in the control stocking rate where no sire x year interactions occurred. However significant differences were found for the combined data and high stocking rate estimates as compared to the DD estimates as sire x year interactions occurred in these analyses.

The low heritabilities probably reflect the inaccuracy of the technique of measurement as much as they reflect the biological situation.

Ewe Staple Strength

Heritability of staple strength in the ewe analyses ranged from 0.00 - 0.36 for PHS estimates and 0.15 - 0.58 for DD estimates. The PHS estimates were similar to those for hogget SST.

Most PHS estimates in the separate age analyses were not significantly different from zero.

II estimates of heritability were higher as compared to the EI estimates in the combined age analyses due to the importance of sire x birth year interactions in the combined age analyses, but the difference was only significant for the pooled data estimates.

DD estimates were similar to the PHS estimates for combined age heritabilities. However in the separate age analyses DD estimates tended to be considerably higher than the PHS estimates, although large standard errors meant that few differences were statistically significant.

4.3.10 CHARACTER GRADE

Hogget Character Grade

Heritability estimates of CHG ranged from 0.21 to 0.35. These estimates in general compare well with other published estimates in New Zealand Romney hoggets (0.20, 0.27 Rae, 1948; 0.12 - 0.25 Rae, 1957; 0.12, 0.22 Rae, 1958; 0.24 - 0.34, Chopra, 1978; 0.25 - 0.50 Blair, 1981; 0.18 - 0.19 Tait, 1983) and are within the range of estimates for hoggets of other breeds (0.15 Botkin *et al.* 1969; 0.23, Elliot, 1975; 0.15, 0.27 Gregory, 1977; 0.19 - 0.37 Gregory, 1982).

There were no significant differences between heritability estimates in the separate stocking rates, between the EI and II calculation methods or between DD and PHS estimates.

Chopra (1978) noted that it had been assumed that selection for CHG in New Zealand Romney would be an inefficient way of using selection potential since the heritability estimates, reported prior to 1978 were of low magnitude (Wickham, 1973). However, Chopra (1978) suggested that the higher estimates of intermediate magnitude found in his study meant there was a possibility of achieving some genetic improvement in CHG by selection. This view is supported by the estimates determined in this study and by other recently published estimates.

Ewe Character Grade

The heritability estimates of CHG computed by EI and II methods ranged between 0.01 and 0.37. DD estimates were between 0.03 and 0.64. No estimates have been published for the heritability of CHG in New Zealand Romney ewes.

Estimates in this study are in good agreement with those of other breeds (0.38 Morley, 1955; 0.25 - 0.78 Mullaney *et al.* 1970; 0.03, 0.26 Gregory, 1977; 0.12 - 0.39 Lewer, 1978).

DD estimates of heritability were similar to PHS estimates calculated by the EI method, but were not significantly different from either estimate except in the combined age analysis.

There were no significant differences between the CSR and HSR estimates and there were no clear age trends in this study. Similar results were reported by Lewer *et al.* (1983), who noted that although Jackson and Chapman (1975) had recorded increasing heritability of crimp abnormality in older Merinos, most of the higher heritability estimates in their study were for groups of sheep older than 5 years.

In the combined age analyses there were significant differences between the EI and II PHS heritability estimates in the combined stocking rates and control stocking rate analyses, reflecting the importance of genotype x year interactions in the control stocking rate.

4.3.11 LUSTRE GRADE

Hogget Lustre Grade

The estimates of heritability for LUS were 0.20 - 0.28. These estimates were similar to the value of 0.27 reported by Rae (1948) in the New Zealand Romney. Estimates calculated by Chopra (1978) were higher, 0.32 - 0.42, but recalculation by techniques used in this study of Chopra's (1978) data obtained estimates of 0.28 - 0.35.

Lack of genotype x environment interactions meant PHS estimates by the EI and II methods were very close.

The difference between the heritabilities in the HSR (0.21) and the CSR (0.34) was not significant.

Ewe Lustre Grade

The estimated heritability of ewe lustre grade was 0.00 - 0.65. No published estimates are available for comparison except hogget estimates which were generally higher than most of the ewe estimates. The large standard errors in this study meant differences were not significant.

PHS estimates of heritability by the EI method were not significantly different from zero. Although II estimates were not significantly different from EI estimates, most were greater than zero.

No age trends or consistent differences between the control and high stocking rate were identifiable.

DD estimates were similar to the PHS estimates, except for the overall and combined age high stocking rate estimates, where DD estimates were significantly higher.

4.3.12 TIPPINESS GRADE

Hogget Tippiness Grade

Heritability of hogget tippiness grade was estimated as 0.10 - 0.21 for PHS estimates and 0.23 - 0.26 by DD methods. The only other estimates published; the PHS estimates calculated by Chopra (1978), of 0.13 - 0.27 are in good agreement with estimates obtained in this study.

There were no significant differences between the estimates in the CSR and HSR. As genotype x environment interactions were non-significant the heritability estimates were similar by the EI and II methods.

Henderson (1968) noted that tippiness was generally assumed to be largely determined by genetic factors although proof of this was lacking. Estimates in this study and those found by Chopra (1978) suggest that tippiness in these flocks was more a result of environment factors such as weathering than an effect of inherited variability of fibre growth rate.

Ewe Tippiness Grade

Heritability estimates of ewe tippiness grade ranged from 0.00 to 0.34. No other estimates of heritability of tippiness grade in ewes have been published. The range of estimates in this study cover those estimated for hogget tippiness grade.

As noted previously there were no genotype x environment interactions of importance in most of the separate age analyses, such that PHS estimates of heritability by the EI and II methods were the same. In the two exceptions, the difference between the methods of estimation were non-significant.

There were no significant differences between separate stocking rate estimates or between separate age estimates. HSR estimates of heritability tended to be lower than CSR estimates. No consistent age trends were identifiable.

The combined-age ewe heritability estimates tended to be higher than the corresponding hogget estimates, although the differences were not significant.

4.3.13 COTTING GRADE

Hogget Cotting Grade

Heritability of cotting grade was 0.16 - 0.32 for paternal half-sib estimates and 0.04 - 0.40 for daughter-dam regression estimates. Chopra (1978) estimated heritability of this trait as 0.12 - 0.67. Recalculation of heritabilities on Chopra's (1978) data resulted in estimates of 0.13 - 0.22, which were in good agreement with heritability estimates in this study.

There were no significant differences between the estimates obtained in the two stocking rates.

Sire x year interactions contributed to the total variance in the CSR resulting in different estimates of heritability by the EI and II methods, however the difference was not significant.

DD estimates of COT were significantly different in the separate stocking rates and the HSR estimate was higher as compared to the CSR estimate. Although the PHS and DD estimates were the same in the pooled analysis, significant differences were found in the separate stocking rates.

Ewe Cotting Grade

Heritability of ewe cotting grade estimates ranged from 0.10 to 0.50 by PHS methods and from 0.00 to 0.48 by DD techniques. No other estimates have been published for the heritability of ewe COT. The estimates were similar to the hogget COT heritability estimates in this study. In selection index studies McPherson (1982) assumed the heritability of cotting was low, using a value of 0.15.

There were no significant differences between estimates in the control and high stocking rates or between estimates in the separate age classes. No consistent trends were identifiable for either case.

Although there were some large differences between the PHS heritability estimates calculated by the EI and II methods, large standard errors meant these differences were not significant in many cases. Significant differences existed in the pooled data estimates and in the combined age HSR estimates, reflecting the importance of sire x year interactions in those classes.

DD estimates of heritability were not significantly different from PHS estimates in general, lying between the EI and II estimates where possible. With the exception, the 2 year old ewe analyses, the DD estimates were significantly higher than PHS estimates.

Cotting is assumed to be a fault associated with heredity, fibre variability being a heritable trait for the sheep, and with the environment through poor nutrition and the presence of moisture (Henderson, 1955). As noted by Chopra (1978), the low to medium size of PHS heritability estimates of COT in these studies suggest that very limited genetic improvement is likely to be achieved by direct selection. DD heritability estimates are medium to high however and would hence suggest that genetic progress could be attained, at a reasonably rapid rate.

4.3.14 COTTED AREA GRADE

Hogget Cotted Area Grade

Heritability of hogget CAG was estimated as 0.00 - 0.14 by DD techniques and as 0.10 - 0.28 by PHS methods. Estimates obtained by Chopra (1978) ranged from 0.18 to 0.53, higher than those found in this study. Recalculation of Chopra's (1978) data obtained estimates of 0.16 - 0.38, in between the other two sources of estimates.

The importance of sire x year interactions in the CSR analysis was reflected in the different estimates obtained by the EI and II methods in the CSR and in the pooled analysis, although differences were not significant.

No differences existed between the separate stocking rate heritability estimates.

DD estimates tended to be lower than the PHS estimates but differences were not significant.

Ewe Cotted Area Grade

Heritability estimates of ewe cotted area grade were 0.03 - 0.50. Other estimates were unavailable for comparison except the hogget estimates of Chopra (1978) and of this study, both of which were covered by the above range.

Heritability estimates in the HSR tended to be higher as compared to the CSR but differences were not significant. Heritability estimates increased as age increased in the combined and separate stocking rates but differences between the ages were not significant.

There were no significant differences between DD and PHS estimates or between EI and II methods of calculating PHS estimates.

Intermediate estimates of heritability for ewe cotted area grade suggested that some progress could be achieved in this flock if this trait was used as a selection criterion.

4.3.15 SOUNDNESS GRADE

Hogget Soundness Grade

Heritability estimates for hogget soundness grade were 0.05 - 0.26 by PHS methods and 0.18 - 0.32 by DD techniques. The PHS estimates agree well with the heritabilities estimated by Chopra (1978) of 0.00 - 0.22.

In Chopra's (1978) study genotype x environment interactions were of no importance. In this study sire x year interactions were significant in the separate stocking rate analyses, leading to different heritabilities estimated by the EI and II methods though the differences were not significant.

There were no significant differences between the estimates from the two stocking rates although the DD and PHS II estimates were higher in the CSR than in the HSR. Chopra (1978) reported similar results with heritabilities of 0.22 in the CSR and 0.00 in the HSR.

DD estimates of heritability of hogget SOU were higher than the II PHS estimates but differences were not significant.

The low to medium magnitude to the heritabilities for hogget SOU suggest that genetic progress on this trait would be slow.

Soundness was a hand assessment of the strength of a single staple and can be compared to staple strength measured as the average of five staples. Estimates of heritability of hogget SST were 0.09 - 0.30 for PHS estimates and 0.03 for DD estimates. The PHS estimates of SOU and SST agreed well, but the SST DD estimate was considerably lower than for SOU.

Ewe Soundness Grade

Heritability of ewe soundness grade was estimated as 0.00 - 0.36 (and one of 0.56). No other estimates of ewe SOU have been published. These estimates are similar to those reported in the hoggets by Chopra (1978) of 0.00 - 0.22 and those found in this study 0.05 - 0.32. In selection index studies McPherson (1982) assumed a low heritability for unsoundness of 0.10.

Large standard errors associated with the heritability estimates meant there were no significant differences between age classes or between the stocking rates. The low magnitude of the sire x environment interactions meant that no significant differences occurred between EI and II estimates.

DD estimates were higher than PHS estimates, with significant differences frequently occurring in the separate age and separate stocking rate analyses.

The low magnitude of the heritability of ewe SOU in this study suggested that little progress could be achieved by direct selection on this trait.

The estimated heritability of measured staple strength was 0.00 - 0.36 for PHS estimates and 0.15 - 0.58 for DD estimates. PHS estimates of SOU and SST were very similar. DD regression estimates of the heritability of SOU were generally lower than for SST, reverse to that found in the hoggets. However, as in the hoggets, it suggests that greatest genetic progress in improving staple strength would be achieved using SST as a selection criterion.

4.3.16 HANDLE GRADE

Hogget Handle Grade

The heritability estimates of hogget handle grade were 0.11 - 0.47. The estimates by Chopra (1978) were higher, 0.23 - 0.66, but recalculation on data used in Chopra's (1978) study obtained estimates of 0.13 - 0.48 which were the same as those in the present study.

No significant differences were found between the separate stocking rate estimates or between DD and PHS estimates. Chopra (1978) also reported no difference between the stocking rate estimates.

Ewe Handle Grade

In the ewe analyses estimates of heritability of handle grade ranged from 0.00 to 0.36 in the main analyses and from 0.00 to 0.65 in the separate age separate stocking rate analyses. Rae (1946) reported an estimate of 0.44, the only other published estimate of heritability of HND in New Zealand Romney ewes. The estimates in this study were similar to estimates in hoggets by Chopra (1978) 0.23 - 0.66 and in this study 0.11 - 0.47. Published estimates in other breeds were in good agreement with this study (0.30 Morley, 1955; 0.08 - 0.56 Mullaney *et al.* 1970).

No consistent age trends or stocking rate differences in estimates could be identified. The only significant differences arose because of the high PHS estimates of heritability in the 3 year old ewe analysis in the control stocking rate and the high DD estimate for the 4 year old ewes in the control stocking rate.

The importance of sire x year interactions were reflected in the differences between the EI and II PHS estimates. The differences, on average about 0.1, were not statistically significant.

In general the intermediate-medium magnitude of the HND heritability estimates (most 0.15 - 0.36) suggested that some genetic improvement in handle of the fleece could be obtained from selection on this criterion.

4.3.17 GREASY MIDSIDE COLOUR GRADE

Hogget Greasy Midside Colour Grade

Estimates of the heritability of greasy midside colour in hoggets ranged from 0.10 to 0.42. Rae (1948) reported an estimate for GCM heritability of 0.00 but only a small number of sheep were involved in his study. Chopra (1978) reported estimates of 0.22 - 0.44, similar to estimates in this study. Tait (1983) estimated the heritability of visual yellowness of greasy wool as 0.25 - 0.26.

DD estimates of hogget GCM heritability were very similar, 0.24 - 0.26. They were not significantly different from the PHS estimates.

PHS estimates calculated by the EI and II methods were similar in the separate stocking rates as the sire x year interactions were not important in those analyses. The combined data estimates were significantly different reflecting the importance of both sire interactions in the pooled analysis.

The intermediate to medium heritability estimates for hogget GCM in this study indicated that some improvement in whiteness of Romney wool would be expected from use of this trait as a selection criterion.

Ewe Greasy Midside Colour Grade

Estimated heritability of ewe greasy midside colour ranged from 0.00 to 0.65. In the main analyses PHS estimates were 0.00 - 0.36. No other studies on New Zealand Romney sheep have reported estimates of ewe GCM heritability but heritabilities in this study are similar to those discussed for hogget GCM. In other breeds estimates obtained were higher than those in this study (0.63 Morley, 1955; 0.27 - 0.41 Mullaney *et al.* 1970).

As the sire variance was generally zero or very low, the PHS EI estimates were not significantly different from zero. The II estimates were significantly different from zero and significantly different from the EI estimates for many cases, reflecting the importance of GxE interactions in this trait.

DD estimates were similar to the PHS estimates, except in the combined age analyses where DD estimates were significantly higher.

4.3.18 SCOURED MIDSIDE COLOUR GRADE

Hogget Scoured Midside Colour Grade

Heritability estimates for hogget scoured midside colour were 0.04 - 0.25. Chopra (1978) reported the only other estimates of SCM in New Zealand Romney hoggets. His estimates of 0.10 - 0.39 were slightly higher than estimates obtained in this study, although large standard errors associated with the higher estimates meant there were no significant differences. Jackson (1973) obtained a value of 0.20 in Merino hoggets. Bigham *et al.* (1983) obtained a heritability estimate of measured yellowness of 0.13.

The estimates obtained for SCM were lower than the heritability estimates for GCM, which Chopra (1978) suggested was because of a genetically influenced coloured contaminant being washed out during scouring or because of greater difficulty in maintaining standards during the visual grading of scoured wool.

Although the heritability estimates were higher in the CSR than in the HSR, the differences between the estimates were non-significant.

There were no significant differences between the DD and PHS estimates.

Ewe Scoured Midside Colour Grade

The heritabilities of ewe scoured midside colour were 0.00 - 0.36 in the PHS estimates and 0.00 - 0.80 in the DD estimates. No estimates have been published for ewe SCM heritabilities. However, these estimates are similar to the hogget SCM heritability estimates (0.20 Jackson, 1973; 0.10 - 0.39, Chopra, 1978).

PHS EI estimates were generally not significantly different from zero, reflecting the lack of sire variance.

DD estimates were also not significantly different from zero, except in the combined age analyses where heritability of SCM was estimated as 0.56 ± 0.06, 0.80 ± 0.10 and 0.58 ± 0.10 in the pooled, CSR and HSR combined age analyses respectively.

As for GCM, the heritability estimates of scoured midside colour were generally low, indicating that little genetic progress could be made in improving fleece colour using this trait as a selection criterion.

4.3.19 GREASY FLEECE COLOUR GRADE

Hogget Greasy Fleece Colour Grade

Heritability estimates for hogget GCF, 0.06 - 0.15, were not significantly different from zero. Chopra (1978) also presented estimates of GCF, his estimates of 0.04 - 0.21 were similar to those in this study.

Low heritability estimates for hogget greasy fleece colour in this study suggest that selection on this trait will result in little genetic progress.

Ewe Greasy Fleece Colour Grade

Heritability estimates of ewe greasy fleece colour ranged from 0.00 - 0.21 (plus one of 0.60) for PHS estimates and from 0.00 - 0.77 for DD estimates.

PHS EI estimates were not significantly different from zero, except the 4-year-old ewe estimate. The presence of some sire x year interactions resulted in higher II heritability estimates but the differences from EI estimates were not statistically significant.

DD estimates were significantly higher than PHS estimates in the combined age analyses only.

4.3.20 NUMBER OF LAMBS BORN

Estimates of the heritability of number of lambs born ranged from 0.00 - 0.48; most were below 0.20. Other estimates of the heritability of NLB in New Zealand Romney ewes also tend to be low (0.05, Ch'ang and Rae, 1970, 0.01 - 0.04 Lundie, 1971).
Rae (1982) reported that the most common range of reliable estimates of heritability of lambs born for New Zealand Romneys was 0.0 - 0.1 for 2 year old ewes and 0.0 - 0.3 for 2-4 year old ewes. Other studies have reported a range of estimates which generally agree with those in this study (0.26 Shelton and Menzies, 1968; 0.08 Forrest and Bichard, 1974; -0.13 - 0.17 Gregory, 1977; 0.12 Clarke and Hohenboken, 1983; 0.01 - 0.31 Rendel, 1985; 0.14 Fogarty *et al.* 1985).

Most of the estimates in this study were not significantly different from zero. EI and II paternal half-sib estimates were identical in the HSR analyses. The II estimates were higher as compared to the EI estimates in the control and combined stocking rates but the differences were not significant.

The daughter-dam heritability estimates were higher than the paternal half-sib EI estimates but no significant differences were found.

Heritability estimates for lifetime number of lambs born did not differ from the separate or combined age estimates. Fogarty *et al.* (1985) also obtained a similar heritability estimate for lifetime performance as for the individual records of ewe performance.

Saoud and Hohenboken (1984) noted that despite the low heritabilities generally reported several researchers have reported successful selection for increased reproductive rate (Clarke, 1972; Hanrahan, 1976; Turner, 1978).

4.3.21 NUMBER OF LAMBS WEANED

Heritability of number of lambs weaned was estimated as 0.00 - 0.29 by paternal half-sib analyses and 0.00 - 0.41 in daughter-dam estimates. Few reported estimates are available for the New Zealand Romney (0.00 - 0.15 Rae and Ch'ang, 1955; 0.03 - 0.07 Lundie, 1971) although Rae (1982) reported a range of 0.0 - 0.1 for heritability of lambs weaned in 2-year-old Romney ewes. Studies in other breeds have obtained a wide range of estimates, similar to those in this study (0.00 - 0.29 Young *et al.* 1963; 0.06 Kennedy, 1967; 0.19 - 0.28 Shelton and Menzies 1968; -0.01 - 0.04 Eikje, 1975; 0.08 - 0.24 O'Ferrall, 1976; -0.17 - 0.26 Gregory, 1977; -0.02 - 0.24 Lewer, 1978; 0.00 Clarke and Hohenboken, 1983; -0.09 - 0.31 Fogarty, Dickerson and Young, 1985; 0.00 - 0.16 Rendel, 1985).

Lack of sire variance meant most paternal half-sib EI estimates of heritability were zero. Sire interactions were also small, hence most II estimates were not significantly different from zero except in the pooled data analyses.

Daughter-dam estimates of heritability were similar to paternal half-sib estimates in the high stocking rate and in the combined age analyses. In 3 and 4 year old separate age analyses the combined and control stocking rate daughter-dam estimates were considerably higher than paternal half-sib estimates, but large standard errors resulted in no significant differences.

No age trends were observable in this study. Fogarty *et al*. (1985) noted there was a tendency for heritability estimates to increase with parity, although the increases were associated with large standard errors because later parities involved fewer data.

Heritability of lifetime number of lambs weaned was higher in the combined and control stocking rate analyses than in the high stocking rate but large standard errors resulted in no significance difference from zero. Fogarty *et al*. (1985) estimated lifetime performance for number of lambs weaned as 0.06 ± 0.05.

4.3.22 WEIGHT OF LAMB WEANED

Paternal half-sib estimates of heritability of weight of lamb weaned ranged from 0.00 to 0.34, while daughter-dam estimates ranged between 0.00 and 0.43. Most estimates in this study tended to be less than 0.15. Estimates obtained in other studies cover a wide range of heritabilities (0.17 Gjedrem, 1967; 0.29 Shelton and

Menzies, 1968; 0.01 - 0.35 Lundie, 1971; 0.11, 0.50 Basuthakar *et al.* 1973; 0.12 Eikje, 1975; -0.05 - 0.53 Gregory, 1977; -0.05 Clarke and Hohenboken, 1983; 0.06 Fogarty *et al.* 1985; 0.00 - 0.34 Rendel, 1985).

Paternal half-sib EI estimates were not significantly different from zero, except for the weight of lamb weaned by 4 year old ewes in the control stocking rate, reflecting the lack of sire variance. II estimates were higher, tending to be around 0.10, reflecting the presence of genotype x environment interactions.

Although daughter-dam estimates were generally higher than paternal half-sib estimates these differences were not statistically significant.

Heritability of lifetime weight of lamb weaned was 0.12 in the combined stocking rate and 0.06 in both separate stocking rates. The combined stocking rate estimate was in good agreement with the 0.15 ± 0.05 reported by Fogarty *et al.* (1985).

4.3.23 WEIGHT PER LAMB WEANED

Estimated heritability of weight per lamb weaned was 0.00 - 0.52, with most estimates less than 0.20. Estimates were similar to heritabilities of total weight of lamb weaned.

Heritability estimates tended to be higher in the control as compared to the high stocking rate; however large standard errors meant differences were not statistically significant.

Paternal half-sib EI estimates were generally not significantly higher than zero, reflecting the absence of sire variance. II estimates of heritability were higher than zero but there were no significant differences between EI and II heritability estimates.

As for total weight of lamb weaned, low heritability of weight per lamb weaned indicates that little genetic progress can be expected in flocks of similar type if WPL was used as a selection criterion.

4.3.24 LAMB SURVIVAL

Heritability of lamb survival was estimated to range from 0.00 to 0.30. Most of the estimates approximated zero, with few being significantly different from zero. Few other estimates of the heritability of lamb survival have been published (0.13, 0.19 livability Shelton and Menzies, 1970; -0.07 - 0.13 preweaning survival Fogarty *et al.* 1985; <0.10 Cloete and Heydenrych, 1987).

With the exception of one estimate all daughter-dam heritabilities were close to zero and similar to PHS EI estimates. Fogarty *et al.* (1985) determined the DD heritability of preweaning survival as -0.12.

4.3.25 HERITABILITIES OF ASSESSED WOOL TRAITS BY CATEGORICAL ANALYSIS

Heritabilities calculated for assessed wool traits using logistic linear mixed model analyses are presented in Table 4.7.

The heritabilities including sire interactions are very similar to PHS II estimates (Table 4.6) for most traits, with the exception of greasy midside colour where the categorical estimate was 0.21 compared to the PHS II estimate of 0.14.

The sire variance was calculated by maximum likelihood estimation in a way that includes a component of the sire interactions. This significantly inflates the heritability estimates in most traits. These estimates lie somewhere between those estimated by continuous trait analysis excluding interactions (PHS EI) and those including interactions (PHS II). Although they may represent a truer estimate than those from PHS EI methods the confounding with some of the interaction effects makes their interpretation more difficult. The greatest deviance between estimates of the assessed wool traits treated as continuous or categorical variables in this way occurred for CHG (0.21 cf 0.10), LUS (0.10 cf 0.03), COT (0.24 cf 0.09), HND (0.28 cf 0.17), GCM (0.12 cf 0.00), and SCM (0.10 cf 0.00). Values were very similar for TIP, CAG, SOU and GCF.

Estimates of environmental effects and heritabilities obtained from treating assessed traits as continuous are very similar to those using categorical analysis techniques. Therefore it is adequate to treat at least some graded traits as continuous. This is convenient for analysis purposes as many techniques for analysis of categorical data have yet to be developed for practical use, such as correlations between continuous and categorical traits.

TABLE 4.7: Heritability estimates of assessed ewe wool traits by categorical analysis

Trait	Heritability Estimates	
	Absorb sire only	Absorb sire within byr within sr
CHG	0.21	0.29
LUS	0.10	0.15
TIP	0.28	0.29
COT	0.24	0.39
CAG	0.22	0.47
SOU	0.05	0.16
HND	0.28	0.34
GCM	0.12	0.21
SCM	0.10	0.14
GCF	0.05	0.08

4.3.26: Efficiency of Indirect Selection

The efficiency of selecting sires at a different stocking rate can be calculated using the equation given by Falconer (1952). Some of these calculations have also been presented by Woolaston (1986). The values are given in Table 4.8.

In most cases it was more efficient to select sires in the environment in which the progeny were to perform. The negative efficiencies for adult body weight and staple strength suggest that selection in the wrong environment is worse than random selection - a phenomenon difficult to explain in biological terms.

Woolaston (1986) pointed out that Falconer's (1952) formula for the efficiency of indirect selection assumes equal selection in both environments. If one environment is more favourable than the other, this will probably not be the case. An increase in weaning percentage from 75% to 85% can increase the selection intensity by about 5%. Under such conditions, the efficiency of indirect selection in the more favoured environment should be increased by this amount.

Table 4.8: The efficiency of indirect selection relative to direct selection for hogget and adult traits (%)

Trait	Stocking Rate		Heritability Estimate	
	Sire	Progeny	EI	II
LWT_1	Control	High	91	70
	High	Control	29	37
LWT_{2-5}	Control	High	-36	-31
	High	Control	-16	-19
GFW_1	Control	High	86	67
	High	Control	82	105
GFW_{2-5}	Control	High	57	71
	High	Control	75	59
CFW_1	Control	High	113	84
	High	Control	70	95
CFW_{2-5}	Control	High	70	71
	High	Control	60	60
Y_1	Control	High	57	57
	High	Control	57	57
Y_{2-5}	Control	High	37	46
	High	Control	48	38
Q_1	Control	High	86	86
	High	Control	84	84
Q_{2-5}	Control	High	70	56
	High	Control	48	60
MFD_1	Control	High	105	122
	High	Control	77	67
MFD_{2-5}	Control	High	88	86
	High	Control	56	57
SL_1	Control	High	80	87
	High	Control	130	120
SL_{2-5}	Control	High	55	55
	High	Control	57	57
TCN_1	Control	High	85	92
	High	Control	89	82

Table 4.8: Continued

Trait	Stocking Rate		Heritability Esti	
	Sire	Progeny	EI	II
TCN$_{2-5}$	Control	High	53	59
	High	Control	51	46
CF$_1$	Control	High	92	92
	High	Control	111	111
CF$_{2-5}$	Control	High	58	64
	High	Control	68	62
SST$_1$	Control	High	83	60
	High	Control	147	201
SST$_{2-5}$	Control	High	-3	-2
	High	Control	-2	-2
CHG$_1$	Control	High	64	74
	High	Control	78	68
CHG$_{2-5}$	Control	High	42	68
	High	Control	85	53
LUS$_1$	Control	High	113	113
	High	Control	70	70
LUS$_{2-5}$	Control	High	*	0
	High	Control	0	0
TIP$_1$	Control	High	75	88
	High	Control	143	123
TIP$_{2-5}$	Control	High	100	91
	High	Control	72	79
COT$_1$	Control	High	124	143
	High	Control	82	71
COT$_{2-5}$	Control	High	75	40
	High	Control	28	53
CAG$_1$	Control	High	85	142
	High	Control	127	76
CAG$_{2-5}$	Control	High	51	64
	High	Control	79	62

* zero heritability estimate for direct selection meant efficiency could not be calculated

Table 4.8: Continued

Trait	Stocking Rate		Heritability Estimate	
	Sire	Progeny	EI	II
SOU_1	Control	High	100	127
	High	Control	100	78
SOU_{2-5}	Control	High	-1	-1
	High	Control	-1	-1
HND_1	Control	High	45	91
	High	Control	119	58
HND_{2-5}	Control	High	105	84
	High	Control	75	94
GCM_1	Control	High	25	22
	High	Control	18	20
GCM_{2-5}	Control	High	85	261
	High	Control	423	137
SCM_1	Control	High	26	14
	High	Control	7	13
SCM_{2-5}	Control	High	-100	-126
	High	Control	-100	-79
GCF_1	Control	High	115	115
	High	Control	87	87
GCF_{2-5}	Control	High	0	34
	High	Control	*	42

4.4 REPEATABILITIES

The repeatability estimates and associated standard errors are presented in Table 4.9. In this study phenotypic correlations between ages were used to estimate repeatabilities. As other studies have often calculated repeatability as the regression of a later record on an earlier record and as different models are frequently used to correct data for temporary environmental effects direct comparison of repeatability estimates obtained in this study with those reported by other researchers may be difficult.

Separate correlation coefficients were calculated for each pair of ages. Correlations between hogget and average ewe records and between 2-tooth and older records were also calculated. It was desirable to obtain an average of all possible correlations for each pair of records. However there was frequently a systematic trend among the estimates so a simple arithmetic average, rather than a weighted average, was calculated.

Hogget repeatability values were generally lower than repeatability of later records, especially hogget-lifetime repeatability as compared with 2 year old - 3-5 year old ewe records. Hogget information was generally less reliable at predicting lifetime performance and 2 year old records would be the preferred selection criteria. However this leads to delays in selection in practise, increasing the generation interval.

The repeatability of most subjectively assessed wool traits was low. This implied that either the accuracy of the assessment was poor or that temporary environmental factors had a large effect, while permanent environment and genetic contributions to between sheep differences were small. A low genetic component was already confirmed in the heritability section. Thus selection on the basis of performance at a single shearing is unlikely to result in a large increase in lifetime production of the flock.

TABLE 4.9: Repeatability estimates of various traits

TRAIT	Age (Yrs)	Age (yrs)				
		2	3	4	5	lifetime
ALW	1*	0.56 ± 0.03	0.48 ± 0.03	0.45 ± 0.03	0.39 ± 0.03	0.56 ± 0.03
(*SLW)	2		0.65 ± 0.03	0.56 ± 0.03	0.48 ± 0.03	0.64 ± 0.03
	3			0.70 ± 0.02	0.57 ± 0.03	
	4				0.65 ± 0.03	
			Average = 0.55			
GFW	1	0.48 ± 0.03	0.37 ± 0.03	0.38 ± 0.03	0.34 ± 0.03	0.47 ± 0.03
	2		0.61 ± 0.03	0.55 ± 0.03	0.49 ± 0.03	0.63 ± 0.03
	3			0.65 ± 0.03	0.57 ± 0.03	
	4				0.66 ± 0.02	
			Average = 0.51			
CFW	1	0.47 ± 0.03	0.39 ± 0.03	0.39 ± 0.03	0.33 ± 0.03	0.48 ± 0.03
	2		0.63 ± 0.03	0.53 ± 0.03	0.50 ± 0.03	0.65 ± 0.03
	3			0.64 ± 0.03	0.57 ± 0.03	
	4				0.64 ± 0.03	
			Average = 0.51			
Y	1	0.28 ± 0.03	0.30 ± 0.03	0.27 ± 0.03	0.25 ± 0.03	0.40 ± 0.03
	2		0.37 ± 0.03	0.24 ± 0.03	0.20 ± 0.03	0.36 ± 0.03
	3			0.36 ± 0.03	0.32 ± 0.03	
	4				0.31 ± 0.03	
			Average = 0.29			

TABLE 4.9: Continued

TRAIT	Age (Yrs)	Age (yrs)				
		2	3	4	5	lifetime
QN	1	0.21 ± 0.03	0.17 ± 0.03	0.45 ± 0.03	0.37 ± 0.03	0.59 ± 0.03
	2		0.53 ± 0.03	0.15 ± 0.03	0.42 ± 0.03	0.58 ± 0.03
	3			0.52 ± 0.03	0.49 ± 0.03	
	4				0.50 ± 0.03	
			Average = 0.38			
MFD	1	0.57 ± 0.03	0.48 ± 0.03	0.45 ± 0.03	0.47 ± 0.03	0.55 ± 0.03
	2		0.73 ± 0.02	0.67 ± 0.03	0.65 ± 0.03	0.76 ± 0.03
	3			0.71 ± 0.02	0.68 ± 0.03	
	4				0.74 ± 0.02	
			Average = 0.62			
SL	1	0.49 ± 0.03	0.49 ± 0.03	0.49 ± 0.03	0.44 ± 0.03	0.59 ± 0.03
	2		0.54 ± 0.03	0.48 ± 0.03	0.44 ± 0.03	0.58 ± 0.03
	3			0.58 ± 0.03	0.54 ± 0.03	
	4				0.56 ± 0.03	
			Average = 0.51			
TCN	1	0.49 ± 0.03	0.40 ± 0.03	0.39 ± 0.03	0.35 ± 0.03	0.53 ± 0.03
	2		0.54 ± 0.03	0.47 ± 0.03	0.41 ± 0.03	0.59 ± 0.03
	3			0.54 ± 0.03	0.45 ± 0.03	
	4				0.46 ± 0.03	
			Average = 0.45			

TABLE 4.9: Continued

TRAIT	Age (Yrs)		Age (yrs)			
		2	3	4	5	lifetime
CF	1	0.57 ± 0.03	0.52 ± 0.03	0.46 ± 0.03	0.42 ± 0.03	0.60 ± 0.03
	2		0.62 ± 0.03	0.55 ± 0.03	0.46 ± 0.03	0.64 ± 0.03
	3			0.61 ± 0.03	0.55 ± 0.03	
	4				0.56 ± 0.03	
			Average = 0.53			
SST	1	0.26 ± 0.05	0.19 ± 0.05	0.13 ± 0.05	0.13 ± 0.05	0.25 ± 0.05
	2		0.28 ± 0.04	0.31 ± 0.04	0.27 ± 0.04	0.38 ± 0.03
	3			0.36 ± 0.03	0.28 ± 0.03	
	4				0.35 ± 0.03	
			Average = 0.26			
CHG	1	0.20 ± 0.03	0.17 ± 0.03	0.11 ± 0.03	0.11 ± 0.03	0.22 ± 0.03
	2		0.20 ± 0.03	0.18 ± 0.03	0.22 ± 0.03	0.28 ± 0.03
	3			0.29 ± 0.03	0.26 ± 0.03	
	4				0.27 ± 0.03	
			Average = 0.20			
LUS	1	0.26 ± 0.03	0.17 ± 0.03	0.19 ± 0.03	0.17 ± 0.03	0.32 ± 0.03
	2		0.15 ± 0.03	0.14 ± 0.03	0.14 ± 0.03	0.21 ± 0.03
	3			0.22 ± 0.03	0.11 ± 0.03	
	4				0.16 ± 0.03	
			Average = 0.17			

TABLE 4.9: Continued

TRAIT	Age (Yrs)	Age (Yrs)				
		2	3	4	5	lifetime
TIP	1	0.34 ± 0.03	0.32 ± 0.03	0.24 ± 0.04	0.24 ± 0.04	0.41 ± 0.03
	2		0.34 ± 0.03	0.29 ± 0.03	0.24 ± 0.03	0.40 ± 0.03
	3			0.35 ± 0.03	0.32 ± 0.03	
	4				0.31 ± 0.03	
			Average = 0.30			
COT	1	0.21 ± 0.03	0.21 ± 0.03	0.19 ± 0.03	0.18 ± 0.03	0.29 ± 0.03
	2		0.35 ± 0.03	0.27 ± 0.03	0.22 ± 0.03	0.38 ± 0.03
	3			0.35 ± 0.03	0.27 ± 0.03	
	4				0.29 ± 0.03	
			Average = 0.25			
CAG	1	0.03 ± 0.03	0.07 ± 0.03	0.10 ± 0.04	0.10 ± 0.04	0.09 ± 0.03
	2		0.82 ± 0.02	0.36 ± 0.04	0.38 ± 0.04	0.71 ± 0.03
	3			0.34 ± 0.03	0.34 ± 0.03	
	4				0.38 ± 0.03	
			Average = 0.29			
SOU	1	0.14 ± 0.03	0.16 ± 0.03	0.11 ± 0.03	0.10 ± 0.03	0.20 ± 0.03
	2		0.20 ± 0.04	0.15 ± 0.04	0.11 ± 0.04	0.21 ± 0.03
	3			0.22 ± 0.04	0.19 ± 0.04	
	4				0.20 ± 0.04	
			Average = 0.16			

TABLE 4.9: Continued

TRAIT	Age (Yrs)	Age (Yrs)				
		2	3	4	5	lifetime
HND	1	0.22 ± 0.03	0.29 ± 0.03	0.25 ± 0.03	0.21 ± 0.03	0.36 ± 0.03
	2		0.21 ± 0.03	0.28 ± 0.03	0.17 ± 0.03	0.30 ± 0.03
	3			0.34 ± 0.03	0.27 ± 0.03	
	4				0.30 ± 0.03	
			Average = 0.25			
GCM	1	0.08 ± 0.03	0.07 ± 0.03	0.09 ± 0.03	0.11 ± 0.03	0.13 ± 0.03
	2		0.40 ± 0.03	0.29 ± 0.03	0.22 ± 0.03	0.40 ± 0.03
	3			0.37 ± 0.03	0.32 ± 0.03	
	4				0.33 ± 0.03	
			Average 0.23			
SCM	1	0.05 ± 0.03	0.14 ± 0.03	0.08 ± 0.03	0.09 ± 0.04	0.15 ± 0.03
	2		0.07 ± 0.03	0.13 ± 0.03	0.12 ± 0.04	0.16 ± 0.03
	3			0.16 ± 0.03	0.15 ± 0.03	
	4				0.16 ± 0.03	
			Average = 0.12			
GCF	1	0.07 ± 0.03	0.02 ± 0.04	0.06 ± 0.04	0.04 ± 0.04	0.06 ± 0.03
	2		0.08 ± 0.02	0.09 ± 0.04	0.10 ± 0.04	0.11 ± 0.03
	3			0.12 ± 0.04	0.09 ± 0.04	
	4				0.20 ± 0.40	
			Average = 0.09			

TABLE 4.9: Continued

TRAIT	Age (Yrs)	Age (Yrs)			
		3	4	5	lifetime
NLB	2	0.19 ± 0.03	0.21 ± 0.03	0.17 ± 0.03	0.27 ± 0.03
	3		0.25 ± 0.03	0.21 ± 0.03	
	4			0.28 ± 0.03	
		Average = 0.22			
NLW	2	0.16 ± 0.03	0.20 ± 0.03	0.20 ± 0.03	0.27 ± 0.03
	3		0.20 ± 0.03	0.21 ± 0.03	
	4			0.17 ± 0.03	
		Average = 0.19			
WLW	2	0.20 ± 0.03	0.17 ± 0.03	0.20 ± 0.03	0.28 ± 0.03
	3		0.20 ± 0.03	0.20 ± 0.03	
	4			0.20 ± 0.03	
		Average = 0.20			
WPL	2	0.20 ± 0.04	0.13 ± 0.04	0.09 ± 0.05	0.20 ± 0.04
	3		0.21 ± 0.04	0.14 ± 0.04	
	4			0.22 ± 0.04	
		Average = 0.17			
LSP	2	0.03 ± 0.04	0.03 ± 0.04	0.13 ± 0.04	0.10 ± 0.04
	3		0.09 ± 0.04	0.01 ± 0.04	
	4			0.02 ± 0.04	
		Average = 0.05			

4.4.1 LIVE WEIGHT

Liveweight tended to have the highest repeatability among the traits in this study (Table 4.9). Estimates were between 0.48 and 0.70 in the ewe records and 0.39 to 0.56 for hogget-ewe correlations. The overall average was 0.55. These estimates were within the range of repeatabilities of liveweight reported in other studies (0.5-0.7 Doney, 1955; 0.67, 0.73 Young *et al.* 1960; 0.48 Shelton and Menzies, 1968; 0.21 Eikje, 1975; 0.73 O'Ferrall, 1976; 0.41, 0.66 Blair, 1981; 0.61 Clarke and Hohenboken, 1983).

The repeatability of adjacent records was highest, with the magnitude decreasing as records became less related in time. The repeatabilities were lowest for the hogget correlations, with no significant differences between repeatabilities of similar time periods in the ewes. As the hogget liveweights were measured in the spring and ewe liveweights in autumn some seasonal variation may have reduced the hogget-older record correlations.

The hogget-ewe lifetime correlation was lower than the 2 year-older ewe estimate. Young *et al.* (1960) estimated the correlation of hogget-lifetime and 2 year-lifetime records as 0.81 and 0.92 respectively, however as the 2 year record was included in the lifetime estimate the last value will be inflated.

The conclusion from the figures in this study is that liveweight at one age is a good indicator of future live weights.

4.4.2 GREASY AND CLEAN FLEECE WEIGHTS

Repeatability values for greasy and clean fleece weights were almost identical. The repeatability of greasy fleece weight has been estimated by many authors. Turner (1956, 1977) reviewed many estimates and found they were between 0.6 and 0.7 for Merino and allied breeds and 0.4 to 0.6 for British breeds. Rae (1982) reported the most common range of reliable estimates of repeatability for New Zealand Romneys was 0.4-0.7. Correlations in this study generally agree well with the above estimates, especially the average of 0.51.

The repeatability of adjacent records was higher than that of more widely spaced records, with repeatability increasing as age increased. This was contrary to Lewer (1978), who reported the tendency in Perendales was for the repeatability to be higher at the younger ages. However Mullaney *et al.* (1970) found that, for 3 breeds, pairs of records for older ewes were more highly correlated than for pairs of records from younger ewes.

The correlations of hogget to ewe records were lower than between any of the ewe records. The repeatability of hogget to lifetime ewe records was lower than that of the 2 year old ewes to older records. Young *et al.* (1960) also found that the hogget-lifetime correlation was lower than the 30 month-lifetime correlation. The estimates of hogget-lifetime correlation were similar that that estimated by Wright and Stevens (1953) in Romneys of 0.44 but lower than correlations between single and compound records in other breeds (0.63 Wolf, 1951; 0.72 Wright and Stevens, 1953; 0.61 Doney, 1958; 0.72 Young *et al.* 1960; 0.56 Elliott, 1975).

4.4.3 CLEAN SCOURED YIELD

Estimated repeatability of yield tended to be low for a quantitative trait, ranging from 0.20 to 0.40. The overall average was 0.29. Few other estimates of repeatability of clean scoured yield were available, Young *et al.* (1960) estimated repeatability as 0.52 and 0.54.

Repeatability of yield records declined as the records were less closely related in time but no trends were observable within repeatabilities of like time periods. Although the hogget-2 year old correlation was lower than repeatability of other adjacent records, the repeatability of hogget-older records tended to be higher than repeatability of older records for the same time period.

The hogget-ewe lifetime correlation was higher than the 2 year-older ewe correlation but the difference was not significant. Young *et al.* (1960) estimated the correlation of hogget-2-5 year records as 0.82 and of 2 year - 2-5 year records as 0.67.

In general the low repeatability of clean scoured yield records and low-medium heritability of yield (0.2 - 0.5 Rae, 1982) suggest that selection for yield will result in only slow responses.

4.4.4 QUALITY NUMBER

Repeatability estimates between pairs of records of quality number ranged from 0.17 - 0.53. This was considerably lower than the range, 0.60 - 0.78, reported by Mullaney *et al.* (1970) for three breeds, Merino, Corriedale and Polwarth. Except for hogget repeatabilities, estimates in this study were similar to those obtained by Lewer (1978) for Perendales of 0.31 - 0.63, with the average, 0.46, comparing well with the 0.38 average in Table 4.9.

Later records were more repeatable than earlier records, with no difference between repeatability of adjacent ewe records. Repeatability of hogget-2 year old, hogget-3 year old and 2 year - 4 year old were considerably lower than other values. However the repeatability of hogget-4 and 5 year old records were of similar magnitude to the older ewe record repeatabilities. No explanation is apparent.

Correlations between hogget and lifetime quality number and 2 year old to older ewes were similar, 0.59 and 0.58 respectively, and agreed well with the estimate of 0.52 reported by Elliott (1975) for the hogget-2-5 year old repeatability in Perendales. They were higher than the estimate of 0.35 obtained by Blair (1981) for 12 month-aged ewe yields in a control Romney flock but considerably lower than the 1.00 and 0.98 he estimated in Romneys selected for face cover and high fleece weight respectively.

4.4.5 MEAN FIBRE DIAMETER

Estimates of repeatability of mean fibre diameter were generally high, ranging from 0.45 to 0.76. These were in good agreement with correlations between MFD records in other studies (0.42 - 0.60 Young *et al.* 1960; 0.53 Beattie, 1961; 0.50 - 0.85 Gjedrem, 1969; 0.66 - 0.68 Mullaney *et al.* 1970; 0.46 - 0.87 Lewer, 1978). The average repeatability, 0.62, was lower than the 0.71 estimate by Lewer (1978) in Perendales but similar to those reported in Australian studies.

Correlation of an early record with lifetime records was studied by Young *et al.* (1960) and Elliott (1975) in regard to fibre diameter and their estimates were higher than for pairs of records as was found in this study (Hogget-lifetime 0.77 Young *et al.* 1960; 0.59 Elliott, 1975; 30 month-lifetime 0.80 Young *et al.* 1960).

As observations were more widely spaced in time, the repeatability fell, but overall the repeatability increased with age. Similar trends were obtained by Gjedrem (1969) and Lewer (1978).

Hogget repeatabilities were significantly lower than repeatabilities between ewe records. This may be a reflection of actual differences but there were also differences in the methods of measuring fibre diameter.

4.4.6 STAPLE LENGTH

The repeatability estimates for staple length are presented in Table 4.9, ranging between 0.44 and 0.59. Regression estimates of repeatability in other studies are above 0.3, except that of Guirgis and Galal (1972) however a higher value (0.32) was calculated by Kadry (1971), cited by Guirgis and Galal, 1972) from data on the same flock. Generally the range was 0.3 to 0.7 (0.57 Terrill, 1939; 0.71 Morley, 1951; 0.31 - 0.61 Katada and Takeda, 1959; 0.39, 0.58 Young *et al.* 1960; 0.57 Beattie, 1961; 0.56 Dalton, 1962; 0.32 Knothe, 1964; 0.64 Gjedrem, 1969; 0.42 - 0.61 Lewer, 1978). Correlations between pairs of records for staple length were higher (0.75 Doney, 1955, 1958; 0.55 - 0.58 Young *et al.* 1960; 0.60 - 0.84 Gjedrem, 1969; 0.57 - 0.69 Mullaney *et al.* 1970). The average repeatability, 0.51, in this study was in good agreement with the average of 0.50 reported by Lewer (1978).

The correlation between hogget and lifetime staple length was the same as the two year-older ewe estimate. Both values were higher than the correlations between any pairs of ages. Young *et al.* (1960) noted values greater than 0.83 for the correlation between single and lifetime staple length records, however the single age was a component of the lifetime data which would inflate the estimates considerably. Other estimates of the correlation between single and compound records are similar to those in this study (0.69 Terrill, 1939; 0.49 Elliott, 1975).

As with most other traits in this study repeatability of adjacent records was higher at older ages than at younger ages. Gjedrem (1969) also found higher estimates at later ages, however Lewer (1978) noted that repeatabilities of adjacent records declined as age increased. As time between pairs of records increased repeatability declined, as was also found by Lewer (1978).

4.4.7 TOTAL CRIMP NUMBER

Repeatability of total crimp number was estimated as 0.35 - 0.59. The average repeatability was 0.45.

Although repeatability declined as the records became more widely spaced, no definite trends were found. Repeatability of adjacent records was higher between 2 and 3 year records than between hogget and two-year records but was lowest between 4 and 5 year records. Similar trends were observed in the records two years apart.

The correlation of single - compound records was greater between the 2 year and older records than the hogget-ewe records but the difference was not significant, however both were higher than between any of the pairs of records for hogget or two year olds.

4.4.8 CRIMP FREQUENCY

Estimates for repeatability of crimp frequency, 0.42 - 0.62, suggested that crimp frequency is highly repeatable, but with a decreasing trend as the records become more widely separated in time. The average repeatability for crimp frequency was 0.53. Young *et al.* (1960) reported estimates of 0.42 and 0.61 for crimp frequency repeatability.

Repeatabilities for crimp frequency followed similar patterns to those observed in TCN, although repeatability of CF tended to be 0.06 - 0.10 higher than corresponding TCN estimates.

The correlations of hogget-lifetime records and 2 year-older ewe records were similar, 0.60 and 0.64 respectively. Young *et al.* (1960) estimated hogget-lifetime production and 2 year - 2-5 year record correlations as 0.85 and 0.90 respectively. Their estimates were considerably higher than those obtained in this study, however as the 2 year - 2-5 year correlation includes the 2 year record on both sides the estimate will be unduly inflated.

4.4.9 STAPLE STRENGTH

Repeatability estimates for staple strength, 0.13 - 0.38, were the lowest in the quantitatively assessed traits. The average repeatability was 0.26.

Repeatability declined as the records became more widely separated in time. However, the estimates tended to increase as the ewes grew older.

The correlation between hogget and ewe lifetime staple strength was significantly lower than between the 2 year and older ewe records.

4.4.10 CHARACTER GRADE

Estimated repeatability of character grade was low, ranging from 0.11 to 0.29. These estimates are in good agreement with those of Lewer (1978), 0.08 - 0.32, but are considerably lower than the estimates of 0.46 - 0.51 found by Mullaney *et al.* (1970). The average repeatability of character grade, 0.20, in this study was similar to the 0.18 average obtained by Lewer (1978).

Repeatability increased as ewes grew older, although the correlation between 4 and 5 year records was not significantly different than between 3 and 4 year records. Repeatability tended to decline as records became more widely separated in time.

The correlation of single to compound records was higher for the 2 year-older ewe than hogget-ewe. These were similar to the estimate of 0.28 obtained by Elliott (1975) between hogget and 2-5 year Perendale ewe records.

4.4.11 LUSTRE GRADE

Repeatability of lustre grade was low, ranging from 0.11 to 0.26 between pairs of records and to 0.32 for single-compound correlations. The average repeatability was 0.17.

No definite trend in repeatability of adjacent records was found. However, the more widely spread records were less repeatable than adjacent records. The maximum repeatability for pairs of records was between hogget and 2-year records.

The correlation of hogget - 2-5 year ewe records was significantly higher than for 2 year - 3-5 year ewe records, 0.32 and 0.21 respectively.

4.4.12 TIPPINESS GRADE

Repeatability of tippiness grade was estimated as 0.24 - 0.35 between pairs of records and 0.40 - 0.41 between single and compound records. The average repeatability was 0.30. These were some of the highest repeatabilities in the subjectively assessed traits.

Repeatability estimates for adjacent records were not significantly different at the various age levels. Similar trends were found when observations were more widely spaced in time.

The correlations of hogget-2-5 ewe records and 2 year-3-5 year ewe records were higher than repeatabilities of pairs of records. The reasonably high estimate of hogget-ewe records suggested that the hogget record is an adequate indicator of later ewe tippiness grade for selection purposes.

4.4.13 COTTING GRADE

Repeatability of fleece cotting grade in this flock was estimated to range from 0.18 to 0.38. The average repeatability was 0.25.

The closer cotting grade measurements were related in time, the more repeatable they were. Repeatability of adjacent records was higher in ewe records as compared to the hogget-2 year records. However, the repeatability estimate was lower between 4 and 5 year records than between 2 and 3 year and between 3 and 4 year records.

The correlation between hogget and ewe lifetime records was lower than between 2 year and older ewe records, 0.29 and 0.38 respectively.

4.4.14 COTTED AREA GRADE

Repeatability of hogget to other records and to the compound ewe record were very low, 0.03 - 0.10. Hence hogget CAG would give no indication of ewe fleece CAG. The fact that the hogget heritability was higher than this repeatability suggests a different genetic mechanism is operating in the hoggets than in the adult ewes.

Repeatability among ewe records was of medium magnitude 0.34 - 0.38 with no significant differences between estimates, except the 2 year - 3 year records repeatability. This estimate was 0.82, resulting in a similarly high estimate for 2 year - 3-5 year correlation. As the estimate was higher than any other repeatability obtained in this study it probably arose by chance rather than representing the true correlation.

The average repeatability for cotted area grade was 0.29.

4.4.15 SOUNDNESS GRADE

Repeatability estimates for soundness grade were low, ranging from 0.11 to 0.21, with an average of 0.16.

Repeatability tended to decrease as records became more widely separated in time and tended to be lower for hoggets than for older ewes, however no differences between the estimates were significant.

Correlations between hogget and ewe lifetime records and between 2 year and older ewe records were close, 0.20 and 0.21 respectively.

4.4.16 HANDLE GRADE

The repeatability of handle grade was estimated as 0.21 - 0.36 (Table 4.9). The average was 0.25.

Trends in the relationship between records were not clear for handle grade, although the tendency was for adjacent records to be more repeatable at older ages.

The correlation between hogget and lifetime ewe handle grade records was higher than between 2 year and 3-5 year ewe records although the difference was not significant. Although hogget handle grade record was not a good indicator of individual ewe records (repeatabilities were less than 0.30), it was a better indicator of ewe lifetime handle grade with a medium repeatability of 0.36.

4.4.17 GREASY MIDSIDE COLOUR GRADE

Correlations of hogget GCM to ewe records were low, estimates were between 0.08 and 0.11, with the correlation of hogget-ewe lifetime records being 0.13. Repeatabilities of ewe greasy midside colour grade were considerably higher, 0.22 - 0.40. The average repeatability, including hoggets was 0.23, but average among the ewe records was 0.32.

Repeatability of adjacent ewe records decreased with increasing age. Repeatability also declined as time between records increased.

The correlation between 2 year and older ewe records was 0.40 indicating that the 2 year old ewe record is a good indicator of ewe greasy midside colour grade.

4.4.18 SCOURED MIDSIDE COLOUR GRADE

Repeatability of scoured midside colour was lowest among the wool traits in this study (Table 4.9). Estimates were between 0.05 and 0.16, with an average of 0.12. Repeatabilities of hogget-ewe records were similar to those for GCM but repeatabilities among ewe records were considerably lower as compared to GCM estimates.

Repeatability of adjacent records increased with increasing age. The repeatability of records separated by two years was higher than the repeatability of adjacent records, however none of the differences between estimates were significant.

Correlations of hogget and 2 year old records to older ewe records were similar, 0.15 and 0.16 respectively, but neither gave a good indication of the scoured midside colour of later ewe fleeces.

4.4.19 GREASY FLEECE COLOUR GRADE

Repeatability of greasy fleece colour grade tended to be low, 0.02 to 0.12, except the estimate - 0.20 between 4 and 5 year records.

Repeatability declined as the records became more widely separated in time, but increased with increasing age.

The conclusion from the figures in Table 4.9 was that greasy fleece colour grade observed at one age was not a good indicator of future greasy fleece colour grade.

4.4.20 NUMBER OF LAMBS BORN

Repeatability of number of lambs born was of intermediate magnitude, between 0.17 and 0.28, with an average repeatability of 0.22. These estimates are in agreement (although tending to the upper end) with the range 0.1 - 0.25 given by Rae (1982) for repeatability of lambs born in New Zealand Romney ewes. The repeatability of NLB in the Romney tends to be higher than for other breeds (0.12 Yalcin and Bichard, 1964; 0.07, 0.18 Kennedy, 1967; 0.12, 0.15 Shelton and Menzies, 1970; 0.09, 0.34 Basuthakar *et al.* 1973; 0.08 Hanrahan, 1977; 0.17 Notter, 1981; 0.14 Dzakuma, Whiteman and McNew, 1982; 0.19 Clarke and Hohenboken, 1983; 0.08 Fogarty, Dickerson and Young, 1985).

Repeatability of adjacent records increased with age, though repeatability tended to decline as records became more widely separated in time.

The correlation of 2 year and 3-5 year records was 0.27.

4.4.21 NUMBER OF LAMBS WEANED

Average repeatability of number of lambs weaned was 0.19. The repeatability of pairs of records was between 0.16 and 0.21, although no significant differences occurred between any of the estimates. Lewer (1978) suggested that the two repeatability values available on the Romney (0.12 - 0.25 Rae and Ch'ang, 1955; 0.17 Lundie, 1971) indicated the possibility that repeatability of NLW for this breed may be higher than for other breeds. Results for this study support this idea, being considerably higher than estimates reported in other breed studies (0.05 - 0.10 Young *et al.* 1963; 0.00 - 0.10 Yalcin and Bichard, 1964; 0.01 - 0.10 Purser, 1965; 0.01 - 0.11 Kennedy, 1967; 0.03 - 0.22 Inskeep, Barr and Cunningham, 1967; -0.07, -0.03 Basuthakar *et al.* 1973; 0.08 Clarke and Hohenboken, 1983; 0.08 Fogarty *et al.* 1985).

Rae (1982) also noted that the repeatability range in Romneys was higher than for Perendales and Merinos, giving the common repeatability ranges as 0.1 - 0.25, 0.05 - 0.2 and 0.05 - 0.1 respectively.

As found by Young *et al.* (1963), records of three year olds were more repeatable than two or four year old ewes. Lewer (1978) noted an upward trend with age, however the differences between the repeatabilities were small.

Two year records may be a better indicator of four and five year production than they are of three year performance. The correlation of two year to 3-5 year records (0.27) was higher than between pairs of records.

4.4.22 WEIGHT OF LAMB WEANED

Repeatabilities for weight of lamb weaned were very consistent (0.20), except the repeatability of 2 year - 4 year records which was not significantly different at 0.17. These estimates were in good agreement with these of 0.16 (Eijke, 1975) and 0.21 (Gjedrem, 1967), but higher than 0.07 (Blackwell and Henderson, 1955), 0.02 (Basuthakur *et al.* 1973), 0.09 (Clarke and Hohenboken, 1983) and 0.11 (Fogarty *et al.* 1985).

As for NLW the correlation of 2 year and 3-5 year records was higher than between pairs of records.

4.4.23 WEIGHT PER LAMB WEANED

Repeatability of weight per lamb weaned was more variable than for WLW, ranging from 0.09 to 0.22. The average repeatability was 0.17, lower than the average of WLW.

Although repeatabilities of records separated by similar periods of time were consistent, the repeatability declined as the time between records increased. Thus the 2 year old record was a poor indicator of the weight per lamb weaned by the ewe as a 5 year old. Development of mammary gland diseases might be a factor in this.

The correlation of 2 year to 3-5 year records was 0.20, similar to repeatability of adjacent records, but lower than the correlation for WLW.

4.4.24 LAMB SURVIVAL

Repeatability of the ewes ability to rear a lamb to weaning was very low, between 0.01 and 0.13, with an average of 0.05. Shelton and Menzies (1970) estimated repeatability of livability as -0.02 - 0.13, which covers the same range as estimates in this study. Fogarty *et al.* (1985) reported the repeatability as 0.14 for preweaning survival, while estimates of Haughey, George and McGuirk (1985) ranged from 0.05 to 0.17, with a mean of 0.10.

Repeatability appeared higher between the 2 year and 5 year records than between the 2 year and 3 or 4 year records. The correlation of 2 year and 3-5 year records was 0.10.

Repeatability of adjacent records increased in the 3 year - 4 year estimate as compared to the 2 year - 3 year record and then declined at the 4 year - 5 year estimate. A similar trend was noted by Shelton and Menzies (1970), who reported a higher repeatability value of livability of the lamb at the intermediate ages.

The low repeatability of lamb survival and lack of heritability indicate that no genetic progress can be expected to be achieved if selection is applied to this trait in this flock.

4.5 INTER-TRAIT GENETIC CORRELATIONS

Phenotypic and genetic correlations and genetic regressions were calculated for all traits for the overall analysis, within each stocking rate, within each age level and between the various age classes. Two methods of calculation were used, paternal half-sib correlation and daughter-dam regression. Differences existed between the genetic correlation estimates obtained by the two estimation methods, however few were significantly different. In view of the large number of correlations possible only the hogget, 2 year old ewe and average adult ewe genetic correlations calculated by the paternal half-sib analyses were presented.

Where sire variance components are zero or close to zero widely varying values can be obtained. If the sire variance for either trait is zero then the genetic correlations excluding interactions can not be calculated. If it is just above zero then its use in the denominator frequently results in extremely high correlations that have no biological explanation. As sire variance components for reproductive traits were zero or very low, genetic correlations between reproductive and wool traits were not able to be calculated or were meaningless. Hence these were not presented.

The methods of calculation of the EI and II estimates mean that there are large differences between the estimates when genotype x environment interaction variance and covariance components are large compared to the sire components.

Daughter-dam genetic correlation estimates showed similar trends to the paternal half-sib estimates but tended to vary more widely with large standard errors associated with the estimates due to the lower number of observations used in the analyses.

As few other studies have included as wide a range of traits no other genetic correlation estimates have been published for many combinations, except those by Chopra (1978) whose data were a subset of those used in this study. Where genetic correlations have been frequently calculated many studies have reviewed and compared the ranges available. Hence, in this study, comparison to other values is kept to a minimum except where unusual or unexpected values were obtained.

Brown and Turner (1968) defined correlations into a number of categories. In this study a similar classification was used:

-0.6 and below	high negative
-0.4 to -0.6	medium negative
-0.2 to -0.4	low negative
-0.2 to 0.2	negligible
0.2 to 0.4	low positive
0.4 to 0.6	medium positive
0.6 and above	high positive

4.5.1 WITHIN-AGE GENETIC CORRELATIONS

4.5.1.1 Association of Liveweight with Wool Characteristics

As liveweight is one of the most important criteria in selection programs for Romney sheep, the associated changes in wool traits as a result of selection for liveweight are of interest.

The correlation between liveweight and fleece weight was negligible for hoggets. The values were similar to those obtained by Chopra (1978) but tended to be lower than many estimates reported for Romneys and at the lower end of the range, 0.11 to 0.54, given for Romneys by Rae (1982) although

Table 4.10: Genetic correlations and standard errors for hogget, two-year old ewe and average ewe performance.

Trait 1	Hogget		2-year-old ewe		Average ewe	
- Trait 2	EI	II	EI	II	EI	II
LW						
- GFW	0.11 ± 0.04	0.10 ± 0.10	-0.90 ± 0.16	0.03 ± 0.16	-0.51 ± 0.50	0.18 ± 0.04
- CFW	-0.02 ± 0.12	0.03 ± 0.11	-0.78 ± 0.80	-0.04 ± 0.17	-0.31 ± 0.39	0.22 ± N
- Y	0.31 ± 0.61	-0.42 ± 0.13	>1	0.03 ± 0.05	0.81 ± 0.22	0.27 ± 0.03
- QN	0.82 ± 0.50	0.37 ± 0.01	>1	0.33 ± 0.09	>1	0.15 ± 0.03
- MFD	-0.12 ± N	-0.41 ± 0.15	<-1	-0.62 ± 0.32	<-1	-0.21 ± 0.09
- SL	-0.08 ± 0.14	0.09 ± N	0.12 ± 0.10	0.55 ± N	0.16 ± N	0.22 ± N
- TCN	>1	0.39 ± N	0.87 ± 0.33	0.43 ± 0.03	>1	0.33 ± N
- CF	>1	0.33 ± N	0.69 ± 0.35	0.18 ± 0.08	0.99 ± 0.50	0.16 ± 0.03
- SST	Z	0.27 ± 0.65	Z	-0.20 ± 0.36	Z	-0.03 ± 0.14
- CHG	>1	0.22 ± N	0.70 ± 0.41	-0.41 ± 0.24	0.03 ± 0.08	-0.01 ± 0.03
- LUS	-0.69 ± 0.36	-0.42 ± 0.05	Z	<-1	<-1	-0.33 ± 0.12
- TIP	0.32 ± 0.10	0.28 ± 0.07	>1	-0.13 ± 0.13	0.32 ± 0.11	0.10 ± 0.01
- COT	0.11 ± N	0.13 ± N	0.08 ± 0.03	-0.91 ± 0.48	-0.91 ± 0.48	-0.13 ± 0.03
- CAG	0.87 ± 0.08	0.01 ± 0.06	N	0.14 ± N	-0.17 ± 0.10	0.04 ± 0.01
- SOU	-0.26 ± 0.30	-0.03 ± 0.11	-0.37 ± 0.30	0.12 ± 0.30	Z	-0.41 ± 0.76
- HND	>1	0.36 ± 0.13	0.78 ± 0.61	-0.03 ± 0.04	0.83 ± 0.58	-0.01 ± 0.04
- GCM	Z	0.05 ± 0.04	>1	0.05 ± 0.05	0.70 ± 0.18	0.25 ± 0.03
- SCM	Z	-0.07 ± 0.04	>1	0.53 ± 0.51	>1	0.09 ± 0.06
- GCF	-0.00 ± 0.09	0.01 ± 0.03	0.99 ± 0.57	0.41 ± 0.33	0.17 ± N	0.47 ± 0.26

N unable to calculate standard error

Z zero sire variance component for one of traits meant correlation could not be calculated

Table 4.10: Continued

Trait 1	Hogget		2-year-old ewe		Average ewe	
- Trait 2	EI	II	EI	II	EI	II
GFW						
- CFW	0.97 ± N	0.97 ± N	>1	0.97 ± N	0.99 ± N	0.97 ± N
- Y	0.48 ± 0.09	0.20 ± 0.05	>1	0.39 ± 0.07	0.54 ± N	0.20 ± N
- QN	-0.06 ± 0.05	-0.01 ± 0.02	-0.06 ± 0.05	-0.16 ± N	-0.49 ± N	-0.38 ± N
- MFD	>1	0.62 ± N	0.42 ± N	0.40 ± N	0.14 ± 0.11	0.45 ± N
- SL	0.78 ± N	0.60 ± N	0.62 ± N	0.64 ± N	0.72 ± N	0.49 ± N
- TCN	0.70 ± N	0.34 ± N	-0.01 ± 0.02	-0.06 ± 0.06	-0.09 ± 0.06	0.04 ± 0.02
- CF	0.14 ± 0.01	0.12 ± 0.05	-0.40 ± N	-0.29 ± N	-0.56 ± N	-0.26 ± N
- SST	-0.44 ± 1.31	-0.22 ± 0.54	Z	<-1	Z	-0.35 ± 0.39
- CHG	0.62 ± N	0.19 ± N	-0.12 ± 0.09	-0.09 ± 0.07	-0.03 ± 0.10	0.10 ± 0.02
- LUS	-0.29 ± N	-0.24 ± 0.09	Z	0.27 ± 0.41	>1	0.39 ± 0.06
- TIP	-0.48 ± 0.18	0.10 ± 0.08	-0.06 ± 0.02	-0.18 ± N	-0.36 ± N	-0.10 ± 0.02
- COT	0.59 ± 0.07	0.29 ± 0.06	-0.06 ± 0.05	-0.37 ± 0.17	-0.09 ± 0.04	-0.06 ± 0.02
- CAG	0.90 ± 0.19	0.44 ± 0.11	N	-0.37 ± 0.17	0.01 ± 0.01	0.00 ± 0.01
- SOU	0.42 ± N	0.67 ± 0.23	-0.49 ± 0.39	-0.38 ± 0.78	Z	-0.51 ± 0.85
- HND	-0.77 ± N	-0.40 ± N	-0.84 ± 0.26	-0.32 ± 0.07	-0.47 ± N	-0.45 ± N
- GCM	Z	-0.51 ± N	>1	0.46 ± 0.05	0.50 ± N	0.24 ± N
- SCM	Z	-0.13 ± N	0.06 ± 0.20	0.31 ± 0.39	-0.23 ± 0.18	-0.22 ± 0.04
- GCF	-0.55 ± N	-0.70 ± 0.21	-0.28 ± N	-0.54 ± 0.23	-0.39 ± 0.18	-0.09 ± 0.02

Table 4.10: Continued

Trait 1	Hogget		2-year-old ewe		Average ewe	
- Trait 2	EI	II	EI	II	EI	II
CFW						
- Y	0.65 ± N	0.46 ± N	Z	0.69 ± N	0.63 ± N	0.45 ± N
- QN	-0.28 ± 0.04	-0.12 ± 0.01	-0.13 ± 0.04	-0.27 ± N	-0.52 ± N	-0.44 ± N
- MFD	0.94 ± N	0.73 ± N	0.28 ± N	0.36 ± N	0.01 ± 0.18	0.44 ± N
- SL	0.76 ± N	0.60 ± N	0.61 ± N	0.61 ± N	0.71 ± N	0.56 ± N
- TCN	0.50 ± N	0.26 ± N	-0.02 ± 0.02	-0.07 ± 0.05	-0.09 ± 0.06	0.03 ± 0.02
- CF	-0.02 ± 0.01	0.03 ± 0.06	-0.38 ± N	-0.28 ± N	-0.54 ± N	-0.30 ± N
- SST	-0.40 ± 1.15	0.04 ± 0.16	Z	<-1	Z	-0.31 ± 0.41
- CHG	0.52 ± 0.05	0.12 ± N	-0.18 ± 0.10	-0.01 ± 0.05	0.04 ± 0.09	0.15 ± 0.02
- LUS	0.10 ± 0.06	-0.20 ± 0.11	Z	0.44 ± 0.61	>1	0.48 ± 0.07
- TIP	-0.50 ± 0.17	0.04 ± 0.07	-0.10 ± N	-0.22 ± N	-0.35 ± N	-0.18 ± N
- COT	0.64 ± 0.16	0.28 ± 0.08	-0.09 ± 0.05	-0.44 ± 0.22	-0.04 ± 0.02	-0.08 ± 0.01
- CAG	>1	0.44 ± 0.10	Z	-0.45 ± 0.28	0.05 ± N	0.00 ± 0.01
- SOU	0.65 ± 0.13	0.77 ± 0.29	-0.07 ± 0.07	-0.25 ± 0.50	Z	-0.47 ± 0.86
- HND	-0.70 ± N	-0.43 ± N	-0.63 ± 0.20	-0.41 ± 0.12	-0.40 ± N	-0.43 ± N
- GCM	Z	-0.45 ± 0.05	>1	0.67 ± N	0.62 ± N	0.45 ± N
- SCM	Z	-0.00 ± 0.04	0.31 ± 0.29	0.28 ± 0.34	0.33 ± 1.51	-0.16 ± 0.02
- GCF	-0.47 ± N	-0.47 ± 0.15	-0.62 ± N	-0.50 ± 0.23	-0.48 ± 0.26	-0.06 ± 0.03

Table 4.10: Continued

Trait 1 - Trait 2	Hogget		2-year-old ewe		Average ewe	
	EI	II	EI	II	EI	II
Y						
- QN	-0.82 ± N	-0.41 ± N	>1	-0.32 ± N	-0.41 ± N	-0.39 ± N
- MFD	0.45 ± N	0.46 ± N	Z	0.14 ± 0.03	<-1	0.03 ± 0.04
- SL	0.46 ± N	0.19 ± N	Z	0.20 ± N	0.48 ± N	0.40 ± N
- TCN	-0.28 ± 0.01	-0.15 ± N	Z	0.10 ± 0.08	0.10 ± 0.05	-0.02 ± 0.02
- CF	-0.45 ± N	-0.26 ± N	Z	0.02 ± 0.09	-0.22 ± N	-0.27 ± N
- SST	Z	0.34 ± 0.62	Z	-0.71 ± 0.91	Z	0.36 ± N
- CHG	-0.03 ± 0.08	-0.18 ± 0.01	Z	0.20 ± 0.08	0.42 ± N	0.18 ± 0.02
- LUS	>1	0.25 ± 0.07	Z	-0.08 ± 0.50	0.85 ± 0.34	0.39 ± 0.04
- TIP	-0.18 ± 0.01	-0.12 ± 0.03	Z	-0.15 ± N	-0.16 ± N	-0.34 ± N
- COT	>1	-0.22 ± 0.14	Z	-0.07 ± N	0.54 ± 0.34	-0.09 ± 0.02
- CAG	0.66 ± 0.15	0.23 ± N	Z	0.14 ± 0.09	0.34 ± 0.11	0.04 ± 0.02
- SOU	>1	0.21 ± N	>1	0.10 ± 0.18	Z	-0.24 ± 0.89
- HND	0.04 ± 0.24	-0.46 ± 0.05	Z	-0.30 ± 0.11	0.07 ± 0.04	-0.06 ± 0.01
- GCM	Z	0.18 ± N	Z	>1	>1	1.00 ± N
- SCM	Z	0.17 ± N	Z	-0.15 ± 0.12	>1	0.19 ± 0.10
- GCF	0.36 ± N	0.38 ± N	Z	-0.63 ± 0.66	-0.24 ± 0.28	0.22 ± 0.09

Table 4.10: Continued

Trait 1	Hogget		2-year-old ewe		Average ewe	
- Trait 2	EI	II	EI	II	EI	II
QN						
- MFD	0.05 ± 0.11	-0.11 ± 0.05	-0.74 ± 0.34	-0.38 ± N	-0.48 ± N	-0.52 ± N
- SL	-0.57 ± N	-0.42 ± N	-0.38 ± N	-0.37 ± N	-0.55 ± N	-0.58 ± N
- TCN	0.76 ± N	0.79 ± N	>1	0.57 ± N	0.79 ± N	0.75 ± N
- CF	>1	0.92 ± N	>1	0.73 ± N	>1	0.96 ± N
- SST	-0.53 ± N	0.21 ± 0.65	Z	0.44 ± 0.89	Z	-0.01 ± 0.30
- CHG	0.80 ± N	0.74 ± N	0.97 ± 0.02	0.13 ± 0.11	0.54 ± N	0.48 ± N
- LUS	-0.78 ± N	-0.86 ± N	Z	<-1	<-1	-0.84 ± N
- TIP	>1	>1	>1	0.83 ± N	0.97 ± N	0.82 ± N
- COT	0.95 ± N	0.25 ± 0.04	0.77 ± N	0.73 ± N	0.30 ± N	0.47 ± N
- CAG	0.88 ± 0.11	0.21 ± 0.04	Z	0.63 ± N	0.32 ± N	0.47 ± N
- SOU	0.31 ± 0.29	-0.02 ± 0.06	0.25 ± 0.31	0.71 ± 1.52	Z	-0.45 ± 0.22
- HND	-0.01 ± 0.01	-0.13 ± 0.10	-0.25 ± 0.21	0.06 ± 0.02	0.53 ± N	0.55 ± N
- GCM	Z	-0.19 ± 0.03	-0.69 ± >1	-0.36 ± N	-0.47 ± N	-0.39 ± N
- SCM	Z	0.35 ± 0.09	<-1	-0.47 ± 0.48	<-1	0.14 ± 0.02
- GCF	0.22 ± 0.13	-0.36 ± 0.18	-0.36 ± 1.18	0.61 ± N	0.42 ± N	0.68 ± 0.24

Table 4.10: Continued

Trait 1	Hogget		2-year-old ewe		Average ewe	
- Trait 2	EI	II	EI	II	EI	II
MFD						
- SL	0.46 ± N	0.38 ± N	0.04 ± 0.04	0.00 ± 0.10	0.04 ± 0.07	0.18 ± N
- TCN	0.50 ± 0.12	0.10 ± 0.07	-0.57 ± N	-0.35 ± N	-0.59 ± N	-0.38 ± N
- CF	0.26 ± 0.16	-0.08 ± 0.08	-0.64 ± N	-0.29 ± 0.02	-0.60 ± N	-0.43 ± N
- SST	0.06 ± 0.10	0.04 ± 0.23	Z	-0.47 ± 0.65	Z	0.24 ± 0.14
- CHG	0.40 ± N	0.32 ± 0.07	-0.61 ± N	-0.36 ± 0.07	<-1	-0.21 ± 0.04
- LUS	-0.39 ± 0.08	-0.08 ± 0.08	Z	-0.33 ± 1.17	0.50 ± 0.66	0.25 ± N
- TIP	0.04 ± 0.10	-0.10 ± N	-0.46 ± 0.15	-0.25 ± N	-0.21 ± N	-0.21 ± N
- COT	0.47 ± N	0.61 ± 0.13	0.18 ± 0.17	-0.05 ± 0.12	0.74 ± 0.67	0.22 ± N
- CAG	>1	0.28 ± 0.10	Z	0.31 ± 0.17	0.15 ± N	0.14 ± N
- SOU	>1	0.70 ± 0.16	-0.59 ± 1.33	-0.34 ± 0.46	Z	0.18 ± 0.05
- HND	<-1	-0.98 ± N	-0.77 ± N	-0.73 ± N	-0.74 ± N	-0.70 ± N
- GCM	Z	-0.18 ± 0.04	Z	0.40 ± 0.22	-0.99 ± 1.41	0.05 ± 0.04
- SCM	Z	0.50 ± 0.32	0.52 ± 0.86	0.15 ± 0.38	Z	-0.02 ± 0.07
- GCF	-0.14 ± 0.02	-0.34 ± 0.11	-0.22 ± N	-0.07 ± 0.09	-0.18 ± 0.15	-0.11 ± 0.04

Table 4.10: continued

Trait 1	Hogget		2-year-old ewe		Average ewe	
- Trait 2	EI	II	EI	II	EI	II
SL						
- TCN	0.30 ± N	0.22 ± 0.07	0.15 ± N	0.12 ± N	0.13 ± N	0.09 ± 0.02
- CF	-0.16 ± 0.07	-0.33 ± N	-0.36 ± 0.02	-0.37 ± N	-0.51 ± N	-0.58 ± N
- SGT	0.27 ± 0.59	0.16 ± 0.30	Z	-0.16 ± 0.68	Z	0.01 ± 0.29
- CHG	-0.27 ± N	-0.15 ± N	-0.50 ± 0.03	-0.18 ± N	-0.42 ± N	-0.23 ± 0.02
- LUS	-0.01 ± 0.06	0.08 ± 0.09	Z	-0.27 ± 0.88	0.14 ± 0.06	0.30 ± N
- TIP	-0.74 ± N	-0.51 ± N	-0.44 ± N	-0.51 ± N	-0.60 ± N	-0.56 ± N
- COT	-0.21 ± N	-0.16 ± N	-0.66 ± N	-0.30 ± N	-0.81 ± N	-0.35 ± N
- CAG	0.23 ± 0.02	0.01 ± 0.02	Z	-0.02 ± 0.11	-0.42 ± N	-0.15 ± N
- SOU	0.22 ± N	0.34 ± N	<-1	0.09 ± 0.07	Z	0.11 ± 0.10
- HND	-0.65 ± N	-0.34 ± 0.05	-0.54 ± 0.19	-0.34 ± 0.09	-0.50. ± N	-0.44 ± N
- GCM	Z	-0.22 ± 0.11	>1	0.20 ± N	0.39 ± N	0.39 ± N
- SCM	Z	-0.10 ± N	0.06 ± 0.07	0.42 ± 0.41	-0.24 ± 0.10	-0.38 ± 0.06
- GCF	0.07 ± 0.02	-0.18 ± 0.09	0.23 ± 0.10	0.05 ± 0.11	-0.59 ± 0.24	-0.08 ± 0.03

Table 4.10: Continued

Trait 1	Hogget		2-year-old ewe		Average ewe	
- Trait 2	EI	II	EI	II	EI	II
TCN						
- CF	0.86 ± N	0.89 ± N	0.87 ± N	0.85 ± N	0.78 ± N	0.75 ± N
- SST	0.82 ± >1	0.22 ± 0.35	Z	0.06 ± 0.17	Z	0.10 ± 0.21
- CHG	0.74 ± N	0.58 ± N	0.33 ± N	0.28 ± N	0.31 ± N	0.50 ± N
- LUS	-0.78 ± N	-0.75 ± N	Z	-0.81 ± 1.27	< -1	-0.72 ± 0.08
- TIP	0.79 ± N	0.53 ± N	0.94 ± N	0.65 ± N	0.55 ± N	0.56 ± N
- COT	0.88 ± N	0.30 ± N	0.46 ± N	0.67 ± N	-0.22 ± 0.28	0.40 ± N
- CAG	0.68 ± N	0.36 ± N	Z	0.29 ± N	-0.00 ± 0.15	0.39 ± N
- SOU	0.98 ± 0.63	0.28 ± 0.17	0.35 ± 0.26	0.82 ± 1.61	Z	-0.24 ± 0.20
- HND	-0.38 ± 0.13	-0.11 ± 0.05	-0.15 ± 0.11	-0.14 ± 0.15	0.18 ± 0.04	0.37 ± N
- GCM	Z	-0.15 ± 0.04	0.05 ± 1.68	0.07 ± 0.07	-0.06 ± 0.01	-0.01 ± 0.03
- SCM	>1	0.11 ± 0.05	-0.90 ± 0.46	-0.69 ± 0.55	<-1	-0.18 ± 0.13
- GCF	0.06 ± 0.06	-0.31 ± 0.18	0.44 ± N	0.46 ± N	-0.04 ± 0.36	0.70 ± 0.29

Table 4.10: Continued

Trait 1	Hogget		2-year-old ewe		Average ewe	
- Trait 2	EI	II	EI	II	EI	II
CF						
- SST	>1	0.24 ± 0.57	Z	0.32 ± 0.86	Z	0.03 ± 0.30
- CHG	0.81 ± N	0.65 ± N	0.54 ± N	0.42 ± N	0.56 ± N	0.55 ± N
- LUS	-0.77 ± N	-0.70 ± N	Z	-0.78 ± 1.01	<-1	-0.75 ± N
- TIP	>1	0.97 ± N	>1	0.86 ± N	0.87 ± N	0.80 ± N
- COT	0.82 ± N	0.58 ± 0.08	0.60 ± N	0.83 ± N	0.29 ± N	0.51 ± N
- CAG	0.53 ± N	0.40 ± 0.05	Z	0.29 ± N	0.29 ± N	0.41 ± N
- SOU	0.56 ± 0.46	0.26 ± 0.33	0.87 ± 0.71	0.81 ± 1.72	Z	-0.28 ± 0.06
- HND	-0.08 ± 0.07	-0.04 ± 0.05	0.06 ± 0.03	0.04 ± 0.06	0.37 ± N	0.56 ± N
- GCM	Z	0.11 ± 0.11	<-1	0.02 ± 0.08	-0.30 ± N	-0.26 ± N
- SCM	>1	0.42 ± 0.08	<-1	0.50 ± 0.37	<-1	0.13 ± 0.04
- GCF	-0.17 ± 0.02	0.14 ± 0.10	0.37 ± N	0.53 ± N	0.38 ± N	0.64 ± 0.24

Table 4.10: Continued

Trait 1	Hogget		2-year-old ewe		Average ewe	
- Trait 2	EI	II	EI	II	EI	II
SST						
- CHG	Z	-0.22 ± 0.26	Z	0.14 ± N	Z	0.07 ± 0.05
- LUS	-0.54 ± 0.71	0.71 ± 1.36	Z	-0.09 ± 0.60	Z	0.17 ± 0.10
- TIP	>1	0.39 ± 0.52	Z	-0.26 ± 0.17	Z	-0.01 ± 0.08
- COT	Z	0.54 ± N	Z	0.65 ± N	Z	0.43 ± 0.25
- CAG	Z	0.18 ± N	Z	-0.23 ± 0.57	Z	0.57 ± 0.22
- SOU	Z	0.84 ± N	Z	>1	Z	>1
- HND	Z	-0.37 ± 0.16	Z	0.56 ± 0.86	Z	0.05 ± 0.20
- GCM	0.96 ± 0.43	0.05 ± 0.08	Z	-0.78 ± 1.04	Z	0.42 ± N
- SCM	Z	>1	Z	-0.04 ± N	Z	-0.43 ± N
- GCF	0.22 ± 0.03	0.19 ± 0.09	Z	-0.16 ± N	Z	-0.53 ± 0.67
CHG						
- LUS	-0.36 ± 0.04	-0.18 ± N	Z	0.67 ± 1.24	-0.10 ± 0.07	-0.11 ± 0.08
- TIP	0.29 ± 0.36	0.91 ± N	0.82 ± N	0.57 ± N	0.73 ± N	0.74 ± N
- COT	0.98 ± N	0.63 ± N	0.44 ± N	0.24 ± N	0.68 ± N	0.59 ± N
- CAG	0.86 ± N	0.49 ± N	Z	0.38 ± N	0.25 ± 0.07	0.57 ± N
- SOU	0.92 ± 0.34	0.41 ± 0.13	0.24 ± 0.04	>1	Z	0.09 ± 0.04
- HND	0.65 ± 0.32	-0.19 ± 0.16	0.64 ± N	0.36 ± N	0.54 ± N	0.47 ± N
- GCM	Z	0.15 ± 0.02	-0.95 ± >1	0.30 ± N	0.40 ± N	0.20 ± 0.02
- SCM	>1	0.16 ± N	-0.47 ± 0.23	-0.54 ± 0.49	0.41 ± 0.81	0.10 ± N
- GCF	-0.37 ± N	-0.36 ± 0.14	0.30 ± N	0.33 ± N	-0.58 ± 0.74	0.59 ± 0.24

Table 4.10: Continued

Trait 1	Hogget		2-year-old ewe		Average ewe	
- Trait 2	EI	II	EI	II	EI	II
LUS						
- TIP	-0.78 ± N	-0.34 ± N	Z	-0.48 ± 0.29	-0.77 ± 0.26	-0.53 ± N
- COT	-0.48 ± 0.14	-0.36 ± 0.15	Z	-0.37 ± 0.51	0.09 ± 0.25	-0.29 ± 0.08
- CAG	-0.80 ± N	-0.80 ± 0.28	Z	<-1	-0.32 ± N	-0.25 ± 0.07
- SOU	-0.00 ± 0.15	-0.02 ± 0.19	Z	-0.61 ± 1.54	Z	0.33 ± N
- HND	0.51 ± N	0.34 ± N	Z	0.82 ± 1.49	-0.82 ± 0.51	-0.15 ± 0.06
- GCM	Z	-0.22 ± 0.18	Z	0.37 ± 0.29	0.82 ± 0.06	0.46 ± 0.06
- SCM	<-1	-0.42 ± 0.18	Z	>1	>1	-0.21 ± N
- GCF	-0.16 ± 0.03	0.06 ± 0.10	Z	-0.89 ± 0.94	<-1	-0.62 ± 0.33
TIP						
- COT	Z	0.64 ± 0.26	>1	0.90 ± N	0.82 ± N	0.67 ± N
- CAG	>1	0.65 ± 0.34	Z	0.81 ± N	0.55 ± N	0.65 ± N
- SOU	-0.67 ± 0.74	0.74 ± 0.73	0.01 ± 0.51	>1	Z	-0.17 ± 0.14
- HND	0.52 ± 0.29	-0.04 ± 0.05	0.28 ± 0.11	-0.20 ± 0.17	0.41 ± N	0.39 ± N
- GCM	-0.52 ± 0.19	-0.16 ± 0.04	-0.51 ± >1	-0.15 ± N	-0.15 ± N	-0.33 ± N
- SCM	Z	0.81 ± 0.60	-0.37 ± 0.13	-0.73 ± 0.64	-0.20 ± 0.71	-0.21 ± N
- GCF	-0.04 ± 0.0	0.31 ± 0.27	0.75 ± 0.31	0.75 ± 0.43	0.74 ± N	0.69 ± 0.27

Table 4.10: Continued

Trait 1	Hogget		2-year-old ewe		Average ewe	
- Trait 2	EI	II	EI	II	EI	II
COT						
- CA6	0.79 ± N	0.82 ± N	Z	>1	>1	0.89 ± N
- SOU	>1	0.55 ± 0.08	0.42 ± N	>1	Z	0.33 ± 0.19
- HND	-0.61 ± 0.07	-0.23 ± 0.06	-0.36 ± 0.32	-0.01 ± 0.16	0.25 ± N	0.20 ± N
- 6CM	Z	0.10 ± 0.01	<-1	-0.13 ± 0.02	0.46 ± 0.29	-0.09 ± 0.02
- SCM	>1	0.46 ± 0.18	-0.83 ± 0.48	-0.77 ± 0.75	-0.31 ± 1.42	0.12 ± N
- 6CF	-0.29 ± 0.11	0.15 ± 0.08	0.16 ± 0.08	0.58 ± N	0.62 ± 0.34	0.55 ± 0.14
CA6						
- SOU	0.60 ± 0.18	0.11 ± 0.05	Z	0.52 ± 0.35	<-1	0.36 ± 0.22
- HND	<-1	-0.68 ± 0.30	Z	-0.48 ± 0.43	-0.27 ± 0.13	0.11 ± 0.03
- 6CM	Z	0.43 ± N	Z	0.03 ± 0.13	0.27 ± 0.08	0.03 ± 0.02
- SCM	Z	0.41 ± 0.01	Z	-0.83 ± 1.08	-0.35 ± 0.98	0.11 ± N
- 6CF	0.30 ± N	0.06 ± 0.19	Z	0.12 ± 0.36	0.59 ± N	0.80 ± N

Table 4.10: Continued

Trait 1	Hogget		2-year-old ewe		Average ewe	
- Trait 2	EI	II	EI	II	EI	II
SOU						
- HND	-0.32 ± N	-0.66 ± 0.42	>1	0.46 ± 1.03	Z	0.00 ± 0.12
- GCM	Z	-0.04 ± 0.07	>1	0.07 ± 0.09	Z	-0.06 ± 0.66
- SCM	Z	0.48 ± 0.28	-0.96 ± 0.60	-0.90 ± 1.54	Z	-0.32 ± N
- GCF	-0.22 ± 0.14	-0.14 ± 0.05	>1	0.18 ± 0.46	<-1	-0.84 ± 1.39
HND						
- GCM	Z	-0.04 ± 0.07	>1	-0.38 ± 0.16	0.05 ± 0.03	-0.06 ± 0.01
- SCM	Z	0.02 ± 0.04	0.05 ± 0.21	0.18 ± N	-0.32 ± 0.99	0.21 ± N
- GCF	0.20 ± 0.09	-0.23 ± 0.15	-0.22 ± 0.22	-0.45 ± 0.59	-0.30 ± 0.33	0.38 ± 0.11
GCM						
- SCM	Z	0.55 ± N	>1	-0.21 ± 0.18	>1	0.16 ± 0.09
- GCF	>1	0.59 ± N	Z	-0.81 ± 0.98	-0.37 ± 0.35	0.21 ± 0.09
SCM						
- GCF	Z	0.15 ± N	<-1	-0.06 ± 0.22	-0.75 ± 3.92	0.55 ± 0.20

other breeds tended to have lower ranges. The two year old and average ewe LW - GFW correlations including interactions were similar to hogget values. The estimates excluding interactions were highly negative; however the standard errors were correspondingly high resulting in values not significantly different from zero.

The large difference between estimates excluding and including interactions in the two year old and average ewe estimates reflected the importance of genotype x environment interactions in both these traits, in the adults in particular.

The relationship between LW and GFW is of particular interest in view of the fact that selection for fleece weight may increase liveweight and food intake and that these correlated changes may limit gains in the efficiency of wool production (Cunningham and Gjedrem, 1970). However, correlations in this and other studies were generally low. Also, in experimental flocks subjected to selection for fleece weight the change in liveweight has been small (Barlow, 1974; Turner, 1977; McGuirk, 1983; Blair *et al*., 1985) supporting the absence of any sizeable genetic correlation.

Correlations between liveweight and Y, the percentage of clean fibre in a greasy sample, were high and positive when interactions were excluded but decreased considerably when interactions were included. Chopra's (1978) previous estimate was lower than values obtained in this study. Blair (1981) obtained a wide range of values (-0.33 to 0.68) for Romney hoggets in a trial involving several selection lines.

Quality number was highly correlated with liveweight when interactions were excluded but, as with yield, decreased when interactions were included. Similarly, medium to high negative correlations of mean fibre diameter with liveweight indicated that as liveweight increased fibre diameter decreased at any age. The correlations between liveweight and QN and MFD are opposite to those expected. In hoggets, on a subset of data used in this study, Chopra (1978) reported a correlation of 0.37 between LW and QN and 0.02 between LW and MFD. Rae (1982) summarized the range of Romney hogget estimates in other studies as 0.02 to 0.24 for the correlation between LW and MFD.

Correlations between LW and SL tended to be negligible except the two year old ewe estimate including interactions.

TCN and CF correlations with liveweight were similar, high positive excluding interactions and medium positive including interactions. A possible explanation is that genetic differences in copper utilization (Wiener, 1982) are partly involved in liveweight differences. Low copper levels lead to inefficient keratinization and a lower crimp number. There is no change in staple length so crimp frequency also decreases and this is reflected in a decrease in quality number (Henderson, 1968).

Correlations between liveweight and subjectively assessed traits were variable, however the trend indicated that higher liveweights tended to be associated with higher CHG values in hoggets and two year olds, lower lustre, blocky rather than tippy staples, less sound wools, softer handle and better greasy and scoured midside colour. There were inconsistent effects for COT, CAG and GCF.

In general genetic correlations of liveweight to other traits were highly variable. This reflects the large environmental and genetic x environmental components to the liveweight variance and low proportion explained by additive genetic variances.

4.5.1.2 Association of Greasy and Clean Fleece Weight with Other Wool Characteristics

As clean fleece weight was derived from greasy fleece weight and the correlation between CFW and GFW was close to 1.0, correlations with other traits were similar for GFW and CFW and they will be discussed together.

The heritabilities of both fleece weight traits are similar. This, together with the high genetic correlation, indicated that there is no reason to select on CFW in Romneys as GFW is more easily assessed and the same progress can be achieved.

Greasy, as well as clean, fleece weight had high positive correlations with yield in most age classes. Estimates of the GFW - Y genetic correlations in other breeds are extremely variable in size and sign (Mullaney *et al.*, 1970).

Fleece weight also had a medium to high positive correlation with MFD, although the correlation tended to decrease with age. QN was not as well correlated to FW as MFD. In hoggets and two year old ewes the correlations were negligible, but they were medium to high negative for older ewes. Most other published information is from Merinos where the correlation FW - MFD tend to be low while FW - QN tend to be higher.

Changes in fleece weight would be closely related to changes in SL as shown by high positive correlation values. Use of staple length as an indirect selection criterion for fleece weight would avoid the necessity to identify and weigh all individual fleeces at shearing. The higher heritability for SL means that selection for hogget SL would improve hogget FW at the same rate as achieved by direct selection on FW when estimates exclude interactions and by two-thirds the rate when estimates include the interactions.

Although hogget TCN and CF were positively correlated to fleece weight, for two year old or average ewes the correlations were close to zero for TCN and medium negative for CF. Thus greater FW would be associated with a higher TCN in hoggets but there would be no consistent change in TCN in older ewes, ewes with greater FW would have lower CF.

Staple strength correlations with FW varied considerably, with large standard errors, but tended to indicate that SST had a medium negative correlation with FW. Thus ewes with greater fleece weights would tend to have lower SST. There was a high positive correlation between hogget SOU and FW but low to medium negative correlations for older ewes, reflecting similar trends as for SST.

Values for correlations of FW and subjectively assessed traits tended to be variable with signs often reversed between hoggets and older ewe estimates. In hoggets higher fleece weights were associated with lower lustre and greater soundness. In breeding ewes they tended to be associated with lower lustre and decreased soundness.

4.5.1.3 Associations Between Other Wool Traits

Yield

The lack of genetic variance in yield indicated by the low heritability was also reflected in highly variable correlation estimates between yield and other traits. Trends tend to suggest that selecting ewes for higher yielding fleeces would result in lower QN, greater MFD, longer SL, lower CF, greater lustre, more tippy staples and more cotting. There would be no correlated changes in HND with changes in yield.

Quality Number

Although two year old and average ewe estimates showed a medium to high negative correlation between QN and MFD, the correlation in hoggets was negligible. Heritability of QN was lower than for MFD so that even in older ewes, with the negative correlation, selection using QN to improve MFD would be considerably slower than direct selection on MFD.

Correlations between QN and SL were medium negative while QN and TCN had a high positive correlation.

Correlations of close to unity between QN and CF and CHG and LUS reflect the influence these factors have on observers when assessing QN.

The medium to high correlations between QN and COT indicated that genes resulting in wool with high QN also result in less cotting. Similar trends occurred for QN and CAG. This might be due to high crimp frequency tending to inhibit felting of fibres (Crewther and Dowling, 1961) or high lustre tending to promote felting.

Mean Fibre Diameter

Except in hoggets, MFD had a medium to high negative correlation with TCN and CF, indicating that TCN and CF tended to increase as MFD decreased. However the heritability of MFD was twice as high as the heritability of TCN or CF so that use of TCN or CF as indirect selection criteria for altering MFD would result in less accurate estimation of ewe MFD than direct measurement.

Correlations of MFD and other wool characteristics indicated that genes for finer ewe fleeces tended to also produce wool with better CHG and more blocky staples (TIP).

Soft handle was highly correlated genetically with fine fibre diameter. However the low heritability of HND limits its usefulness as an indirect selection criterion for MFD.

The genetic correlations between MFD and colour assessments were generally low and inconsistent in sign.

Staple Length

The correlation between SL and TCN was negligible in the ewes and low positive in hoggets. Hence, since CF was derived from TCN/SL, longer staples tended to be associated with lower CF. SL had a high positive correlation to GFW and CFW and there was a low to medium negative correlation between GFW and CF.

The medium negative correlation between SL and CHG and high negative correlation between SL and TIP indicated that longer staples tended to be associated with less well-defined crimp and more tippy staples.

Longer staples were not associated with a consistent increase in COT in hoggets but there was a medium to high negative correlation in older ewes. Hence using SL to select higher fleece weight ewes would be effective in increasing FW but would lead to an increase in cotting whereas direct selection on FW would not increase the amount of cotting.

Total Crimp Number and Crimp Frequency

TCN had very high positive correlations with CF in all age classes (0.75 to 0.89). The correlation between TCN and CF was far higher than that between SL and CF suggesting that genes promoting high crimping are more important in determining CF than those which change crimps per centimetre through changes in length.

Increases in TCN and CF were associated with better CHG, lower lustre, more blocky staples (TIP), greater resistance to cotting and more sound wool. The high negative correlation with LUS was expected since crimp tends to suppress lustre (Orwin and Woods, 1983). Correlations of TCN and CF with HND were inconsistent, being negligible or low negative for hoggets and two year old ewes but low to medium positive for average ewe production.

Staple Strength

Estimates including interactions indicated that SST and COT had a medium positive correlation. This was expected since wool with a higher staple strength would break less so there would be less fibre entanglement and cotting grade would be higher.

The extremely high correlation beteen SST and SOU was of interest as it suggested that SOU could be used to predict SST. However as the heritability of SOU is low selecting on SOU would only lead to slow improvement in SST. As soundness was only assessed on one staple, while SST was calculated on 5 staples, accuracy of SOU might be able to be improved if several staples were assessed. This would provide a lot easier method of assessing SST than direct measurement.

Character

CHG had medium to high positive correlations with TIP, COT, CAG and HND. Hence genes for better character wool were associated with blockier staples, greater resistance to cotting, less cotted area in the fleece and a softer handle.

In the hoggets and two year old ewes there were medium to high positive correlations between CHG and SOU. However CHG was not positively correlated with SST.

There were no consistent trends in the correlations between CHG and colour assessments.

Lustre

Negative correlations between LUS and TIP and COT and CAG indicated that selecting for increased lustre would be associated with increased tippiness of staples and an increase in the degree and area of cotting in the fleece. These may be because lustre is associated with a smoother surface and a tendency for fibre to slide past one another more easily or it may reflect the association of lustre with crimp mentioned earlier.

Tippiness

The high positive correlation between TIP and COT and TIP and CAG indicates more tippy wools are associated with a higher degree of fibre entanglement (cotting) as expected.

4.5.2 ACROSS-AGE GENETIC CORRELATIONS

Of particular interest in selection programs are the effects of selection on hoggets or two year old traits in relation to effects on the lifetime performance of the ewe for both the direct trait considered and changes in other traits. The possible increase in accuracy of using two year old measurements must be considered in relation to the increase in generation time and extra numbers of ewes that must be kept until the later age prior to selection.

The records used to calculate the average ewe estimates varied between the hogget and two year old ewe correlations. Hoggets were correlated with the average ewe production at 2, 3, 4 and 5 years of age, while two year old ewes were only correlated to average ewe production at 3, 4 and 5 years of age. This avoids inflation of values due to having the two year old ewe information on both sides of the estimate.

Heritabilities of trait 1 for the hogget or two year old ewe is provided at the top of each table (Table 4.11) to provide information for assessing the practical significance of the correlations.

For most traits direct genetic correlation estimates between hoggets or two year old ewes and average ewe production were close to unity when interactions were excluded and generally still very high positive when interactions were included. This suggests that the same genes that control traits at one age generally control the trait at later ages, despite low repeatabilities for some traits due to widely varying temporary environmental influences. Hence for traits such as liveweight and fleece weight with low intra-trait correlations different genes are affected by the different stocking rates but within stocking rate the same genes affect most traits across ages.

4.5.2.1 Association of Hogget and Two Year Old Ewe Liveweight With Older Ewe Characteristics

Direct genetic correlation estimates for liveweight were close to unity, indicating that selection on hoggets or on two year old ewes would have a direct effect on older ewe liveweight. However, while still high positive, correlation estimates declined after inclusion of interactions.

Hogget liveweight was negatively correlated to ewe fleece weight, although estimates including interactions were close to zero. Thus although there was not much relationship genetically between hogget LW and ewe FW, if anything the relationship was negative. One theory suggests that there is competiton for limited resources within the sheep, so that choosing sheep with greater liveweights means that those individuals put greater amounts of their resources into

Table 4.11: Genetic correlations and standard errors between hogget and average ewe performance and between two-year-old and older ewe average performance

Trait	Hogget-Average ewe		2 year old ewe-Average ewe	
- Trait 2	EI	II	EI	II
LW				
H^2	0.07 ± 0.09	0.35 ± 0.08	0.10 ± 0.13	0.41 ± 0.13
- LW	>1	0.74 ± N	>1	0.81 ± N
- GFW	-0.41 ± 0.51	-0.10 ± 0.11	-0.31 ± 0.25	-0.01 ± 0.10
- CFW	-0.44 ± 0.58	-0.01 ± 0.07	-0.22 ± 0.22	0.17 ± N
- Y	0.15 ± 0.11	0.31 ± 0.11	0.01 ± 0.13	0.65 ± 0.26
- QN	>1	0.32 ± 0.06	>1	0.08 ± 0.08
- MFD	-0.60 ± 0.28	-0.37 ± 0.09	<-1	-0.51 ± 0.22
- SL	-0.21 ± 0.16	0.11 ± 0.02	0.18 ± N	0.15 ± N
- TCN	>1	0.37 ± 0.06	>1	0.44 ± 0.11
- CF	>1	0.30 ± 0.07	0.92 ± 0.43	0.24 ± 0.07
- SST	Z	0.95 ± 1.06	<-1	0.05 ± 0.07
- CHG	0.11 ± N	0.13 ± 0.04	-0.29 ± 0.28	0.17 ± 0.11
- LUS	<-1	-0.24 ± N	-0.90 ± 0.17	-0.29 ± N
- TIP	0.40 ± 0.14	0.26 ± 0.03	0.15 ± N	0.18 ± 0.05
- COT	0.09 ± 0.10	-0.18 ± 0.07	<-1	-0.28 ± 0.08
- CAG	-0.21 ± 0.29	0.24 ± N	-0.16 ± 0.04	-0.21 ± 0.14
- SOU	<-1	<-1	<-1	-0.85 ± 1.13
- HND	0.69 ± 0.40	0.14 ± 0.06	0.92 ± 0.55	0.09 ± 0.11
- GCM	0.05 ± 0.08	0.23 ± 0.09	-0.02 ± 0.15	0.60 ± 0.24
- SCM	0.71 ± 2.55	0.07 ± 0.08	0.38 ± 0.83	-0.25 ± 0.08
- GCF	<-1	0.56 ± 0.56	-0.73 ± 1.35	0.64 ± 0.31

N unable to calculate standard error

Z zero sire variance component for one of traits meant correlation could not be calculated

Table 4.11: Continued

Trait	Hogget-Average ewe		2 year old ewe-Average ewe	
- Trait 2	EI	II	EI	II
GFW				
H^2	0.23 ± 0.11	0.48 ± 0.10	0.19 ± 0.16	0.64 ± 0.15
- LW	0.16 ± 0.04	-0.19 ± 0.15	-0.38 ± 0.22	-0.10 ± 0.14
- GFW	>1	0.84 ± N	>1	0.79 ± N
- CFW	>1	0.81 ± N	0.92 ± N	0.78 ± N
- Y	0.57 ± 0.10	0.12 ± 0.03	-0.18 ± 0.11	0.02 ± 0.03
- QN	-0.24 ± N	-0.28 ± N	-0.37 ± N	-0.35 ± N
- MFD	0.50 ± N	0.41 ± N	0.31 ± N	0.21 ± 0.05
- SL	0.62 ± N	0.44 ± N	0.87 ± N	0.42 ± N
- TCN	0.24 ± N	0.21 ± 0.07	0.19 ± N	0.35 ± 0.15
- CF	-0.13 ± 0.01	-0.23 ± N	-0.45 ± 0.05	-0.14 ± 0.02
- SST	Z	-0.37 ± 0.49	<-1	-0.49 ± 0.45
- CHG	0.26 ± N	0.19 ± 0.05	0.13 ± N	0.27 ± 0.10
- LUS	0.56 ± N	0.24 ± N	0.42 ± 0.07	0.43 ± 0.16
- TIP	-0.16 ± 0.03	0.01 ± 0.01	-0.28 ± 0.09	-0.10 ± 0.04
- COT	0.55 ± 0.11	0.10 ± 0.02	-0.28 ± 0.10	-0.10 ± 0.02
- CAG	-0.13 ± N	-0.05 ± 0.01	0.09 ± 0.02	-0.06 ± 0.03
- SOU	-0.68 ± 1.95	-0.49 ± 0.98	<-1	<-1
- HND	-0.29 ± N	-0.42 ± N	-0.39 ± N	-0.51 ± N
- GCM	0.50 ± N	0.23 ± 0.05	-0.11 ± 0.08	0.03 ± 0.03
- SCM	-0.00 ± 0.09	-0.11 ± N	-0.94 ± 0.94	-0.29 ± 0.02
- GCF	-0.41 ± N	-0.27 ± 0.10	<-1	0.34 ± 0.27

Table 4.11: Continued

Trait - Trait 2	Hogget-Average ewe EI	 II	2 year old ewe-Average ewe EI	 II
CFW				
H^2	0.29 ± 0.11	0.51 ± 0.10	0.25 ± 0.17	0.67 ± 0.15
- LW	0.19 ± 0.07	-0.20 ± 0.15	-0.12 ± 0.10	-0.10 ± 0.12
- GFW	>1	0.79 ± N	>1	0.75 ± N
- CFW	>1	0.81 ± N	>1	0.78 ± N
- Y	0.73	0.32 ± N	0.20 ± N	0.14 ± N
- QN	-0.41 ± N	-0.36 ± N	-0.42 ± N	-0.40 ± N
- MFD	0.51 ± N	0.42 ± N	0.27 ± N	0.19 ± 0.07
- SL	0.64 ± N	0.46 ± N	0.90 ± N	0.54 ± N
- TCN	0.12 ± 0.03	0.11 ± 0.08	0.24 ± N	0.38 ± 0.16
- CF	-0.26 ± N	-0.35 ± N	-0.42 ± N	-0.18 ± N
- SST	Z	-0.31 ± 0.57	<-1	-0.45 ± 0.45
- CHG	0.38 ± N	0.20 ± 0.06	0.23 ± N	0.33 ± 0.09
- LUS	0.76 ± N	0.33 ± N	0.56 ± N	0.43 ± 0.08
- TIP	-0.17 ± N	-0.12 ± 0.01	-0.30 ± 0.07	-0.16 ± 0.04
- COT	0.59 ± 0.13	0.05 ± 0.03	-0.08 ± N	-0.14 ± 0.02
- CAG	-0.15 ± N	-0.19 ± 0.05	0.12 ± 0.03	-0.09 ± 0.04
- SOU	<-1	-0.14 ± 0.48	<-1	<-1
- HND	-0.18 ± 0.04	-0.40 ± N	-0.37 ± N	-0.47 ± N
- GCM	0.71 ± N	0.41 ± N	0.21 ± N	0.19 ± N
- SCM	0.36 ± 0.33	-0.12 ± 0.03	-0.41 ± 0.33	-0.33 ± 0.06
- GCF	-0.58 ± 0.12	-0.48 ± 0.32	<-1	0.40 ± 0.28

N unable to calculate standard error

Z zero sire variance component for one of traits meant correlation could not be calculated

Table 4.11: Continued

Trait - Trait 2	Hogget-Average ewe		2 year old ewe-Average ewe	
	EI	II	EI	II
Y				
H^2	0.19 ± 0.09	0.32 ± 0.08	0.02 ± 0.13	0.38 ± 0.12
- LW	0.32 ± 0.17	-0.02 ± 0.04	>1	-0.07 ± 0.10
- GFW	0.56 ± 0.24	0.10 ± 0.05	>1	0.28 ± 0.07
- CFW	0.84 ± 0.42	0.21 ± 0.04	Z	0.43 ± 0.03
- Y	>1	0.52 ± N	>1	0.61 ± N
- QN	-0.67 ± N	-0.43 ± N	<-1	-0.20 ± N
- MFD	0.35 ± 0.38	0.06 ± 0.03	Z	0.25 ± 0.08
- SL	0.60 ± 0.21	0.05 ± 0.07	>1	0.36 ± N
- TCN	-0.24 ± N	-0.26 ± N	>1	0.19 ± 0.10
- CF	-0.64 ± 0.07	-0.29 ± N	0.28 ± 2.85	-0.13 ± N
- SST	Z	0.01 ± 0.22	Z	0.22 ± 0.22
- CHG	0.62 ± 0.26	0.15 ± 0.10	>1	0.37 ± 0.10
- LUS	0.94 ± 0.13	0.51 ± 0.16	>1	0.16 ± N
- TIP	-0.23 ± N	-0.29 ± N	-0.78 ± 4.86	-0.15 ± N
- COT	0.32 ± 0.16	0.05 ± 0.05	>1	-0.22 ± 0.10
- CAG	<-1	-0.48 ± N	-0.62 ± 0.37	-0.11 ± 0.05
- SOU	Z	0.71 ± 0.77	Z	-0.65 ± 0.93
- HND	0.11 ± 0.05	0.19 ± 0.14	-0.63 ± 3.58	-0.05 ± 0.03
- GCM	>1	0.54 ± N	>1	0.59 ± N
- SCM	0.87 ± 0.55	0.18 ± 0.09	0.81 ± 1.12	-0.14 ± 0.08
- GCF	<-1	0.05 ± 0.11	-0.49 ± 0.85	0.51 ± 0.29

Table 4.11: Continued

Trait - Trait 2	Hogget-Average ewe EI	 II	2 year old ewe-Average ewe EI	 II
QN				
H^2	0.28 ± 0.10	0.33 ± 0.09	0.17 ± 0.14	0.49 ± 0.13
- LW	0.42 ± 0.06	0.15 ± 0.02	0.70 ± 0.15	0.22 ± 0.04
- GFW	-0.37 ± 0.02	-0.17 ± 0.02	-0.33 ± N	-0.33 ± N
- CFW	-0.37 ± N	-0.23 ± N	-0.40 ± N	-0.42 ± N
- Y	-0.30 ± N	-0.36 ± N	-0.63 ± N	-0.36 ± N
- QN	0.78 ± N	0.72 ± M	>1	0.68 ± N
- MFD	-0.07 ± 0.04	-0.12 ± 0.03	-0.62 ± 0.29	-0.55 ± N
- SL	-0.46 ± N	-0.32 ± N	-0.62 ± N	-0.54 ± N
- TCN	0.36 ± 0.06	0.53 ± N	0.65 ± N	0.42 ± N
- CF	0.60 ± N	0.67 ± N	>1	0.65 ± N
- SST	Z	0.31 ± 0.52	Z	-0.22 ± N
- CHG	0.29 ± N	0.35 ± N	0.17 ± N	0.37 ± N
- LUS	-0.86 ± N	-0.51 ± N	-0.82 ± N	-0.85 ± N
- TIP	0.80 ± N	0.76 ± N	>1	0.40 ± N
- COT	0.58 ± N	0.38 ± N	0.14 ± 0.05	0.38 ± N
- CAG	0.44 ± N	0.62 ± N	0.49 ± N	0.57 ± N
- SOU	<-1	-0.74 ± 0.84	Z	-0.85 ± 0.68
- HND	0.22 ± N	0.25 ± N	0.36 ± N	0.44 ± N
- GCM	-0.31 ± N	-0.42 ± N	-0.55 ± N	-0.42 ± N
- SCM	-0.80 ± 0.62	-0.05 ± 0.13	-0.52 ± 0.67	-0.09 ± 0.10
- GCF	0.42 ± N	0.15 ± 0.09	0.86 ± 0.56	0.58 ± 0.07

Table 4.11: Continued

Trait	Hogget-Average ewe		2 year old ewe-Average ewe	
- Trait 2	EI	II	EI	II
MFD				
H^2	0.33 ± 0.11	0.46 ± 0.11	0.58 ± 0.18	0.61 ± 0.18
- LW	-0.30 ± N	-0.34 ± 0.08	-0.56 ± 0.03	-0.49 ± 0.19
- GFW	0.63 ± N	0.59 ± N	0.29 ± 0.02	0.38 ± N
- CFW	0.59 ± N	0.62 ± N	0.15 ± 0.07	0.32 ± N
- Y	0.07 ± 0.07	0.37 ± N	-0.52 ± 0.16	-0.35 ± 0.25
- QN	-0.45 ± N	-0.36 ± N	-0.43 ± N	-0.45 ± N
- MFD	0.88 ± N	0.91 ± N	0.97 ± N	1.00 ± N
- SL	0.60 ± 0.03	0.10 ± 0.05	0.12 ± N	0.07 ± 0.04
- TCN	-0.12 ± 0.05	-0.21 ± N	-0.38 ± N	-0.35 ± N
- CF	-0.46 ± N	-0.35 ± N	-0.49 ± N	-0.28 ± N
- SST	0.33 ± 0.32	-0.09 ± 0.22	-0.05 ± 0.17	-0.04 ± 0.14
- CHG	0.20 ± N	0.25 ± 0.11	-0.71 ± 0.22	-0.18 ± N
- LUS	0.52 ± N	0.36 ± N	0.27 ± N	0.31 ± 0.10
- TIP	-0.23 ± N	0.01 ± 0.07	-0.16 ± N	-0.09 ± 0.05
- COT	0.76 ± N	0.27 ± N	0.50 ± 0.15	0.34 ± N
- CAG	0.14 ± 0.07	-0.01 ± 0.03	0.16 ± 0.06	-0.00 ± 0.03
- SOU	0.65 ± 0.46	0.21 ± N	0.10 ± 0.04	-0.20 ± 0.47
- HND	-0.58 ± N	-0.52 ± N	-0.75 ± N	-0.64 ± N
- GCM	0.11 ± 0.06	0.39 ± N	-0.49 ± 0.13	-0.36 ± 0.27
- SCM	0.20 ± 0.38	-0.06 ± 0.06	0.58 ± 0.71	0.22 ± 0.17
- GCF	-0.68 ± 0.33	-0.17 ± N	Z	-0.11 ± 0.05

Table 4.11: Continued

Trait	Hogget-Average ewe		2 year old ewe-Average ewe	
- Trait 2	EI	II	EI	II
SL				
H^2	0.45 ± 0.12	0.51 ± 0.11	0.34 ± 0.14	0.43 ± 0.14
- LW	0.03 ± 0.05	0.25 ± N	0.22 ± N	0.19 ± N
- GFW	0.61 ± N	0.54 ± N	0.44 ± N	0.31 ± N
- CFW	0.58 ± N	0.62 ± N	0.35 ± N	0.35 ± N
- Y	0.38 ± N	0.58 ± N	0.02 ± 0.07	0.13 ± N
- QN	-0.45 ± N	-0.54 ± N	-0.26 ± 0.02	-0.25 ± N
- MFD	0.18 ± N	0.29 ± N	-0.14 ± 0.06	-0.20 ± 0.18
- SL	0.93 ± N	0.87 ± N	0.87 ± N	0.83 ± N
- TCN	0.23 ± N	0.24 ± 0.12	0.45 ± 0.03	0.44 ± 0.21
- CF	-0.34 ± N	-0.48 ± N	-0.25 ± 0.03	-0.28 ± N
- SST	Z	0.11 ± 0.04	<-1	-0.35 ± 0.58
- CHG	-0.10 ± 0.03	-0.21 ± N	-0.32 ± N	-0.08 ± 0.05
- LUS	-0.06 ± 0.11	0.22 ± N	-0.24 ± 0.12	-0.06 ± 0.20
- TIP	-0.47 ± N	-0.55 ± N	-0.43 ± N	-0.45 ± N
- COT	-0.29 ± N	-0.21 ± N	-0.91 ± N	-0.59 ± N
- CAG	-0.34 ± N	-0.13 ± 0.04	-0.48 ± N	-0.39 ± N
- SOU	>1	-0.10 ± 0.49	<-1	-0.47 ± 0.93
- HND	-0.59 ± N	-0.56 ± N	-0.26 ± N	-0.25 ± N
- GCM	0.33 ± N	0.54 ± N	-0.04 ± 0.08	0.10 ± 0.04
- SCM	0.15 ± 0.19	-0.02 ± 0.10	-0.81 ± 0.89	-0.39 ± N
- GCF	-0.36 ± 0.18	-0.27 ± 0.21	<-1	-0.20 ± 0.06

Table 4.11: Continued

Trait - Trait 2	Hogget-Average ewe EI	 II	2 year old ewe-Average ewe EI	 II
TCN				
H^2	0.49 ± 0.13	0.56 ± 0.12	0.42 ± 0.14	0.42 ± 0.14
- LW	0.65 ± N	0.39 ± 0.07	0.63 ± N	0.25 ± N
- GFW	0.04 ± 0.05	0.25 ± 0.05	-0.22 ± 0.01	-0.22 ± 0.07
- CFW	0.05 ± 0.03	0.22 ± 0.06	-0.26 ± N	-0.26 ± 0.07
- Y	0.07 ± 0.06	-0.05 ± 0.03	-0.38 ± N	-0.13 ± N
- QN	0.66 ± N	0.58 ± N	0.77 ± N	0.76 ± N
- MFD	0.09 ± 0.05	-0.04 ± 0.04	-0.66 ± N	-0.44 ± N
- SL	0.10 ± N	0.24 ± 0.10	0.33 ± N	-0.01 ± 0.01
- TCN	0.78 ± N	0.92 ± N	0.90 ± N	0.91 ± N
- CF	0.60 ± N	0.62 ± N	0.78 ± N	0.62 ± N
- SST	Z	0.14 ± 0.36	0.18 ± 0.20	0.06 ± 0.10
- CHG	0.38 ± N	0.34 ± N	0.22 ± N	0.15 ± N
- LUS	-0.97 ± N	-0.44 ± N	-0.74 ± N	-0.74 ± N
- TIP	0.54 ± N	0.59 ± N	0.42 ± N	0.41 ± N
- COT	0.52 ± N	0.31 ± N	0.00 ± 0.06	-0.02 ± 0.10
- CAG	0.42 ± N	0.35 ± N	0.26 ± N	0.26 ± N
- SOU	Z	-0.13 ± 0.47	-0.92 ± 1.06	-0.22 ± 0.17
- HND	-0.05 ± 0.07	0.09 ± 0.03	0.41 ± N	0.35 ± N
- GCM	-0.00 ± 0.04	-0.09 ± N	-0.45 ± N	-0.13 ± N
- SCM	-0.27 ± 0.14	-0.17 ± 0.15	<-1	-0.50 ± 0.21
- GCF	0.42 ± 0.14	0.11 ± 0.06	0.49 ± 0.39	0.20 ± N

Table 4.11: Continued

Trait - Trait 2	Hogget-Average ewe EI	 II	2 year old ewe-Average ewe EI	 II
CF				
H^2	0.39 ± 0.10	0.40 ± 0.10	0.29 ± 0.12	0.29 ± 0.12
- LW	0.57 ± 0.04	0.39 ± 0.13	0.42 ± 0.07	0.14 ± 0.02
- GFW	-0.24 ± 0.04	-0.05 ± 0.04	-0.44 ± N	-0.32 ± N
- CFW	-0.21 ± N	-0.05 ± 0.06	-0.41 ± N	-0.41 ± N
- Y	-0.13 ± N	-0.21 ± N	-0.41 ± N	-0.13 ± 0.01
- QN	0.85 ± N	0.76 ± N	0.84 ± N	0.81 ± N
- MFD	-0.08 ± 0.04	-0.19 ± N	-0.62 ± N	-0.32 ± N
- SL	-0.33 ± N	-0.18 ± 0.06	-0.44 ± N	-0.36 ± N
- TCN	0.65 ± N	0.79 ± N	0.61 ± N	0.61 ± N
- CF	0.86 ± N	0.68 ± N	0.92 ± N	0.62 ± N
- SST	Z	0.34 ± 0.83	0.82 ± 0.99	0.13 ± 0.31
- CHG	0.53 ± N	0.38 ± N	0.33 ± N	0.27 ± N
- LUS	-0.98 ± N	-0.45 ± N	-0.59 ± N	-0.59 ± N
- TIP	0.85 ± N	0.72 ± N	0.59 ± N	0.56 ± N
- COT	0.47 ± N	0.54 ± N	0.40 ± N	0.32 ± N
- CAG	>1	>1	>1	>1
- SOU	Z	-0.21 ± 0.63	-0.52 ± 0.44	-0.11 ± N
- HND	0.32 ± N	0.34 ± N	0.44 ± N	0.36 ± N
- GCM	-0.18 ± N	-0.28 ± N	-0.39 ± N	-0.20 ± N
- SCM	-0.44 ± 0.26	-0.12 ± 0.19	-0.69 ± 0.95	-0.27 ± 0.22
- GCF	0.25 ± 0.02	0.50 ± 0.28	>1	0.46 ± N

Table 4.11: Continued

Trait - Trait 2	Hogget-Average ewe EI	 II	2 year old ewe-Average ewe EI	 II
SST				
H^2	0.17 ± 0.09	0.20 ± 0.09	0.00 ± 0.12	0.10 ± 0.12
- LW	Z	-0.04 ± 0.05	Z	-0.29 ± 0.31
- GFW	-0.37 ± N	-0.60 ± 0.39	Z	<-1
- CFW	-0.39 ± 0.08	-0.53 ± 0.37	Z	<-1
- Y	Z	0.71 ± 0.68	Z	0.27 ± N
- QN	0.11 ± 0.17	0.36 ± 0.58	Z	0.42 ± 0.89
- MFD	-0.35 ± 0.12	-0.32 ± 0.30	Z	-0.43 ± 0.55
- SL	-0.20 ± 0.31	-0.07 ± 0.18	Z	-0.68 ± 0.96
- TCN	0.26 ± 0.13	0.13 ± 0.17	Z	0.06 ± 0.27
- CF	0.32 ± 0.23	0.13 ± 0.28	Z	0.78 ± 1.19
- SST	0.51 ± N	0.64 ± N	Z	-0.13 ± 0.94
- CHG	0.48 ± N	0.65 ± 0.43	Z	0.45 ± 0.52
- LUS	<-1	0.11 ± 0.04	Z	<-1
- TIP	0.78 ± 0.26	0.23 ± 0.14	Z	0.30 ± 0.46
- COT	0.61 ± 0.11	0.49 ± 0.29	Z	0.16 ± 0.16
- CAG	0.27 ± 0.16	0.47 ± 0.32	Z	0.35 ± N
- SOU	>1	0.85 ± 0.71	Z	0.21 ± 0.49
- HND	0.21 ± 0.09	0.40 ± 0.28	Z	0.91 ± 1.10
- GCM	Z	>1	Z	>1
- SCM	0.70 ± 1.34	0.34 ± 0.57	Z	-0.14 ± N
- GCF	-0.65 ± 0.69	0.75 ± 1.21	Z	-0.32 ± 0.24

Table 4.11: Continued

Trait	Hogget-Average ewe		2 year old ewe-Average ewe	
- Trait 2	EI	II	EI	II
CHG				
H^2	0.23 ± 0.09	0.31 ± 0.08	0.27 ± 0.12	0.27 ± 0.12
- LW	0.13 ± N	0.20 ± N	0.23 ± 0.08	0.05 ± 0.04
- GFW	0.02 ± 0.03	0.06 ± N	-0.08 ± 0.03	-0.14 ± 0.08
- CFW	-0.01 ± 0.00	-0.01 ± 0.01	-0.17 ± 0.06	0.07 ± 0.04
- Y	-0.17 ± N	-0.20 ± N	-0.20 ± 0.11	0.24 ± 0.12
- QN	0.86 ± 0.13	0.28 ± N	0.65 ± N	0.51 ± N
- MFD	-0.49 ± 0.12	-0.38 ± 0.05	-0.62 ± N	-0.55 ± 0.12
- SL	-0.15 ± N	-0.02 ± 0.03	-0.51 ± N	-0.26 ± N
- TCN	0.55 ± N	0.37 ± N	0.64 ± N	0.54 ± N
- CF	0.58 ± 0.04	0.18 ± 0.02	0.97 ± N	0.50 ± N
- SST	Z	-0.91 ± 1.29	<-1	0.84 ± 0.65
- CHG	0.45 ± N	0.55 ± N	>1	>1
- LUS	-0.67 ± 0.21	-0.15 ± 0.04	-0.41 ± N	-0.36 ± 0.13
- TIP	0.39 ± N	0.49 ± N	0.94 ± N	0.71 ± N
- COT	0.43 ± N	0.22 ± N	>1	0.23 ± N
- CAG	-0.08 ± 0.21	0.16 ± N	0.32 ± N	0.43 ± 0.10
- SOU	Z	-0.21 ± 0.40	-0.05 ± 0.34	0.22 ± 0.14
- HND	>1	0.31 ± 0.04	0.72 ± N	0.40 ± N
- GCM	-0.19 ± N	-0.25 ± N	-0.15 ± 0.08	0.19 ± 0.09
- SCM	-0.41 ± 0.19	-0.12 ± N	0.55 ± 0.58	0.31 ± 0.14
- GCF	0.43 ± 0.43	-0.33 ± 0.47	0.67 ± 0.63	0.05 ± 0.07

Table 4.11: Continued

Trait - Trait 2	Hogget-Average ewe EI	 II	2 year old ewe-Average ewe EI	 II
LUS				
H^2	0.24 ± 0.08	0.27 ± 0.08	0.00 ± 0.10	0.14 ± 0.10
- LW	-0.49 ± 0.09	-0.23 ± 0.07	Z	-0.99 ± 2.32
- GFW	0.11 ± N	-0.04 ± 0.06	Z	0.24 ± 0.39
- CFW	0.10 ± N	0.01 ± 0.06	Z	0.39 ± 0.38
- Y	0.26 ± N	0.06 ± 0.10	Z	0.69 ± 0.82
- QN	-0.44 ± N	-0.47 ± N	Z	-0.80 ± 1.58
- MFD	-0.42 ± 0.01	-0.53 ± 0.25	Z	-0.61 ± 1.68
- SL	0.12 ± 0.02	0.01 ± 0.11	Z	-0.12 ± 0.60
- TCN	-0.38 ± N	-0.39 ± N	Z	-0.72 ± 1.68
- CF	-0.33 ± N	-0.45 ± N	Z	-0.52 ± 1.00
- SST	Z	-0.57 ± 0.76	<-1	0.72 ± 0.51
- CHG	0.21 ± 0.03	0.07 ± 0.03	Z	0.22 ± 0.50
- LUS	0.65 ± N	0.53 ± N	Z	>1
- TIP	-0.60 ± N	-0.52 ± N	Z	-0.41 ± 1.20
- COT	-0.41 ± N	-0.57 ± N	Z	-0.50 ± 1.00
- CAG	-0.59 ± N	-0.71 ± N	Z	-0.33 ± 0.39
- SOU	0.57 ± 1.28	0.45 ± 0.55	Z	0.36 ± N
- HND	0.53 ± 0.06	0.28 ± 0.08	Z	0.72 ± 1.89
- GCM	0.30 ± N	0.09 ± 0.09	Z	0.69 ± 0.77
- SCM	0.73 ± 0.49	0.18 ± 0.13	Z	0.01 ± 0.22
- GCF	-0.00 ± 0.23	-0.68 ± 0.58	Z	0.09 ± 0.46

Table 4.11: Continued

Trait - Trait 2	Hogget-Average ewe		2 year old ewe-Average ewe	
	EI	II	EI	II
TIP				
H^2	0.16 ± 0.07	0.19 ± 0.07	0.11 ± 0.11	0.26 ± 0.11
- LW	0.10 ± 0.05	0.26 ± N	0.79 ± 0.40	0.07 ± 0.09
- GFW	-0.73 ± 0.35	0.08 ± 0.09	-0.24 ± N	-0.13 ± N
- CFW	-0.55 ± 0.21	0.02 ± 0.07	-0.24 ± N	-0.28 ± N
- Y	0.18 ± 0.21	-0.07 ± 0.02	-0.29 ± N	-0.40 ± N
- QN	0.78 ± N	0.78 ± N	>1	0.83 ± N
- MFD	-0.25 ± N	-0.04 ± 0.03	-0.38 ± 0.04	-0.16 ± N
- SL	-0.88 ± N	-0.31 ± N	-0.53 ± N	-0.53 ± N
- TCN	0.15 ± 0.04	0.19 ± N	0.78 ± N	0.48 ± N
- CF	0.73 ± N	0.27 ± N	>1	0.70 ± N
- SST	Z	-0.13 ± 0.28	Z	-0.96 ± >1
- CHG	0.23 ± 0.22	>1	0.46 ± N	0.76 ± 0.16
- LUS	<-1	0.06 ± 0.35	-0.69 ± 0.10	-0.28 ± N
- TIP	0.83 ± N	0.90 ± N	>1	0.78 ± N
- COT	0.32 ± N	0.65 ± N	0.98 ± N	0.46 ± N
- CAG	0.71 ± N	0.82 ± N	>1	0.57 ± N
- SOU	Z	-0.23 ± 0.33	Z	<-1
- HND	0.75 ± 0.09	0.53 ± 0.22	0.58 ± N	0.31 ± N
- GCM	0.14 ± 0.14	-0.04 ± 0.03	-0.23 ± N	-0.48 ± N
- SCM	-0.20 ± 0.46	0.23 ± N	-0.54 ± 1.00	0.09 ± N
- GCF	-0.36 ± 0.68	0.65 ± N	>1	0.59 ± 0.25

Table 4.11: Continued

Trait - Trait 2	Hogget-Average ewe EI	 II	2 year old ewe-Average ewe EI	 II
COT				
H^2	0.23 ± 0.08	0.23 ± 0.08	0.20 ± 0.13	0.36 ± 0.12
- LW	-0.23 ± 0.10	-0.08 ± 0.06	0.08 ± 0.02	-0.07 ± 0.08
- GFW	-0.24 ± 0.05	-0.04 ± 0.02	-0.14 ± 0.01	-0.24 ± 0.07
- CFW	-0.33 ± 0.06	-0.05 ± 0.02	-0.20 ± N	-0.25 ± 0.05
- Y	-0.34 ± 0.08	0.07 ± 0.07	-0.32 ± N	-0.08 ± N
- QN	0.62 ± 0.05	0.46 ± 0.08	0.57 ± N	0.87 ± 0.20
- MFD	Z	0.10 ± 0.05	0.55 ± 0.46	-0.02 ± 0.07
- SL	-0.23 ± 0.07	-0.06 ± 0.02	-0.59 ± 0.06	-0.23 ± N
- TCN	0.39 ± N	0.26 ± N	0.32 ± N	0.54 ± N
- CF	0.19 ± 0.05	0.49 ± 0.13	0.53 ± N	0.61 ± 0.10
- SST	Z	0.09 ± N	>1	>1
- CHG	0.75 ± N	0.55 ± 0.06	0.13 ± 0.08	0.59 ± N
- LUS	-0.22 ± 0.09	-0.46 ± 0.26	-0.75 ± 0.10	-0.69 ± 0.39
- TIP	0.76 ± N	0.57 ± N	0.92 ± N	0.58 ± N
- COT	0.74 ± N	0.83 ± N	>1	0.72 ± N
- CAG	>1	>1	>1	>1
- SOU	Z	0.00 ± 0.41	-0.72 ± 1.73	>1
- HND	0.48 ± 0.14	0.12 ± 0.05	0.36 ± N	0.47 ± 0.09
- GCM	-0.41 ± 0.12	0.08 ± 0.08	-0.33 ± N	-0.06 ± N
- SCM	0.01 ± 0.09	-0.26 ± 0.12	-0.09 ± 0.24	-0.36 ± 0.32
- GCF	<-1	0.49 ± 0.89	>1	0.66 ± N

Table 4.11: Continued

Trait - Trait 2	Hogget-Average ewe EI	 II	2 year old ewe-Average ewe EI	 II
CAG				
H^2	0.17 ± 0.08	0.22 ± 0.08	0.07 ± 0.14	0.24 ± 0.13
- LW	0.25 ± N	0.21 ± N	Z	-0.09 ± 0.16
- GFW	0.17 ± 0.03	0.26 ± 0.08	Z	-0.38 ± 0.17
- CFW	0.24 ± 0.03	0.25 ± 0.07	Z	-0.43 ± 0.18
- Y	0.58 ± N	0.35 ± 0.06	Z	0.17 ± 0.22
- QN	0.06 ± 0.04	0.37 ± 0.19	>1	0.33 ± N
- MFD	0.20 ± 0.08	0.21 ± 0.08	>1	0.18 ± 0.08
- SL	0.18 ± N	0.11 ± N	Z	-0.15 ± N
- TCN	0.24 ± N	0.10 ± N	Z	0.35 ± N
- CF	-0.18 ± 0.06	0.22 ± 0.12	Z	0.41 ± N
- SST	Z	-0.16 ± 0.38	Z	0.74 ± 0.64
- CHG	0.54 ± 0.04	0.25 ± 0.03	Z	0.80 ± N
- LUS	-0.14 ± 0.11	-0.04 ± 0.06	Z	<-1
- TIP	0.47 ± N	0.43 ± 0.05	>1	0.63 ± N
- COT	0.76 ± N	0.59 ± N	Z	0.51 ± N
- CAG	0.44 ± 0.10	0.31 ± N	>1	0.48 ± N
- SOU	Z	0.37 ± 0.71	Z	0.12 ± N
- HND	-0.27 ± 0.04	-0.26 ± 0.08	0.12 ± >1	0.18 ± 0.04
- GCM	0.61 ± 0.07	0.24 ± 0.01	<-1	0.10 ± 0.14
- SCM	0.15 ± 0.14	-0.13 ± 0.10	>1	0.11 ± N
- GCF	-0.25 ± 0.24	0.62 ± 1.12	Z	0.08 ± 0.21

Table 4.11: Continued

Trait - Trait 2	Hogget-Average ewe EI	 II	2 year old ewe-Average ewe EI	 II
SOU				
H^2	0.12 ± 0.06	0.16 ± 0.06	0.01 ± 0.10	0.07 ± 0.10
- LW	-0.73 ± 0.54	0.22 ± 0.07	-0.41 ± 0.75	-0.44 ± 0.98
- GFW	0.28 ± 0.11	0.25 ± 0.07	-0.43 ± 0.40	-0.37 ± 0.77
- CFW	0.08 ± 0.07	0.21 ± 0.03	-0.43 ± 0.44	-0.46 ± 1.05
- Y	0.07 ± 0.09	0.47 ± 0.26	0.35 ± 0.24	0.18 ± 0.22
- QN	0.21 ± 0.30	0.15 ± 0.26	0.81 ± 0.68	0.77 ± 1.59
- MFD	0.13 ± N	0.42 ± 0.21	-0.36 ± 0.77	-0.32 ± 0.34
- SL	0.10 ± 0.04	-0.09 ± 0.13	-0.70 ± 0.72	-0.26 ± 0.64
- TCN	0.53 ± 0.46	0.18 ± 0.22	0.67 ± 0.55	0.98 ± 2.09
- CF	0.39 ± 0.39	0.10 ± 0.19	>1	0.86 ± 2.01
- SST	Z	0.19 ± N	<-1	0.92 ± N
- CHG	0.42 ± 0.06	0.42 ± 0.25	0.93 ± 0.75	0.95 ± 1.93
- LUS	-0.16 ± 0.29	0.06 ± 0.09	-0.87 ± 1.12	-0.19 ± 0.88
- TIP	0.44 ± 0.28	0.22 ± 0.10	0.57 ± 0.45	0.67 ± 1.25
- COT	0.85 ± 0.58	0.45 ± 0.21	>1	0.24 ± 0.44
- CAG	-0.10 ± 0.27	0.46 ± 0.15	0.54 ± 1.57	0.77 ± 1.07
- SOU	>1	0.57 ± N	-0.28 ± 1.51	-0.59 ± 1.74
- HND	0.29 ± 0.26	0.16 ± 0.12	0.92 ± 0.71	0.79 ± 1.45
- GCM	0.12 ± 0.17	0.47 ± 0.24	0.38 ± 0.19	0.06 ± N
- SCM	>1	0.27 ± 0.38	Z	-0.35 ± 0.41
- GCF	<-1	0.28 ± 0.29	<-1	>1

Table 4.11: Continued

Trait - Trait 2	Hogget-Average ewe EI	 II	2 year old ewe-Average ewe EI	 II
HND				
H^2	0.15 ± 0.08	0.33 ± 0.08	0.11 ± 0.11	0.23 ± 0.11
- LW	0.50 ± 0.16	0.19 ± 0.09	0.13 ± 0.15	-0.07 ± N
- GFW	-0.94 ± 0.09	-0.38 ± 0.05	-0.46 ± 0.16	-0.40 ± 0.12
- CFW	-0.97 ± 0.10	-0.42 ± 0.05	-0.27 ± 0.05	-0.30 ± 0.07
- Y	-0.54 ± N	-0.20 ± N	0.35 ± 0.13	0.28 ± 0.17
- QN	0.76 ± 0.14	0.34 ± 0.08	0.51 ± 0.10	0.27 ± N
- MFD	-0.98 ± N	-0.55 ± N	-0.90 ± N	-0.74 ± N
- SL	-0.70 ± 0.25	-0.07 ± 0.06	-0.65 ± 0.29	-0.66 ± 0.23
- TCN	0.08 ± 0.08	0.21 ± N	0.03 ± 0.06	-0.02 ± 0.11
- CF	0.57 ± 0.07	0.12 ± 0.05	0.38 ± N	0.39 ± N
- SST	Z	-0.25 ± 0.12	0.80 ± 1.65	-0.77 ± 0.59
- CHG	0.20 ± 0.03	-0.03 ± 0.07	0.28 ± N	0.47 ± N
- LUS	<-1	-0.15 ± 0.14	-0.35 ± 0.26	-0.21 ± 0.25
- TIP	0.18 ± 0.00	-0.06 ± 0.09	0.39 ± 0.13	0.01 ± 0.11
- COT	-0.54 ± 0.14	-0.23 ± 0.04	0.59 ± 0.34	-0.15 ± 0.12
- CAG	-0.33 ± 0.07	-0.28 ± 0.15	-0.06 ± 0.06	-0.11 ± 0.10
- SOU	>1	-0.22 ± 0.32	-0.24 ± 0.27	-0.75 ± 1.13
- HND	>1	0.59 ± N	>1	>1
- GCM	-0.58 ± N	-0.21 ± N	0.35 ± 0.14	0.37 ± 0.23
- SCM	0.17 ± N	0.20 ± N	0.27 ± 0.29	-0.06 ± 0.16
- GCF	-0.34 ± 0.26	0.34 ± 0.32	-0.31 ± 0.57	0.38 ± 0.12

Table 4.11: Continued

Trait - Trait 2	Hogget-Average ewe EI	 II	2 year old ewe-Average ewe EI	 II
GCM				
H^2	0.10 ± 0.10	0.42 ± 0.09	0.00 ± 0.09	0.04 ± 0.09
- LW	Z	0.39 ± 0.13	>1	-0.16 ± 0.12
- GFW	Z	-0.44 ± 0.06	>1	0.34 ± 0.05
- CFW	Z	-0.35 ± 0.07	Z	0.46 ± N
- Y	Z	0.27 ± N	>1	0.57 ± N
- QN	Z	0.19 ± 0.16	<-1	-0.37 ± N
- MFD	-0.65 ± 0.16	-0.38 ± 0.10	Z	0.49 ± 0.31
- SL	Z	0.02 ± 0.05	Z	0.73 ± 0.44
- TCN	Z	-0.04 ± 0.01	Z	0.95 ± 0.82
- CF	Z	0.04 ± 0.08	Z	0.35 ± 0.41
- SST	Z	0.05 ± 0.12	Z	0.19 ± 0.19
- CHG	Z	0.13 ± 0.10	Z	0.28 ± 0.13
- LUS	Z	0.07 ± N	Z	0.14 ± N
- TIP	Z	-0.13 ± 0.01	Z	0.13 ± 0.17
- COT	Z	-0.03 ± 0.03	Z	-0.10 ± 0.04
- CAG	0.23 ± 0.20	-0.04 ± 0.07	Z	-0.11 ± 0.08
- SOU	>1	-0.00 ± 0.19	Z	-0.87 ± 1.64
- HND	Z	0.11 ± 0.04	Z	0.05 ± 0.08
- GCM	Z	0.34 ± N	Z	0.91 ± N
- SCM	>1	-0.14 ± 0.13	Z	0.22 ± 0.26
- GCF	0.24 ± 0.20	-0.47 ± 0.53	Z	0.82 ± 0.50

Table 4.11: Continued

Trait - Trait 2	Hogget-Average ewe EI	 II	2 year old ewe-Average ewe EI	 II
SCM				
H^2	0.05 ± 0.07	0.22 ± 0.07	0.03 ± 0.09	0.11 ± 0.10
- LW	Z	0.31 ± 0.11	0.83 ± 0.84	0.51 ± 0.53
- GFW	Z	-0.13 ± 0.03	0.56 ± 1.36	0.07 ± 0.24
- CFW	Z	-0.07 ± 0.04	0.56 ± 0.84	0.20 ± 0.38
- Y	Z	0.44 ± 0.25	0.79 ± 0.74	0.71 ± 0.83
- QN	>1	0.30 ± 0.22	-0.97 ± 0.89	-0.68 ± 0.80
- MFD	Z	0.34 ± 0.43	0.23 ± 0.31	0.24 ± 0.65
- SL	<-1	0.04 ± 0.05	0.35 ± 0.41	0.50 ± 0.62
- TCN	0.88 ± 2.15	0.15 ± 0.03	<-1	-0.62 ± 0.59
- CF	>1	-0.02 ± 0.09	<-1	-0.89 ± 0.96
- SST	Z	0.00 ± 0.24	<-1	0.50 ± 0.68
- CHG	>1	0.02 ± 0.04	<-1	-0.41 ± 0.46
- LUS	<-1	-0.48 ± 0.35	>1	0.80 ± 1.12
- TIP	>1	0.09 ± 0.06	-1.00 ± 1.04	-0.41 ± 0.52
- COT	>1	0.04 ± 0.07	-0.41 ± N	-0.96 ± 0.95
- CAG	Z	>1	>1	0.89 ± N
- SOU	Z	0.23 ± 0.24	-0.86 ± 1.48	-0.31 ± 0.60
- HND	0.67 ± 1.82	-0.02 ± 0.07	-0.09 ± 0.21	-0.05 ± 0.19
- GCM	Z	0.44 ± 0.31	0.64 ± 0.59	0.69 ± 0.69
- SCM	Z	-0.19 ± 0.27	>1	0.05 ± 0.18
- GCF	Z	0.16 ± N	Z	0.42 ± N

Table 4.11: Continued

Trait	Hogget-Average ewe		2 year old ewe-Average ewe	
- Trait 2	EI	II	EI	II
GCF				
H^2	0.10 ± 0.06	0.10 ± 0.06	0.07 ± 0.12	0.07 ± 0.12
- LW	0.18 ± N	0.39 ± 0.17	0.70 ± 0.20	0.40 ± 0.29
- GFW	-0.44 ± N	-0.49 ± 0.09	-0.19 ± N	-0.32 ± 0.13
- CFW	-0.29 ± N	-0.30 ± 0.03	-0.18 ± N	-0.19 ± N
- Y	0.31 ± N	0.48 ± 0.03	0.32 ± 0.17	0.15 ± 0.18
- QN	0.01 ± 0.03	0.28 ± 0.16	0.07 ± 0.12	0.47 ± N
- MFD	-0.19 ± 0.02	-0.35 ± 0.17	0.08 ± 0.08	-0.17 ± N
- SL	-0.06 ± 0.05	-0.01 ± 0.04	0.28 ± 0.08	0.17 ± 0.17
- TCN	-0.10 ± 0.01	-0.16 ± 0.10	0.32 ± N	0.41 ± N
- CF	-0.17 ± 0.03	0.06 ± 0.04	0.03 ± 0.16	0.24 ± N
- SST	Z	0.11 ± 0.14	0.75 ± 0.61	>1
- CHG	0.02 ± 0.02	0.13 ± 0.09	-0.29 ± 0.42	0.22 ± N
- LUS	-0.49 ± 0.12	-0.24 ± 0.09	-0.78 ± N	-0.52 ± N
- TIP	0.15 ± 0.02	0.15 ± 0.08	0.15 ± N	0.16 ± N
- COT	-0.28 ± 0.07	0.13 ± 0.09	-0.16 ± 0.27	0.24 ± N
- CAG	0.30 ± 0.07	0.30 ± 0.22	0.28 ± N	0.28 ± N
- SOU	<-1	0.42 ± 0.69	-0.99 ± 0.28	0.31 ± 0.43
- HND	-0.04 ± 0.01	-0.05 ± 0.03	0.08 ± N	-0.04 ± 0.13
- GCM	0.36 ± N	0.42 ± N	0.39 ± 0.20	-0.02 ± 0.05
- SCM	>1	0.46 ± 0.16	0.45 ± 0.62	-0.16 ± 0.25
- GCF	0.74 ± 0.53	0.14 ± N	Z	0.07 ± 0.12

liveweight and consequently have lower fleece weights and finer MFD. Correlations in this study follow these trends.

Selection for hogget liveweight would result in increased ewe liveweights and ewe fleeces with lower weights, slightly increased Y, increased QN, finer MFD, increased TCN and CF, decreased LUS and more blocky staples (higher TIP). Similar changes would occur from selection on two year old ewe liveweight. As there are no significant changes in correlations and two year old ewe heritability for liveweight is only slightly higher than for hoggets there would be little to gain from keeping ewes an extra year until two years of age to select on liveweight.

Genotype x environment interactions had the largest effect on liveweight correlations. In other traits the inclusion of interactions in the correlation estimates generally changed the values only slightly. However for liveweight correlations large variations in the sign and size of the estimates often occurred.

4.5.2.2 Association of Hogget Fleece Weight with Ewe Characteristics

Selection for increased hogget fleece weight would increase later ewe fleece weights and would also result in increased yield, decreased QN, increased MFD, increased SL and TCN, decreased CF, more bulky staples, lower SST and SOU, increased lustre and harsher handle in ewe fleeces.

Although selection for increased hogget GFW would decrease the degree of cotting in ewe fleeces, selection for increased two year old fleece weight would result in an increase in the amount of cotting in older ewe fleeces.

As for within ages the correlations for GFW and CFW were very similar and reinforces that for Romneys GFW is an adequate selection criterion and there is no need to consider CFW.

4.5.2.3 Association of Other Hogget Fleece Characteristics with Ewe Characteristics

Quality Number

The correlations between hogget and two year old QN assessments and older ewe QN were high positive, indicating that hogget QN was effective at predicting adult QN.

Correlations between hogget QN and ewe MFD were negligible, indicating that, even with the moderate heritability for hogget QN, any attempts to select on hogget QN will be ineffectual at affecting ewe MFD. There was a far higher negative correlation between two year old ewe QN and older ewe MFD, such that if any selection on MFD was to be carried out using QN then it should be applied to two year old ewes at the earliest.

Compared to the selection progress achieved under direct selection using hogget MFD to improve older ewe MFD, use of two year old QN would be less than two-thirds as effective plus would cause an additional year's delay before selection could be made.

Mean Fibre Diameter

Hogget MFD had an extremely high positive correlation with adult MFD. The slightly lower correlation of hogget MFD than two year old ewes to adult MFD may have been due to the different methods of determining MFD in the hoggets to older ewes, projection microscope and airflow techniques respectively.

High correlations between hogget MFD and adult GFW and CFW reinforce the close association between FW and MFD at all ages and highlight the effects selection for either trait will have on the other.

Selection for finer MFD would appear likely to lead to increased cotting while conversely, selection for finer QN appears likely to lead to reduced cotting. This latter association is probably due to effects of crimp frequency or lustre.

Staple Length

Hogget SL had a correlation close to unity with adult SL. The correlation of hogget SL with adult GFW and CFW was high positive. Since the heritability of hogget SL was as high or higher than that of hogget GFW and CFW then selection progress using hogget SL to improve adult FW would result in progress similar to that using direct selection on hogget GFW.

There was also a lower correlation between hogget SL and adult MFD such that selection on hogget SL would increase adult GFW without as large a change in adult MFD as would occur if using hogget GFW as the selection criterion.

A similar trend occurs for two year old SL correlations. Using two year old ewe SL as a selection criterion would increase adult GFW and CFW at a slightly slower rate than in hoggets, however there would be a slight decrease in adult MFD with the increase in adult GFW.

Total Crimp Number and Crimp Frequency

Similar correlations occurred for SL, TCN and CF between hoggets and adults as occurred within the separate ages. Changes in hogget TCN would be closely correlated to adult TCN. This would be highly correlated with changes in adult CF but there would be little associated change in adult SL.

Hogget TCN and CF had high negative correlations with adult LUS. The reverse relationship of hogget LUS with adult TCN and CF was not as strong, due in part to the lower correlation of hogget LUS with adult LUS.

Hogget TCN and CF had medium to high correlations with several adult subjectively assessed traits, including CHG, LUS, TIP, COT and CAG. With the high heritability estimates for hogget TCN and CF compared to heritabilities of subjective traits (generally lower than 0.25) plus direct correlations of hogget to adult assessed traits of less than unity, indirect selection on hogget TCN or CF would result in gains in subjective traits as fast or faster than direct selection on the subjective hogget traits.

Character

Hogget CHG had only a medium correlation with adult CHG, indicating that assessment of hogget CHG was influenced by different factors to adult CHG.

Hogget CHG had a medium negative correlation to adult MFD, but no correlation with adult GFW or CFW, so that hogget CHG could be used as an indirect selection criterion for changing adult MFD without affecting adult FW. However selection progress in adult MFD would be only 1/3 to 1/2 that obtained selecting on hogget MFD.

There have been suggestions that selection for better fleece character in hoggets would lead to higher fleece weights and less discolouration in later fleeces. The present genetic correlations do not support these suggestions.

Lustre
A similar relationship between hogget LUS and adult MFD, GFW and CFW was found as for hogget CHG, providing another possible, though less efficient, selection route.

Hogget LUS had medium negative correlations with both QN and MFD. A similar relationship existed for within-hogget traits. Hence although decreased LUS was associated with an increased MFD, to an observer the decrease in LUS must have suggested a finer fibre and hence increased QN.

Hogget LUS had medium correlations with many adult traits such that selection for lower LUS in hoggets in this flock would result in ewe fleeces with higher QN, higher MFD, higher TCN and CF, decreased tippiness (higher TIP grade), decreased COT and CAG, decreased soundness (lower SOU grade) and harsher handle.

Tippiness
The genetic correlations between hogget tippiness and average ewe greasy and clean fleece weights excluding interactions were medium to high negative but declined to neglibible when interactions were included.

Hogget TIP and adult QN were highly positively correlated. Hence selection in hoggets for more blocky staples, although having very little effect on adult MFD, would increase adult QN.

Hogget TIP was also well correlated with adult TIP, COT, CAG and HND indicating that selection for less tippy wool in hoggets would lead to improvement in adult TIP and would also decrease cotting in adult fleeces and improve handle.

CHG, SOU, TIP, CAG and COT

Correlations between several of the assessed traits tended to be consistent between hogget and adult levels. CHG, TIP, COT, CAG and SOU were medium to highly correlated for most combinations. However, heritabilities of these traits tended to be low so selection on them would not be very effective at obtaining improvement in the next generations.

Handle

Hogget HND had strong associations with several important traits. It had a high negative correlation with adult fleece weight and mean fibre diameter. However selection on hogget HND to decrease adult MFD would result in only 50-70% of possible progress in adult MFD and a greater decline in adult GFW and CFW than direct selection on hogget MFD.

CHAPTER FIVE

CONCLUSIONS

The New Zealand Romney is generally considered a dual-purpose sheep breed. The major selection objectives are number of lambs weaned, fleece weight and weaning weight (Morris, Clarke and Elliott, 1982). Evidence presented in this study indicates that if genotype x environment interactions are not taken into account they may be of sufficient importance to limit genetic progress in New Zealand Romney breeding programs. Sire x stocking rate and sire x year interactions were important sources of variation in liveweight and fleece weight, two of the main selection objectives in Romneys.

Highly significant sire x year interactions were found for hogget LW but sire x stocking rate interactions were statistically non-significant. Nutritional differences between years may explain the sire x year interactions or they may be due to disease effects, such as parasites, with variation in larval survival associated with climatic differences between years or different drenching policies. More research is required to identify the differences between years which give rise to the sire x year interactions.

Although the sire x stocking rate interaction was not statistically significant it contributed a similar amount of variance as the sire component, supporting the observation that the sire x stocking rate interactions, though small relative to the error and sire x year variances, have a considerable impact in hogget liveweight genetic improvement plans. In later years, hoggets were reared together from weaning through to hogget weighing and shearing which reduced sire x stocking rate interactions for hogget traits and may have lead to the lower significance of G x E interactions overall for hogget as compared to ewe liveweight and wool traits.

The relatively small sire variance and importance of genotype x environment interactions in hogget liveweight is reflected in the heritability estimates. Estimates increased from neglible to moderate with inclusion of G x E interactions.

In the ewe liveweight analyses, sire x stocking rate interactions were most important. The estimated intra-trait genetic correlation was -0.24 ± 0.03, implying that genes controlling liveweight in one of the stocking rates had the opposite effect in the other stocking rate.

The results of this study suggest that the low (control) stocking rate is more favourable for the expression of the genetic differences in liveweight - heritabilities tended to be twice as high in the CSR as in the HSR. However, the low hogget intra-trait genetic correlation means that direct selection of sires at the stocking rate in which their progeny are to perform would yield better genetic gains in hogget liveweight than selection of sires at the stocking rate other than that in which their progeny are to perform. The negative intra-trait genetic correlation for ewe liveweight implies that selection of sires at a stocking rate other than that in which their progeny are to perform is worse than no selection for ewe liveweight at all. This finding is not readily accepted and it may be more realistic to consider the intra-trait genetic correlation to be zero.

Sire x stocking rate interactions were of little importance for hogget clean and greasy fleece weight. The high intra-trait genetic correlations mean there would be little loss of genetic gain in fleece weight if sires are selected at a different stocking rate to which they will be used.

In ewe clean and greasy fleece weight traits sire x stocking rate interactions were more important. The intra-trait genetic correlations of less than unity means that genes controlling fleece weight in the control stocking rate have a different effect in part in the high stocking rate. Selection of sires in the CSR for use in the HSR results in only 56 to 79% of the genetic gains possible in ewe fleece weight.

Sire x year interactions were significant for GFW and CFW in both hoggets and ewes.

The presence of these interactions in fleece weight has implications in commercial breeding. The breeding values of sires estimated from performance in one year and at one stocking rate may not be very accurate when the same sires are used in a different year or different stocking rate.

The connotations of the significant genotype x environment interactions for liveweight and fleece weight are that selection of rams should occur at the 'commercial' stocking rate. For this to be put into effect in sheep breeding practise ram buyers would have to be prepared to accept rams which are not so well grown as most tend to expect at present and they will have to take the environment of the stud into account when assessing mean performance records of the stud.

With the exception of clean scoured yield, sire x stocking rate interactions were of low magnitude for hogget wool characteristics. This was confirmed by the high intra-trait genetic correlations between the two stocking rates for most of the traits. Although sire x stocking rate inte ractions were not statistically significant for GCM and SCM, low sire variances resulted in intra-trait genetic correlations between stocking rates that were significantly less than unity.

Assessment errors are a source of environmental variation that contributes to the error variance in subjectively assessed traits. As a result sire and interaction variances control less of the total variation and heritability estimates tend to be lower for assessed than quantitatively measured traits.

Sire x year interactions also tended to be of little importance for hogget wool traits. This is reflected by the heritability estimates for the separate stocking rates, there is little or no difference between heritability estimates excluding and including interactions for most traits.

Sire x environment interactions were important sources of variation for most adult ewe wool characteristics, as was found for ewe GFW and CFW. However, as these traits are not included in the selection objectives they have less practical significance in New Zealand Romney breeding programs.

Sire x stocking rate interactions were generally significant for ewe wool traits and intra-trait genetic correlations tended to be significantly lower for ewe than for hogget traits. Sire x birth year interactions were also significant. The two interactions combined tended to contribute more to the total variation than the sire variance. This was reflected in the heritability estimates with EI estimates tending to be less than half the II estimates.

Ewe wool traits not affected by sire x environment interactions were TIP, GCM and SCM. This was supported for TIP by the high intra-trait genetic correlation (0.85 ± 0.02) and EI and II heritability estimates which were relatively consistent for the combined age analyses. However, zero sire variances for GCM and SCM meant that large negative intra-trait genetic correlations were obtained for these traits.

Between sire differences averaged over environments contributed little or none of the total variance in reproductive traits recorded each year, hence sire interactions accounted for most of the genetic variance.

However, for lifetime reproductive performance no significant sire interactions were identifiable and sire variance, though small, controlled most of the genetic variation. Low or zero values for sire and interaction variance components resulted in meaningless intra-trait genetic correlation values and heritability estimates were negligible. When single year reproduction traits were assessed, birth year effects would also have included year of record effects. With lifetime traits, birth year effects would still be included but year of record effects would be averaged.

Significant genotype x environment interactions will also have important implications in relation to breeding systems used to assist in the genetic improvement of the sheep population. Group breeding schemes and sire reference programs will be affected.

In group breeding schemes high producing animals from several flocks may be transferred to a common nucleus unit in which sires are bred for transfer back to contributing flocks. One potential disadvantage is the difficulty of making valid genetic comparisons among animals from different flocks because of the different environmental conditions in which these perform. In a computer simulation study, del-Bosque-Gonzalez and Kinghorn (1987) found that when the GBS nucleus is in a different environment from the base, both closed and open schemes can suffer a considerable loss in overall selection response when genotype x environment interactions exist. For closed nucleus breeding plans, if there are two environments it is almost always better to have two separate closed-nucleus schemes, rather than one larger scheme covering both environments. For open-nucleus schemes, one larger scheme is better if the genetic correlation between the same trait expressed in the two environments is greater than about 0.78.

Comparison of sires across flocks using sire referencing is currently receiving much attention. If sire x environment interactions are important, inconsistencies may occur in the ranking of sires. Should this occur, it may be necessary to categorise participating flocks according to specified environmental criteria, and select superior sires for each category (Woolaston, 1987). A more efficient alternative would be to use the technqiue developed by James (1961), where the performance of progeny in each environment is entered into an index for overall gain. This method can produce greater overall gain than separate selection, but it relies on accurate estimates of genetic parameters, including intra-trait genetic correlations for the population (Woolaston, 1987). It would be extremely difficult and costly to obtain adequate estimates of these intra-trait genetic correlations for a New Zealand sheep population. Another major problem is that home sires are only tested in one environment.

In addition to intra-trait genetic correlations between stocking rates, between trait genetic correlations within age classes and across ages were evaluated in relation to selection policies of New Zealand Romney sheep.

Although phenotypically hogget LW to ewe GFW correlations are generally positive (Osman and Bradford, 1965; Elliott, 1975) the present data suggest that genetically they are negative. The positive phenotypic relationship, together with the positive genetic correlation between hogget LW and hogget GFW, is often used as justification for using liveweight to increase fleece weight, however the phenotypic relationship between ages may be purely environmental in origin. Although the standard errors associated with estimates in this study were large, the trend in the genetic correlations was for selection on hogget liveweight to lead to a small reduction in adult fleece weight.

The large G x E effects for liveweight and the low EI estimates of the heritability of liveweight are further evidence indicating that selection on liveweight is not as effective at increasing GFW as previously thought.

The high genetic correlations between hogget and adult ewe LW means that attempted use of hogget LW to increase adult GFW would increase adult ewe LW.

The correlations between liveweight and mean fibre diameter were negative, indicating MFD is likely to decline as a result of selection for liveweight. However MFD changes are not very important in New Zealand Romneys.

All the evidence suggests that exactly the same response is obtained selecting for GFW as for CFW in terms of correlated responses. Hence it is unnecessary to scour wool to obtain CFW for use in selection programs for New Zealand Romneys.

Quality number correlations indicate that selection on hogget QN will not do much except increase QN and reduce FW. It will have little effect on MFD.

Selection on mean fibre diameter will be highly effective at changing MFD but will also change fleece weight in the same direction i.e. selection for finer MFD will decrease GFW drastically.

Staple length has many favourable correlations. It would be an effective way of increasing fleece weight if breeders do not want to weigh fleeces. However, it might also result in a slight increase in susceptibility to cotting. Evidence from other sources (Bigham *et al.*, 1983) suggests that it would also reduce bulk which would be likely to be undesirable.

Chopra (1978) in a subset of the data highlighted the fact that hogget TCN had many favourable correlations and a high heritability. While the high heritability was still obtained in this study, the correlations are not as favourable. There would be a relatively small improvement in adult ewe fleece weight with selection for hogget TCN, plus it would confer some resistance to cotting.

This set of data indicates that selection on hogget CHG will not result in any improvement in fleece weight at older ages, although it may do within the hogget. There is also no evidence that selection for CHG will improve colour which some people have suggested in the past (Henderson, 1973).

While SOU and SST are subjective and objective assessments of the same trait their relationship was unclear. A mixture of positive and negative genetic correlations was obtained which was difficult to interpret. The low genetic influence on these traits points to the main problem with the assessment of SOU. Assessment of SOU based on more staples might have been more reliable and may have enabled firmer conclusions to be reached.

Selection on hogget COT should result in progress in improving adult COT. The heritability is not high but hogget COT has a very good genetic correlation to older ages, at the expense of a slightly decreased fleece weight.

Correlations of colour with other traits are inconsistent and it is difficult to make any recommendations. The heritability of midside colour is moderate but there are unfavourable genetic correlations.

Low genetic variances for reproductive traits meant that EI estimates of genetic correlations could not be calculated and II estimates were outside the correlation range or had high standard errors. More research is required into the association between reproductive and wool traits.

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