ESTIMATES OF GENETIC AND PHENOTYPIC PARAMETERS IN COLUMBIA AND COLUMBIA X SOUTHDALE SHEEP

by

Donald James Balch, B.S., M.S.

Thesis Submitted to the Graduate Faculty

of the

Virginia Polytechnic Institute

in candidacy for the degree of

DOCTOR OF PHILOSOPHY

in

Animal Husbandry (Animal Breeding)

May 1962

Blacksburg, Virginia

ACKNOWLEDGMENTS

The author wishes to express his sincere appreciation to Dr. Robert C. Carter for his great interest, inspiration and guidance which contributed so much to the completion of this study. He is also greatly indebted to Dr. James A. Gaines for his invaluable assistance in making known the intracacies of the IBM equipment and aiding in the calculations.

The author is most appreciative of the cooperation afforded by Drs. Clair E. Terrill and George M. Sidwell of the United States Department of Agriculture, Animal Husbandry Research Division, Sheep and Fur Animal Research Branch, Beltsville, Maryland for making much of the data available and for their most helpful suggestions.

Appreciation is extended also to Mrs. W. H. Whiter and her staff for their cooperation in the use of the Computing Center at Virginia Polytechnic Institute and to the personnel at the University of Vermont Morgan Horse Farm for their efforts in caring for the flock and keeping complete and accurate records.

The author, fully realizing their contribution, thanks his wife and children for their patience and encouragement during the years of this study.

TABLE OF CONTENTS

	Page
INTRODUCTION	1
REVIEW OF LITERATURE	4
A. Effect of Environmental Factors on Weanling and Yearling Traits Under Selection	4
B. Heritabilities of Weanling and Yearling Traits	10
C. Phenotypic Correlations Among Weanling and Yearling Traits	14
D. Genetic Correlations Among Weanling and Yearling Traits	24
SOURCE AND DESCRIPTION OF THE DATA	32
A. The Experimental Flock	32
B. Management and Environment	37
1. The Middlebury Station	37
2. The Beltsville Station	39
C. The Observations	40
ANALYSIS OF THE DATA	43
A. Estimation of Constants for Environmental Effects	43
B. Estimation of Heritabilities	48
C. Correlations	52
1. Phenotypic Correlations	52
2. Genetic Correlations	53
RESULTS	55
A. Environmental Factors Affecting Weanling and Yearling Traits	55
B. Heritability Estimates of Weanling and Yearling Traits	73

	Page
C. Phenotypic Correlations Among Weanling and Yearling Traits	79
D. Genetic Correlations Among Weanling and Yearling Traits	82
E. Comparisons Between Columbia and Columbia X Southdale Sheep	87
DISCUSSION	88
SUMMARY	98
LITERATURE CITED	101
VITA	109
APPENDICES	111
A. System of Coding for Subjective Scores	111
B. Unadjusted and Adjusted Means	112
C. Phenotypic Correlations Among Weanling and Yearling Traits Calculated from Unadjusted and Adjusted Data	113

LIST OF TABLES

		Page
Table 1.	Means, Standard Deviations and Differences due to Environmental Factors for Yearling Traits	8
Table 2.	Estimates of Heritability for Body and Fleece Traits in Yearling Sheep	15
Table 3.	Estimates of Heritability for Body Traits in Weanling Lambs	18
Table 4.	Phenotypic Correlations of Traits at Weanling Age with those at Weanling and Yearling Ages for Range Rambouillet Rams	23
Table 5.	Some Phenotypic Correlations Among Yearling Traits of Range Rambouillet Rams	23
Table 6.	Phenotypic Correlations Among Fleece and Body Traits of Yearling New Zealand Romney Marsh Sheep	23
Table 7.	Genetic Correlations Among Traits of New Zealand Romney Marsh Sheep	28
Table 8.	Genetic Correlations Among Weanling Traits of Range Rambouillet Lambs	29
Table 9.	Genetic Correlations Among Weanling Traits of Navajo Crossbred Range Lambs	30
Table 10.	Rotational Mating Scheme Used in Amalgamating the Inheritance of the Original Columbia Rams and Southdale Ewes	35
Table 11.	The Numbers of Lambs Occurring in Each Subclass of the Environmental Effects - Weaning Weight Analysis	45
Table 12.	Estimates of Constants for Fixed Effects from Least Squares Analysis - Weaning Traits	58
Table 13.	Estimates of Constants for Fixed Effects from Least Squares Analysis - Yearling Traits	61
Table 14.	Least Squares Analysis of Variance Due to Year of Birth, Age of Dam, Type of Birth and Rearing, Sex, Breed, and Station	74

		Page
Table 15.	Analysis of Variance for Weaning Traits	76
Table 16.	Analysis of Variance for Yearling Body Traits	76
Table 17.	Analysis of Variance for Yearling Fleece Traits	77
Table 18.	Sire Components, k_o Values, Heritability Estimates and Standard Errors	77
Table 19.	Phenotypic Correlations Among Weanling and Yearling Traits	81
Table 20.	Genetic Variances and Covariances Used for Calculating Genetic Correlations	84
Table 21.	Genetic Correlations Among Weanling and Yearling Traits	86
Table 22.	Unadjusted Means of Weanling and Yearling Traits for Columbia and Columbia X Southdale Sheep	87

INTRODUCTION

The development of new breeds and types of sheep to provide better adaptation to both environmental conditions and to the changing needs of consumers of lamb and wool is a necessity to insure a continued supply of these important products. To help fulfull this requirement, the United States Department of Agriculture and the Vermont Agricultural Experiment Station have cooperated in the synthesis of a new strain from three existing breeds, the Corriedale, Southdown, and Columbia. The resulting Columbia X Southdale sheep provided the majority of data for this study with purebred Columbias contributing a share.

Improvement in the efficiency of new and existing breeds and strains will be facilitated by effective methods of selection and breeding plans. To obtain maximum positive results by means of selection and mating systems a breeder must have reasonably accurate knowledge of certain phenotypic and genetic parameters concerning the population with which he is working.

Perhaps the most important parameter estimates are those of the heritabilities of important economic traits. According to Lush (1935), heritability is important to the animal breeder because it represents the proportion of the genetic improvement in the selected parents which is transmitted to the offspring. In addition, estimates of heritability are necessary in developing efficient breeding systems and in formulating selection indexes.

Breeding animals are rarely selected on single traits because the total merit of the animal is determined by many traits, some genetically independent and others having a definite relationship with each other. It is therefore necessary to establish the genetic and phenotypic correlations among traits to determine to what degree selection in one trait will improve another if positively correlated, or impede progress if negatively associated.

The purpose of this investigation was to obtain information which will be a definite contribution to the store of knowledge needed to facilitate accurate and efficient selection in farm sheep generally. More specifically, it was intended to gain a thorough enough understanding of the phenotypic and genetic correlations and heritabilities, applicable to the flocks involved, to enable more rapid progress in the improvement of them.

The specific objectives of the investigation were to study the following economic traits of weanling lambs and yearling sheep: weaning weight, type, condition, and yearling body weight, type, condition, fleece weight, fleece character, and staple length. Measurements and scores on these traits were thus available to enable calculation of the following:

1. Correction factors for the known environmental influence of year of birth, age of dam, type of birth and rearing, sex, breed, and station.
2. Estimates of heritability of each trait.
3. Estimates of phenotypic correlations.
4. Estimates of genetic correlations.

Although a complete comparison between the Columbia and Columbia X Southdale was not the objective of this study, the differences between the two in the traits studied were of interest.

REVIEW OF LITERATURE

A. Effects of Environmental Factors on Weanling and Yearling Traits Under Selection

The phenotype of any individual is the visual expression of a combination of its genotypic and environmental components. It becomes necessary therefore, to partition the phenotypic (total) variance into its genotypic and environmental components for the purpose of learning the relative importance of each as a contributor to the phenotypic value. This knowledge is essential for proper evaluation of an animal's true breeding or genotypic value because differences caused by environmental effects may obscure genetic differences and lead to costly mistakes in the selection of individuals to become parents.

According to Falconer (1960) environmental variance, by definition, embraces all variation of non-genetic origin and has a great variety of causes. Nutritional and climatic factors are perhaps the most common of the external causes of environmental variation. Maternal effects, both prenatal and postnatal, particularly in mammals, form an important source of environmental variation.

Some of the environmental effects are fixed for a particular population and where they are known, allowances can be made in order to place animals on a more comparable basis for selection purposes, (Hazel and Terrill, 1946c). Factors which may be measured or recorded such as type of birth and rearing, sex, age of dam, year of birth, breed, location, and percent inbreeding, may be considered fixed effects and their individual contribution to the environmental component of variance determined. Adjustment for such environmental differences is necessary before the genetic parameters can be estimated with any degree of accuracy.

A very comprehensive study of the effects of environmental factors has been made by Hazel and Terrill (1945b, 1946c, 1946d), and Terrill et al. (1947, 1948a, 1948b). Other contributors include Price et al. (1953), Sidwell and Grandstaff, (1949), Sidwell et al. (1951a, 1951b), Grandstaff (1948), Phillips and Dawson (1937, 1940), Donald and McLean (1935), Bonsma (1939), Ercanbrack (1952), Ali (1952), Barnicoat et al. (1949), Hammond (1932), Verges (1939), Wallace (1948), McNaughton (1957), Hundley (1956), Rae (1950), Blackwell and Henderson (1955), and Givens et al. (1960).

Among the earlier work reported concerning environmental effects on lamb traits was that of Donald and McLean (1935) in New Zealand. Using data on English Leicester and Southdown lambs they found that ewe lambs were smaller than ram lambs and that lambs from 2-year old dams were smaller than those from older dams.

Sidwell and Grandstaff (1949) and Sidwell et al. (1951a, 1951b), studied the effects of age of dam, type of rearing and age at weaning on weaning weight, body type and condition of range Navajo and Navajo crossbred lambs. The effects of all three environmental factors were significant, as was the effect of the sex of the lamb, on staple length, weaning weight, and condition. The poorer type lambs, those with less condition and those with smaller body weight had either very young or old dams. Such lambs were reared as twins or were among the younger lambs at weaning. In general, the ewe lambs carried better condition, were lighter in weight and had longer staple fleeces.

Hazel and Terrill (1945b, 1946d) studied the effects of environmental factors on the weaning weight, staple length, body type, condition, face covering and neck folds of Rambouillet, Columbia, Corriedale and Targhee lambs. They found that ewe lambs were superior to ram lambs in all traits except weaning weight although differences in condition between the two sexes were not great. Single lambs and lambs from 2-year old ewes in all traits except face covering and neck folds. Important differences in favor of older lambs were evident in weaning weight, staple length, and body type. Although older lambs were in better condition at weaning age the difference was small. In all breeds but the Rambouillet, younger lambs showed greater neck fold development than did the older lambs.

The investigation of Hazel and Terrill (1946c) on range Rambouillet yearling ewes and the study of Terrill <u>et al</u>. (1947) on yearling Targhee and Columbia ewes are both of considerable interest for comparison with the data of this study. The factors studied were type of birth, year of birth, age of dam, age at shearing and percent inbreeding. The traits included body type, condition, body weight, grease fleece weight, staple length, face covering, and neck folds. The most important source of environmental variation was the difference among years. Other sources in descending order of importance were type of birth, age at shearing, percent inbreeding and age of the dam. Yearling ewes born as singles and those from mature dams were heavier, produced more wool and had longer staple than those born as twins and from 2-year old dams respectively. In Rambouillets, the traits which were most strongly influenced by environmental factors were body weight, staple length and grease fleece weight. These traits were all measured objectively as opposed to type, condition, face covering and neck folds which were evaluated by subjective scoring.

In his study of New Zealand Romney Marsh sheep, Rae (1950) reported environmental differences affecting several traits of yearling sheep. These differences for the same traits under consideration in this study are listed in table 1.

Terrill et al. (1948b) working with yearling Rambouillet rams, found that years, inbreeding, age at shearing and type of birth each had significant effects on grease fleece weight accounting for 24, 8, 2 and 1 percent, respectively, of the total variance. Thus, adjustments for inbreeding and possibly age at shearing should be made prior to selections for mating. Staple length was affected significantly in this study by years and age at shearing. The regression of staple length on age at shearing was 0.02 centimeter per day. Environmental factors had the greatest effect on body weight of any of the traits considered, accounting for 44 percent of the total variance. Again, years, and inbreeding effects were important sources of variation. Years and inbreeding were the only factors having important effects on type and condition.

The work of Price et al. (1953) using data from yearling Navajo

Table 1. Means, Standard Deviations and Differences Due to Environmental Factors for Yearling Traits (1948)[1]

	Staple length (centimeters)	Fleece quality (score)	Fleece weight (pounds)	Body type (score)	Body weight (pounds)
Mean	12.94	8.08	7.06	8.09	87.80
Standard deviation	1.72	1.49	0.89	1.04	6.28
Single minus twin raised singly	-.30 ± 0.40	-.26 ± 0.32	-.22 ± 0.24	-.33 ± 0.29	2.24 ± 1.79
Single minus twin	-.42 ± 0.25	-.14 ± 0.20	0.18 ± 0.15	-.04 ± 0.19	6.65 ± 1.13
3-year old dam minus 2-year old dam	-.04 ± 0.23	0.14 ± 0.19	0.16 ± 0.14	-.02 ± 0.17	1.38 ± 1.05
Regression on age	0.017 ± 0.014	-.007 ± 0.011	0.018 ± 0.009	0.023 ± 0.011	0.230 ± 0.060

1 Data from Rae (1950)

and Navajo crossbred ewes showed that when measurements were taken at the yearling age, ewes from mature dams had 0.18 cm. longer staple than those born of 2-year old ewes. Staple length was 0.52 and 0.56 cm. longer in ewes born as singles than in twins and twins raised as singles, respectively. The regression of staple length on age at sampling was 0.02 centimeter per day. Wool production was 0.20 pound greater from ewes born of mature dams than those of 2-year old dams. Fleeces from ewes born as singles were 0.9 pound heavier than fleeces from twins and 0.18 pound heavier than fleeces from twins raised as singles. Regression of fleece weight on age at shearing was 0.03 pound per day. The study revealed that ewes from mature dams were three pounds heavier at yearling age than were the ewes from 2-year old dams. Also, there was a difference of 6.5 pounds between single ewes and twin ewes at the yearling age and only 1.47 pounds between singles and twins raised as singles.

Sidwell and Grandstaff (1949) found a difference of 11 pounds between single and twin lambs at weaning, and three pounds between singles and twins raised singly. In range sheep Phillips et al. (1940) found single lambs to be heavier than twins for their entire first year but, with farm flocks, Phillips and Dawson (1940) concluded that differences caused by type of birth tended to disappear by yearling age. The regression of body weight on age was 0.12 pound per day in the Sidwell-Grandstaff study. These workers also found that age of the dam did not effect scores for body type, that single ewes had better type than twins or twins raised singly. Differences between breeding groups accounted for most of the variation. This was true also for condition, although differences between years were important. Single ewes scored higher for condition than did twins or twins raised as singles at yearling age. The regression of type and condition scores on age were found to be too small to be of practical importance.

It is evident from the literature that a large part of the variation in several traits of lambs and yearlings is caused by differences in sex, type of birth and rearing, year of birth or year of record, the age of the dam and other factors. The breeder must not, however, lose sight of the fact that these estimates of environmental effects are applicable to the particular population to which selection is to be applied. In addition, it must be realized that there are certain unmeasurable or uncontrollable effects which contribute some variation and the experimenter does not have a final, complete and exact knowledge of all factors affecting a particular trait. According to Ercanbrack (1952) such factors as poisoning from noxious plants, certain diseases and internal or external parasitic infestations may impair normal physiological processes. Occurrences of this nature could severely effect performance and if overlooked might tend to bias the evaluation of an animal's genotype and impede genetic progress because of the discarding of genetically superior individual when selecting for the breeding flock or herd.

B. Heritabilities of Weanling and Yearling Traits

The most important function of the heritability in the genetic study of metric characters is its predictive role, expressing the reliability of the phenotypic value as a guide to the breeding value, (Falconer 1960).

Heritability is defined by Lush (1949) as the fraction of the observed or phenotypic variance which is caused by additively genetic differences between individuals. Lush (1948) also describes heritability in the narrow sense in a more precise manner as:

$$\frac{\sigma_G^2}{\sigma_G^2 + \sigma_D^2 + \sigma_I^2 + \sigma_E^2 + \sigma_{EH}^2}$$

where:

σ_G^2 is the variance resulting from the average effect of a gene substitution over all genotypes in a particular population.

σ_D^2 is the variance caused by non-additive effects of allelic genes; i.e., the dominance deviations.

σ_I^2 is the variance caused by interactions between genes which are not allelic; i.e., the epistatic variance.

σ_E^2 is the variance caused by the environmental conditions to which the animal is exposed.

σ_{EH}^2 represents the variance caused by the joint effects of environment and heredity.

Estimates of heritability are based on resemblances among related individuals. Fisher (1918) and Wright (1921) have shown that under random mating the genetic relationship between full-sibs is one-half the additive plus one-fourth the dominance variance and between half-sibs one-fourth the additive genetic variance. As pointed out by Lush (1948) estimates based on relationships less than half-sibs are of limited value as the sampling error of the estimate is likely to be high.

Falconer (1960) adequately compared the merits of different types of relatives for estimating heritability. He showed that the choice of method employed in making the estimate was dependent upon circumstances. Usually, the half-sib correlation and the regression of offspring on sire are the most reliable from the point of view of minimizing the environmental component of variance. The regression of offspring on dam may give too high an estimate because of maternal effects as it would with body size in farm animals. From a practical standpoint much depends on the type of relatives from which the data are drawn. Lush (1948) has discussed the limitations and usefulness of the several methods of estimating heritability. Falconer (1960) sets forth the principles and procedures used in developing heritability estimates by the different known methods. He also discussed the achievement and importance of a high degree of statistical precision in making these estimates.

According to Sidwell (1954) the two most commonly used methods for estimating heritabilities of sheep traits have been the methods of half-sib correlation and intra-sire regression of offspring on dam.

The inheritance of different traits in sheep was reviewed in a comprehensive manner by Serra (1948). Estimates of heritabilities of several body and fleece traits of yearling or older sheep were made by Terrill and Hazel (1943), Rasmussen (1942), McMahon (1943), Phillips et al. (1945), Goot (1945), Jones et al. (1946), Rae (1948, 1950), Cockerham (1949), Morley (1950, 1955), Kyle and Terrill (1953), Blackwell and Henderson (1955) and Felts et al. (1958). Table 2 presents a compilation of heritability estimates for body and fleece traits in yearling sheep. The estimates in the table represent the same traits investigated in this study and are of especial interest to the author. However, other traits have been studied and the results may be found in the literature. In general, heritabilities of yearling grease fleece weight and staple length have been reported as being relatively high, whereas values for yearling body type and yearling fleece character have been moderately low. Estimates for yearling body weight have been variable, ranging from 0.09 reported by Morley (1955) to 0.40 found by Terrill and Hazel (1943). Very few estimates of the heritability of yearling condition are evident in the literature. The work of Kyle and Terrill (1953) yielded values of 0.46 and 0.39 respectively for this trait in Targhee and Columbia sheep. More studies have considered staple length and grease fleece weight than the other characters mentioned above, principally because these traits are of prime economic importance and can be measured rather simply.

Heritability estimates of lamb (weanling) traits are less numerous. Nevertheless, several investigators have contributed in this area. They are: Nelson and Venkalatachalam (1949), Hazel and Terrill (1945a, 1946a, 1946b), Terrill and Hazel (1946), Ercanbrack (1952), Karam et al. (1953), Sidwell (1954), Blackwell and Henderson (1955), Felts et al. (1957), Warwick and Cartwright (1957), Givens et al. (1960) and Bailey et al. (1961). A few other workers have reported estimates for traits other than those considered in this study and are not listed here. Table 3 shows evidence of rather large differences in heritabilities of weaning weight, depending upon the breed studied. Since the different breeds are actually different populations the wide variation in weaning weight values indicate that it is important to confine the application of heritability estimates to the population from which they were derived.

Weanling type and condition as evaluated by scoring have yielded low heritabilities in the studies reported to date. Sidwell (1954) obtained an estimate of heritability of 0.04 for weanling type using data from Navajo crossbred range lambs while Ercanbrack (1952), working with lambs of Rambouillet, Columbia, and Targhee breeding found the heritability of this trait to be 0.19. Other estimates by Hazel and Terrill (1946a, 1946b) were 0.13 and 0.07 respectively for Rambouillet lambs and those of Columbia, Targhee and Corriedale breeding. Heritabilities for weanling condition have ranged from 0.04 found by Hazel and Terrill (1946a) to 0.25 obtained by Ercanbrack (1952).

The statement that, "an accurate estimate of heritability is the most important single genetic parameter needed to make effective breeding plans for the improvement of economic characters in farm livestock" (Kincaid and Carter 1958), serves to point out the need of emphasizing the role of heritability estimates in a sheep breeding improvement program designed to be of a permanent and cumulative nature.

C. Phenotypic Correlations Among Weanling and Yearling Traits

The importance of possessing reasonably accurate estimates of correlation coefficients among traits under selection is great if maximum

Table 2. Estimates of Heritability for Body Fleece Traits in Yearling Sheep

Traits	Heritability estimate	Breed	Remarks	Reference
Body weight	0.40	Rambouillet	1622 pairs, parent offspring	Terrill & Hazel (1943)
	0.36	Merino	Parent-offspring regression	Morley (1955)
	0.09*	Merino	Half-sib correlation	Morley (1955)
Type	0.15	Romney Marsh	Extensive data	McMahon (1943)
	0.12	Rambouillet	1622 pairs, parent offspring	Terrill & Hazel (1943)
	0.12	Romney Marsh	200 pairs, parent offspring	Rae (1948)
	0.14 ± 0.07	Romney Marsh	Regression-daughter on dam 640 d.f.	Rae (1950)
	0.17	Romney Marsh	Paternal half-sib correlations	Rae (1950)
Condition	0.46	Targhee	For ewes only, 17 sire groups	Kyle & Terrill (1953)
	0.39	Columbia	For ewes only, 15 sire groups	Kyle & Terrill (1953)
Grease fleece weight	0.40	Rambouillet	70 pairs, parent offspring	Rasmussen (1942)
	0.14	Romney	213 pairs, parent offspring	Rasmussen (1942)
	0.24	Corriedale	173 pairs, parent offspring	Rasmussen (1942)
	0.28	Rambouillet	1622 pairs, parent offspring	Terrill & Hazel (1943)

Table 2. Continued

Trait	Heritability estimate	Breed	Remarks	Reference
Grease fleece weight	0.10 to 0.15	Romney Marsh	200 pairs, parent offspring	Rae (1948)
	0.32	Romney Marsh	Paternal half-sibs correlations	Rae (1950)
	0.39	Australian Merino	529 d.f., parent offspring	Morley (1950)
	0.43	Avg. of three breeds & crosses	Dam offspring regression	Ali (1952)
	0.65 ± 0.48	Rambouillet	For ewes only, 6 sire groups	Kyle & Terrill (1953)
	0.43 ± 0.21	Columbia	For ewes only, 15 sire groups	Kyle & Terrill (1953)
	0.40 ± 0.06	Australian Merino	Dam offspring regression	Morley (1955)
	0.44*	Australian Merino	Half sib correlation	Morley (1955)
	0.42 ± 0.18	Dorset, Hampshire, Shropshire and Corriedale	538 offspring, dam pairs	Blackwell & Henderson (1955)
	0.39	Mixed breeds	Data from 32 flocks	Felts *et al.* (1957)

Table 2. Continued

Trait	Heritability estimate	Breed	Remarks	Reference
Fleece character	0.14	Romney Marsh	Extensive Data	McMahon (1943)
	0.14	Romney Marsh	200 pairs, parent offspring	Rae (1948)
	0.22 ± 0.07	Romney Marsh	Regression-daughter on dam 640 d.f.	Rae (1950)
Staple length	0.36	Rambouillet	1622 pairs, parent offspring	Terrill & Hazel (1943)
	0.21	Romney Marsh	200 pairs, parent offspring	Rae (1948)
	0.22	Merino	107 d.f., parent offspring	Morley (1950)
	0.35 ± 0.07	Romney Marsh	Dam-daughter regression	Rae (1950)
	0.86 ± 0.24	Targhee	For ewes only, 17 sire groups	Kyle & Terrill (1953)
	0.56 ± 0.07	Australian Merino	Dam offspring regression	Morley (1955)
	0.52*	Australian Merino	Half-sib correlation	Morley (1955)

* These estimates are subject to bias caused by selection of sires.

Table 3. **Estimates of Heritability for Body Traits in Weanling Lambs**

Trait	Heritablity estimate	Breed	Remarks	Reference
Weaning weight	0.30 ± 0.04	Rambouillet	Weighted avg. of 2 methods 2183 lambs, 892 dam offspring pairs	Hazel & Terrill (1945a)
	0.17 ± 0.05	Columbia, Corriedale, Targhee	1711 lambs, 798 dam offspring pairs, avg. of 6 estimates	Hazel & Terrill (1946b)
	0.29 ± 0.05	Five breeds	348 dam offspring pairs	Nelson & Venkalatachalam(1949)
	0.42 ± 0.21	Five breeds	Paternal half-sib method	Nelson & Venkalatachalam(1949)
	0.33 ± 0.12	Five breeds	Weighted avg. of 2 methods	Nelson & Venkalatachalam(1949)
	0.33 ± 0.09	Rambouillet, Columbia & Targhee breeding	Regression, offspring on dam	Ercanbrack (1952)
	0.34	Shropshire	33 d.f. for paternal half-sibs	Karam _et_ _al._ (1953)
	0.21 ± 0.06	Navajo crossbred range lambs	Intra-sire regression of offspring on dam. 1078 dam offspring pairs	Sidwell (1954)
	0.07 ± 0.19	Dorset, Hampshire Shropshire & Corriedale	1295 lambs, 276 dam offspring pairs	Blackwell & Henderson (1955)
	0.15	Mixed breeds		Felts _et_ _al._ (1957)
	0.56	Rambouillet, Suffolk, Dorset, Mouflon & Romney	Intra-sire correlation, 1281 lambs	Warwick & Cartwright (1957)
	0.07 ± 0.02	Predominantly grade Hampshire & Rambouillet	Paternal half-sib comparisons	Givens _et_ _al._ (1960)
	0.43	Mixed breeds	Regression of offspring on dam, 1855 ewe lambs	Bailey _et_ _al._ (1961)

Table 3. Continued

Trait	Heritability estimate	Breed	Remarks	Reference
Type	0.13 ± 0.04	Rambouillet	Weighted avg. of 8 estimates using half-sib & intra-sire regression methods	Hazel & Terrill (1946a)
	0.07 ± 0.04	Columbia, Targhee & Corriedale breeding	Weighted avg. of both half-sibs correlation and dam offspring regression. 1711 lambs, 798 pairs	Hazel & Terrill (1946b)
	0.19 ± 0.08	Rambouillet, Columbia & Targhee breeding	Regression, offspring on dam	Ercanbrack (1952)
	0.04 ± 0.05	Navajo crossbred range lambs	Intra-sire regression of offspring on dam. 1078 dam offspring pairs	Sidwell (1954)
Condition	0.04 ± 0.03	Rambouillet	Weighted avg. of 8 estimates using half-sibs and intra-sire regression methods	Hazel & Terrill (1946a)
	0.21 ± 0.05	Columbia, Targhee & Corriedale breeding	Weighted avg. of 6 estimates 1711 lambs, 798 dam offspring pairs	Hazel & Terrill (1946b)
	0.25 ± 0.09	Rambouillet, Columbia & Targhee breeding	Regression, offspring on dam	Ercanbrack (1952)
	0.11 ± 0.05	Navajo crossbred range lambs	Intra-sire regression of offspring on dam. 1078 dam offspring pairs	Sidwell (1954)

efficiency is to be attained. This is true because it is seldom that only one trait is selected for improvement at a given time. In selecting farm sheep it is necessary to consider several traits of economic importance. It thus becomes essential to know the relationships among them in order to estimate the effects that selection for these various traits will have upon each other. Armed with this information, the animal breeder is able to adjust his selection emphasis advantageously.

A knowledge of the phenotypic correlations among productive traits is essential for the construction of selection indexes designed to maximize the rate of genetic improvement (Hazel 1943). In addition, it is possible, and sometimes desirable to use an easily recognized and measurable trait or combinations thereof, to predict the magnitude of another trait which may be more difficult and more expensive to measure (Rae 1950).

According to Terrill et al. (1945), Pohle and Keller (1943) the use of staple length and grease fleece weight is helpful in predicting clean fleece weight. The work of Sidwell (1954) showed that lambs which were heaviest at weaning were also scored the best for body type and condition. If enough accurate estimates are made to definitely establish high correlations between such traits, expensive scoring procedures might well be eliminated.

Considerable work has been done concerning phenotypic correlations among traits in sheep. The majority however, has dealt with sheep of the range breeds rather than the farm breeds. Papers published by Hill (1921), Spencer et al. (1928), Pohle and Keller (1943), Jones et al. (1944), and Terrill et al. (1945) have shown phenotypic correlations among various fleece and body traits of several range breeds. Other contributors in this field include Pohle (1942), Jones et al. (1936), Pohle and Hazel (1944), Pohle and Schott (1943), Hardy (1943), Blunn and Grandstaff (1945), Pohle et al. (1945), Grandstaff and Wolf (1947), Terrill et al. (1950), Morley (1950), Rae (1950), Ercanbrack (1952), and Sidwell (1954).

The results of studies of phenotypic relationships of traits at weanling age with those at weanling and yearling age for range Rambouillet rams are given in table 4, (Terrill et al. 1950). The traits listed here are all included in this investigation of Columbia and Columbia X Southdale sheep. Table 5, Terrill et al. (1950), summarizes some phenotypic correlations among yearling traits of range Rambouillet rams. The present investigation also includes all of the relationships shown in this table.

In the interpretation of these tables it should be pointed out that merit in the trait increases as score values decrease in the trait evaluated by scoring. For this reason, in table 4, correlation of -.59 between weanling body weight and weanling body type score in reality means that heavier lambs have the best body type.

Table 6, Rae (1950), presents some phenotypic correlations among fleece and body traits of yearling New Zealand Romney Marsh sheep.

Of the correlations studied, perhaps the most consistent under a variety of conditions and reported by a number of different workers, is that of greasy fleece weight with staple length. The following have been published: 0.56 Hill (1921), -.01 Spencer et al. (1928), 0.38, 0.43, 0.22, 0.42, for four different breeds, Pohle and Keller (1943), 0.35 Jones et al.

(1944), 0.22 Morley (1950), and 0.45 Rae (1950). With the exception of the -.01 value of Spencer et al. (1928) there is considerable uniformity. Other traits that have shown a high degree of relationship with each other are weaning weight, weaning type and weaning condition, (Terrill et al. 1950, Hrcanbrack 1952 and Sidwell 1954).

Most correlations between body type and fleece characters were found to be low. For example, Sidwell (1954) reported a zero correlation between body type and staple length in Navajo crossbred range lambs. He also reported correlations of 0.08 and -.11 between body type and percent medullated fiber and fiber diameter respectively. Relatively low values were also reported by Sidwell for correlations between body condition and staple length, percent medullated fiber and fiber diameter. The values were 0.05, 0.10, and -.20 respectively. Relationships between body weight and fleece weight have been reported by several workers as being high. Terrill et al. (1950) found values of 0.30 and 0.59 respectively for the correlations between grease fleece weight and yearling body weight and grease fleece weight and weaning weight. Pohle and Keller (1943) found that body weight had a greater influence on grease fleece weight than on other fleece characters. Correlations between body weight and grease fleece weight were 0.52, 0.41, 0.30, and 0.48 for the Rambouillet, Targhee, Columbia, and Corriedale breeds respectively.

Very few correlations have been reported between fleece character and other traits. Spencer et al. (1928) found values of 0.003, 0.308 and -.005 for the relationship between fleece character and grease fleece

Table 4. Phenotypic Correlations of Traits at Weaning Age with Those at Weanling and Yearling Ages for Range Rambouillet Rams[1]

Trait	Age	Weanling Traits		
		Body weight	Body type	Body condition
Grease fleece wt.	Yearling	0.59*	-.38*	-.26*
Staple length	Yearling	0.16*	-.31*	-.14*
Body type	Weanling	-.59*	----	0.52*
Body type	Yearling	-.29*	0.26*	0.20*
Condition	Weanling	-.51*	0.52*	----
Condition	Yearling	-.26*	0.27*	0.20*

1 Terrill, Kyle and Hazel (1950)
* Significant ($P < .01$)

Table 5. Some Phenotypic Correlations Among Yearling Traits of Range Rambouillet Rams[1]

Trait	Staple length	Body weight	Type	Condition
Grease fleece wt.	0.30*	0.54*	-.15*	-.16*
Staple length		0.07	-.07	-.06
Body weight			-.49*	-.42*
Type				0.71*

1 Terrill, Kyle and Hazel (1950)
* Significant ($P < .01$)

Table 6. Phenotypic Correlations Among Fleece and Body Traits of Yearling New Zealand Romney Marsh Sheep[1]

Trait	Fleece quality	Fleece weight	Body type
Staple length	0.20*	0.45*	0.16*
Fleece quality		0.15*	0.12*
Fleece weight			0.17*

1 Data from Rae (1950)
* Significant ($P < .01$)

weight, length of staple and mutton type respectively. Rae (1950) studied the relationship between fleece quality (comparable to fleece character) and grease fleece weight, staple length and spinning count or fineness. He found the correlations to be 0.15, 0.20, and 0.06 respectively.

No previous correlations involving Columbia X Southdale sheep are found in the literature since they are still an experimental strain under investigation at the Vermont Agricultural Experiment Station's Morgan Horse Farm, Middlebury, Vermont and the United States Department of Agriculture's Research Center, Beltsville, Maryland.

D. Genetic Correlations Among Weanling and Yearling Traits

Genetic correlations occur when a gene or genes affect two or more characters simultaneously, a type of gene action known as pleiotropy. A genetic correlation is sometimes defined as a measure of the relationship between the additive deviations in two characters caused by the same gene or genes.

Selection for either of two traits that are positively correlated genetically will lead to improvement of both simultaneously. Conversely, selection for a trait that is negatively correlated with another will cause some degree of retrogression in the other trait. A number of estimates of genetic correlations among important economic traits in sheep have been published, although not nearly so many as phenotypic relationships.

Morley (1955) working with Australian Merinos, found negative genetic correlations of a magnitude to limit genetic progress in clean-fleece weight and staple length when selection was based on crimps per inch of fiber. Rae (1950) reported similar negative genetic correlations between spinning count (a measure of fineness as is crimps per inch) and staple length and fleece weight in Romney Marsh sheep in New Zealand. The values found were -.73 ± 0.16 and -.47 ± 0.19 respectively. Karam et al. (1953) observed negative genetic correlations as follows: between body weight and staple length -.17, body weight and face covering -.57, and staple length and face covering -.96. Correlations between the same characters in weanling Rambouillet lambs at the Western Sheep Breeding Laboratory (1946) were -.26, -.13, and 0.08 respectively. Among other reports is the work of Ercanbrack (1952) who observed that staple length and weaning weight were negatively correlated. His report showed the correlation between these two traits to be -.13, -.18, and -.14 for Rambouillet, Columbia, and Targhee lambs respectively. The exceptionally high standard errors however, casts some doubt on the accuracy of these values. The same study revealed a negative correlation between weaning weight and freedom from folds or wrinkles.

According to Rice et al. (1957) most of the negative relationships reported are not intense enough to prevent progress by selection. They will, however, lower the rate of improvement in comparison to what could be accomplished if selection was for one trait at a time. Rae (1950) states that the heritability estimate for a given trait may be used to predict genetic gains from selecting for this trait. The qualifications attached to this statement are that in order to obtain a reasonably accurate prediction from a heritability estimate, selection must be for a single trait or this trait must be uncorrelated genetically with any other traits which might affect the overall merit of the animal. It is clear that the actual genetic gain may be less than the expected genetic gain, as calculated from a knowledge of the heritability of the trait, if negative correlations exist.

A number of positive genetic correlations among lamb traits have been reported. The Western Sheep Breeding Laboratory (1946) showed a positive genetic relationship between weaning weight and weaning body type, weaning condition and neck folds in Rambouillet weanling lambs. A high correlation between weaning type and weaning condition was also reported in this study. Similar values were found for the same traits, except for neck folds, when data from Rambouillet, Columbia, and Targhee lambs were analyzed at the same location (1946). Sidwell (1954) found positive although smaller genetic correlations between weaning weight, weaning type, and weaning condition in Navajo crossbred range lambs.

Working with New Zealand Romney Marsh sheep, Rae (1950) reported positive genetic correlations between staple length and fleece weight and between staple length and hairiness. The work of Ercanbrack (1952) showed high positive correlations between weaning weight, weaning body type, and weaning condition. In addition, he found a high positive relationship between weaning body type and weaning condition.

Tables 7, 8, and 9 show many of the genetic relationships among the traits mentioned as well as some additional ones.

Comparisons of genetic and phenotypic correlations between characters are of considerable interest and importance. Morley (1955) found that the phenotypic and genetic correlations between clean fleece weight and body weight were on the order of 0.4 and zero respectively. If these relationships are correct, it indicates that the phenotypic correlation is caused by environmental factors which stimulate both increased fleece production and body weight. Selecting for clean fleece weight under the above conditions would, therefore, bring about no genetic improvement in body weight as might be expected from the relatively high phenotypic correlation. The knowledge that genetic antagonisms exist between some characters and that between others, there is little or no genetic relationship, emphasizes the necessity for a clear understanding of the relative importance of the various traits in order to avoid selection based on those that are of minor value. In addition, these facts imply that accurate measurements are mandatory if exceptional individuals with above average genotypes in several characters are to be consistently selected.

The literature clearly shows the importance of possessing good estimates of both genetic and phenotypic correlations in developing an efficient selection procedure. However, as pointed out by Hale (1961), estimates of genetic correlations and heritability coefficients as well are subject to large sampling errors and refer strictly to the population from which they were derived and to the environmental conditions under which it existed. These limitations should be constantly in mind in the interpretation and practical application of genetic parameters. Also to be considered is the consequence of simultaneous selection for

Table 7. Genetic Correlations Among Traits of New Zealand Romney Marsh Sheep[1]

Trait	Staple length	Fleece quality	Fleece weight	Hairiness	Body type
Count	$-.73 \pm 0.16$	0.21 ± 0.17	$-.47 \pm 0.19$	$-.30 \pm 0.11$	0.08 ± 0.22
Staple length		0.13 ± 0.19	0.25 ± 0.19	0.41 ± 0.12	0.21 ± 0.31
Fleece quality			0.08 ± 0.22	$-.12 \pm 0.12$	0.48 ± 0.32
Fleece weight				0.28 ± 0.16	0.06 ± 0.30
Hairiness					$-.30 \pm 0.25$

1 Data from Rae (1950)
Note: High score in body type indicates superior merit in this study

Table 8. Genetic Correlations Among Weanling Traits of Range Rambouillet Lambs[1]

Trait	Staple length	Weaning weight	Score for Body type	Score for Condition	Score for Neck folds
Face cover	0.08	-.13	-.03	0.06	0.13
Staple length		-.26	-.37	0.01	-.27
Weaning weight			-.38	-.14	-.14
Body type				0.61	0.48
Condition					0.01

1 Data from the Western Sheep Breeding Laboratory (1946)

Table 9. Genetic Correlations Among Weanling Traits of Navajo Crossbred Range Lambs[1]

Trait	Body type	Condition	Staple length	Percent medullation	Fiber diameter
Weaning weight	-.26	-.09	-.10	0.13	1.19
Body type		-2.17	0.68	0.22	0.24
Condition			-2.29	0.24	0.26
Staple length				-.15	0.36
Percent medullation					0.45

1 Data from Sidwell (1954)

several characters. According to Falconer (1960) after selection has been applied for some time, genetic correlations are expected to change. In fact, if selection has been applied to two characters simultaneously the genetic correlation will likely become negative eventually.

The fact that genetic correlations and a selection limit are closely associated is amply demonstrated by Dickerson (1955). Working with a commercial poultry flock he showed that even though selection for economic value had been applied for many years, recent progress in component characters, viz. egg production and egg weight, was low even though the heritability of each character was relatively high. The high negative genetic correlation of -.59 between the two characters accounted for this failure of selection response.

In dealing with selection in farm sheep with their attendant variety of economic characters, several of which must be considered simultaneously, it is evident that the correlations, both phenotypic and genetic are important items of consideration.

SOURCE AND DESCRIPTION OF THE DATA

A. The Experimental Flock

The data used in this study were obtained from flocks of Columbia X Southdale sheep located at the University of Vermont Morgan Horse Farm, Middlebury, Vermont and the United States Department of Agriculture's Research Center at Beltsville, Maryland. Included also are data from the Columbia flock at the University of Vermont Morgan Horse Farm. Observations were recorded from these flocks during a fifteen year span, from 1945 through 1959. The present study includes the analysis of these data for the entire period.

The Columbia X Southdale flock was established by the United States Department of Agriculture. According to Spencer (1955), Corriedale ewes were mated to Southdown rams in the fall of 1929 for the purpose of studying the production of market lambs created by this cross. The work was initiated at the United States Sheep Experiment Station, Dubois, Idaho. The resulting Southdown X Corriedale lambs grew and fattened so well on the high lush range forage west of Yellowstone Park and were so much in demand by packers on the Chicago market that the department sheep specialists thought such sheep should be useful for lamb and wool production in New England. Accordingly, work was initiated in the fall of 1930 to determine the practicability of Southdown X Corriedale sheep under conditions existing at the Morgan Horse Farm (then owned by the United States Government). Southdown rams were mated with Corriedale ewes in 1930 and in 1931. In 1932 some choice Corriedale rams were mated with Southdown ewes and their offspring were found to be satisfactory. The majority of the matings through 1939 involved the use of Southdown rams and Corriedale ewes. The offspring from these matings were the foundation parents for the strain of sheep that was named the "Southdale". The cross bred rams and ewes and their descendants were interbred without back crossing to either the Southdown or the Corriedale.

The original intent of the program was to combine the excellent mutton characteristics of the Southdown with the good wool characteristics of the Corriedale to produce a new strain of which the lambs would fatten readily on the dam's milk and pasture. The Southdales evolved as small to medium sized sheep that produced lambs finishing at handy weights of 70 to 80 pounds. Mature rams in good breeding condition weighed 140 to 175 pounds; the ewes averaged about 115 pounds in the fall, just after weaning their lambs, and the weaned lambs in feeder condition weighed about 50 to 60 pounds. The annual fleece weights of mature ewes averaged about 7 pounds grading chiefly 56's, 58's, and 60's. These fleeces yielded about 50 to 55 percent clean scoured wool. The Southdales were hornless and averaged a very light brown or mouse color on their face and legs, but they varied from the white of the Corriedale to the mouse color of the Southdown.

By 1944 it appeared that the Southdales averaged too small in size and were lacking in lamb and wool production per ewe to the extent of being unsatisfactory to most sheep producers. It was decided at this time to introduce the Columbia into the strain. The Columbia was chosen for its large size, rapid rate of growth and heavy fleece of good quality.

The first matings of Columbia rams and Southdale ewes were made in the fall of 1944 at Middlebury, Vermont. Four Columbia rams, as unrelated as possible, were selected from the Bureau of Animal Industry flocks at the United States Sheep Experiment Station (now the United States Department of Agriculture Western Sheep Breeding Laboratory), Dubois, Idaho. These rams were mated to 80 selected Southdale ewes divided into four breeding flocks. The Columbia X Southdale offspring from these matings and their descendants have been bred inter se, without back crossing to either parent stock, until the present time. The breeding has been conducted in accordance with a carefully designed pattern for an orderly amalgamation of the inheritance of all the Southdale ewes and Columbia rams used in the original cross. This mating scheme is shown in table 10.

The breeding system may be seen clearly by following the matings in lot 1, through four generations: al ewes (F_1) produced by mating Columbia ram a to Southdale ewes in lot 1 were mated to an F_1 ram from lot 4. The resulting F_2 ewes were mated to an F_2 ram from lot 3. The F_3 ewes from this mating were bred to an F_3 ram from lot 2. Because a similar procedure was followed in each lot the fourth generation in all lots was composed of sheep possessing inheritance representative of all the original combinations in the four groups.

On July 1, 1951 the United States Government turned over to the University of Vermont College of Agriculture the entire experimental

Table 10. Rotational Mating Scheme Used in Amalgamating the Inheritance of the Original Columbia Rams and Southdale Ewes[1]

Lot number	1	2	3	4
Columbia rams	a	b	c	d
Southdale ewes	1	2	3	4
F_1	a1	b2	c3	d4
Lines indicate shift of rams				
F_2	d4 / a1	a1 / b2	b2 / c3	c3 / d4
F_3	b2 / c3 / d4 / a1	c3 / d4 / a1 / b2	d4 / a1 / b2 / c3	a1 / b2 / c3 / d4
Note combination of all inheritance in each lot F_4	c3 / d4 / a1 / b2 / b2 / c3 / d4 / a1	d4 / a1 / b2 / c3 / c3 / d4 / a1 / b2	a1 / b2 / c3 / d4 / d4 / a1 / b2 / c3	b2 / c3 / d4 / a1 / a1 / b2 / c3 / d4

1 U.S. Dept. Agr. Res. Adm., Rev. March 4, 1946 (ARA Form No. 1)

Note that equilibrium of all inheritance is maintained yet the path of each genetic combination is different in each lot.

Morgan Horse Farm at Middlebury, Vermont. In addition, approximately one-half of the experimental sheep flock was given to the University while the rest of the Columbia X Southdale sheep were transferred to the United States Department of Agriculture Research Center, Beltsville, Maryland. The experimental sheep breeding work has been continued at both stations with the work at Vermont being conducted by the author in cooperation with personnel of the Agricultural Research Service, United States Department of Agriculture and personnel at the University of Vermont Morgan Horse Farm.

By 1957 the original plan of rotational breeding was felt to have accomplished its purpose of thoroughly amalgamating the inheritance of the original parent stock with a minimum of inbreeding. A plan to change to a program of straight selection was proposed by Terrill (1957). Since that time selection of the Columbia X Southdale sheep at both stations has been based on lamb and wool production, including such specific traits as fertility, twinning, weaning weight, rate of growth, mutton conformation, condition, face covering, staple length, and fleece weight. It has been attempted to maintain fleece grade or fineness at 48's, 50's and 56's. Ewes have been assigned at random to each of the breeding groups with the exclusion of half-brother-sister and other close matings, and selection of the rams has been limited to within the established lines. The Columbia X Southdale strain today phenotypically resemble the Columbia breed to a large degree, being open faced with white hair on the face and legs. They are, however, shorter legged; more compact, lighter in weight and fatten more readily than the Columbia. The mature ewes shear about 10.5 pounds of wool, grading within the limits of the spinning counts mentioned above. A more detailed description is given by Balch (1956) and Chapin (1959).

The purebred Columbia sheep from which data were collected were transferred from the United States Sheep Experiment Station at Dubois, Idaho to the Morgan Horse Farm at Middlebury, Vermont in the fall of 1948. It was intended that they be used as a check flock to compare lamb and wool production with the Columbia X Southdale strain and to test their productive ability under North Atlantic farm conditions. An excellent description of the origin of the Columbia breed is given by Marshall (1949).

B. Management and Environment

The entire flock of Columbia X Southdale sheep was maintained at the Morgan Horse Farm, Middlebury, Vermont from 1945 to 1951. From 1951 to 1959 the Columbia X Southdale sheep contributing data to this study were reared both at Middlebury and the Agricultural Research Center, Beltsville, Maryland. The Columbias were maintained only at Middlebury (1948 to 1959).

The Middlebury Station - The Morgan Horse Farm consisting of 942 acres, is located in Addison County at the lower end of the Champlain Valley on the western perimeter of Vermont. The soil types predominating on the farm are known as Champlain clays with Vergennes Catena being the most prevalent of these. This is a moderately well drained soil and is excellent alfalfa land with a naturally high potash and sodium content. The topography is gently sloping to rolling in the pasture areas. The amount and distribution of rainfall throughout the year is normally very satisfactory for good pasture growth. Temperatures normally range from about 90° F. in the summer to winter lows of -25° to - 30° F.

At the Middlebury Station the ewes were bred each fall, commencing the first week of November, the rams remaining with the ewes approximately 54 days. A system of pen mating was employed. The rams were placed with the ewes during the night only, being separated during the day to feed and rest. Ewes were at least 18 months of age at first breeding and each ram was allotted approximately the same number of ewes of each age group. Numbers of ewes per ram varied over the years from as few as five to as many as 37 but within years the numbers per ram were kept as near equal as was consistent with the breeding scheme. Numbers of rams used in any one year varied from as few as five to as many as 10 at the Middlebury Station. The ewes were separated only during the breeding period and were handled as one flock for the remainder of the year. Such treatment ~~tends~~ to eliminate environmental correlations among members of the same sire progeny relative to other progenies.

Each lamb's weight was individually taken and recorded at birth. At this time each lamb was tagged with a flock number in the form of a self locking aluminum tag in the left ear. Ram lambs were not castrated due to the necessity of delaying selection until weaning age because of the nature of the breeding experiment. The lambs were weaned when they had reached the vicinity of 140 days of age, at which time weaning weights and other scores and observations were taken. An effort was made throughout the years to treat all ewes and lambs alike with respect to routine practices of management such as feeding, housing, and drenching.

The Beltsville Station - The Agricultural Research Center is located at Beltsville, Maryland in Prince George's County. The soil type predominating on the Research Center is in the main a heavy red clay. The topography could be described as gently rolling. The annual precipitation averages about 40 inches with about half of the moisture coming as snow during the winter months. The temperature normally ranges between 95° F. in the summer to a low of 10° F. in the winter. Temperatures outside this range would be fairly unusual. The summers are characterized by hot humid days, typical of most of the Southeastern United States. Because of the hot humid summer climate, internal parasites become one of the chief problems encountered in these Eastern farm flocks during June, July, and August.

From 1951 through 1957 the breeding season extended from about September 15 to November 1. The lambing dates then extended from February 15 to about April 1. In 1958 the breeding dates were advanced to September 1, and in 1959 the breeding began on August 15. By lambing a month early all lambs could be weaned before the onset of the hot humid summer months, when the parasite problem becomes acute. From 1951 through 1956 all ewes were hand mated. Since 1956 the ewes have been pen mated on pasture. The ewes were divided into three pens of about 30 ewes each. All matings were random except that half-sib, son-mother and other closely related matings were avoided. Each lamb is individually weighed and the birth weight recorded, also each lamb is ear tagged with a numbered, permanent type metal tag. No ram lambs are castrated since the breeding replacements are not selected until the lambs reach weanling age at about 140 days of age. At this age all lambs are again weighed, scored and staple length measured.

During the years with which this study is concerned the Columbia X Southdale ewes were run with Shropshire, Hampshire, Southdown, Merino and a few crossbred ewes. All sheep were treated alike as far as possible with respect to management practices.

C. The Observations

The first lambs on which scores and measurements were obtained for this study were born in 1945 at the Middlebury Station. Weanling measurements were taken on successive years up to and including 1959. A total of 2442 lambs from 1707 ewes provided the data for weaning weight. The number of records available for weaning type and condition scores was 2024, a figure somewhat lower than that for weaning weight because scoring for type and condition was not accomplished in every year at both stations.

The ewes and lambs were usually brought in from pasture and separated about 24 hours before the measurements and scores were taken. Weaning type and weaning condition were evaluated independently on the basis of scores by a committee of two or three persons. By averaging the committee scores the final evaluation thus became a more objective measure of the trait. In addition, it was possible to identify and correct gross errors that infrequently appeared on the score sheets. The scoring system used was developed by the United States Sheep Experiment Station (United States Department of Agricultural, Bureau of Animal

Industry). In this system scoring units range from 1 to 5 with the most desirable animals being scored 1 and the most inferior ones being scored 5. Each unit is further refined by the inclusion of a plus or minus rating. It thus becomes possible to have as many as 15 different scores under this system.

The evaluation of type is a subjective measurement and consists of comparing each individual animal to an ideal or standard of perfection combining all the characters which contribute to the animal's value and efficiency for the purpose specified. In this case the appraisal of type was based on an estimation of those factors which embody a desirable meat type sheep with evidence of good quantity and quality of wool. Condition refers to the amount and distribution of fat over the body. It is determined largely by handling the lamb along the back and over the ribs and loin. This was done independently by the committee members and recorded.

A total of six traits were evaluated on the yearling sheep. They were: body weight, body type, body condition, fleece weight, fleece character, and staple length. The observations on body type, condition and fleece character were taken at the Middlebury Station at about the same time that the weanling traits were measured. This was the latter part of August and did not necessarily coincide with the Beltsville Station with respect to calendar dates. This was so because of the geographical difference with a resulting difference in breeding and management schedules.

Yearling body weight was available on 1039 individuals and was recorded as the weight taken just after shearing. Since lambing occurred one to two months earlier than shearing, in the year previous, the sheep were approximately 13 to 14 months of age when yearling body weight were recorded. Individual fleece weights were also recorded on 1039 yearlings at this age.

A total of 947 yearlings were scored for type, condition and fleece character. The same procedures used for evaluating type and condition in the lambs were used here. Fleece character was scored accoring to the specification set forth in the United States Department of Agriculture, Range Sheep Breeding Investigations Score-Record Book (Bureau of Animal Industry). The character was scored at the sides of the fleeces on a basis of regularity and uniformity of crimp, luster or brightness, and evenness of distribution of wool oil or grease. The units of scoring were 1 to 5 as in type and condition scoring.

Staple length was measured before shearing on 666 yearlings and recorded to the nearest tenth of a centimeter. The measurement was taken midway of the lambs side between the longer wool on the breech and the shorter wool on the shoulder. The committee using short centimeter rules; measured the unstretched staple independently on each sheep. This measurement, perhaps more than any other, requires a great deal of care and concentration to achieve a consistent degree of accuracy due to the possible movement of the sheep, position and angle of the rule and the variation in the tapering of the tips of the wool fibers.

ANALYSIS OF THE DATA

A. Estimation of Constants for Environmental Effects

Many environmental factors can influence the performance of young sheep. Removal of these environmental effects from the data is essential in order to obtain an unbiased estimate of an animal's genotype. It was necessary, therefore, to obtain estimates of constants for the measurable environmental effects so that adjustment of the data might be made prior to the estimation of the genetic and phenotypic parameters. Year of birth, age of dam, type of birth and rearing, sex, breed, and station were considered fixed environmental effects.

The number of lambs occurring in the various classifications for the 15 years of the study are listed in table 11. The numbers shown in this table represents the records available for the study of weaning weight. Not all lambs whose weaning weights were recorded were scored for type and condition. Neither did all lambs remain in the flock until yearling age to become available for measurements at that time. Therefore, different numbers of records were available for analysis of weaning weight, weaning type and condition, yearling body type and condition and fleece character scores, and yearling staple length. This situation increased the complexity of the computations as will be shown.

Reference to table 11 shows a marked disproportion in the numbers of animals included in each subclass of the environmental factors. Therefore, the method of least squares analysis for multiple classification with disproportionate numbers was deemed appropriate and consequently employed. This method was described by Yates (1934), Hazel (1946) and Henderson (1948), and is based on the fitting of constants for each of the independent variables, which in this case are the measurable environmental factors.

The mathematical model assumed was:

$$Y_{ijklmn} = u + x_i + a_j + t_k + s_l + b_m + l_n + e_{ijklmn}$$

Assuming that the e_{ijklmn}'s had an expectation of zero, were uncorrelated, and had equal variance, σ^2, least squares analysis could logically be employed. In the model, Y_{ijklmn} is an observation on an individual lamb or yearling, u is the general mean of all lambs or yearlings.

x_i is an effect due to year of birth, ($i = 1, ...15$)

a_j is an effect due to the age of the dam, ($j = 1, ...8$)

t_k is an effect due to the type of birth and rearing, ($k = 1, ...3$)

s_l is an effect due to sex (ewe or ram), ($l = 1, 2$)

b_m is an effect due to breed, ($m = 1, 2$)

l_n is an effect due to location (station), ($n = 1, 2$)

e_{ijklmn} is an effect peculiar to an individual lamb

The x_i effect is common to all records taken in the $_i$th year and includes differences caused by the environmental conditions peculiar to each year. These may affect the traits of the animal either directly or indirectly by influencing nutrition and general health. Variations in annual rainfall, temperature, humidity and such man-influenced conditions as housing, management and changes in scoring methods may all

Table 11. The Numbers of Lambs Occurring in Each Subclass of the Environmental Effects - Weaning Weight Analysis

Year of birth	Age of Dam								Type of birth and rearing			Sex		Breed		Station		Year total
	2	3	4	5	6	7	8	9	Single	Twin-Single	Twin	Ram	Ewe	C.S.	Col.	M'bury	B'ville	
1945	9	15	14	23	5	0	2	1	44	1	24	34	35	69	0	69	0	69
1946	16	13	29	20	14	3	0	0	55	7	33	49	46	95	0	95	0	95
1947	15	15	5	25	10	7	2	0	44	4	42	46	44	90	0	90	0	90
1948	29	26	23	9	21	8	6	1	44	9	70	59	64	123	0	123	0	123
1949	34	30	33	16	10	20	17	11	57	24	90	74	97	128	43	171	0	171
1950	33	32	25	25	1	3	4	16	45	20	74	63	76	113	26	139	0	139
1951	48	23	26	16	14	0	0	0	45	14	68	57	70	117	10	53	74	127
1952	30	41	23	20	18	11	0	0	63	14	66	62	81	129	14	49	94	143
1953	45	35	46	19	15	13	7	0	76	15	89	94	86	151	29	92	88	180
1954	25	49	32	45	14	7	5	4	65	18	98	91	90	148	33	92	89	181
1955	56	45	46	14	38	6	4	1	83	21	106	105	105	174	36	129	81	210
1956	57	55	40	28	6	12	0	0	80	23	95	93	105	158	40	136	62	198
1957	55	61	46	28	24	5	7	1	85	29	113	112	115	190	37	156	71	227
1958	57	53	64	38	19	14	3	0	96	19	133	142	106	202	46	169	79	248
1959	60	61	45	37	26	11	1	0	89	9	143	130	111	195	46	173	68	241
																	Grand total	2442

contribute toward affecting the various traits. In addition, changes in the average annual genetic composition of the breeding flock may contribute to the year effect.

The a_j include any effect which the age of the dam may have on the trait in question. The dams in the present study ranged in age from two to nine years. It has been shown by other investigators, Bonsma (1939), Barnicoat et al. (1949), Sidwell (1954) and others, that significant differences in quantity of milk occur among ewes of the different ages that are included here.

The t_k include any effect caused by the type of birth and rearing. Differences exist in pre-natal as well as pre-weaning nourishment between single and twin born lambs. Also, lambs born twins but reared as single lambs are subject to differences. The single lambs, lacking competition for uterine space and the dams supply of milk from birth to weaning, enjoy a definite advantage.

The s_l include any effect caused by differences in the sex of the animal, whether a ram or a ewe. The b_m include any effect of differences between Columbia X Southdale and Columbia sheep and the l_n include any effect of differences because of the geographical location of the two experimental stations involved, Middlebury, Vermont and Beltsville, Maryland.

The e_{ijklmn} effect, peculiar to an individual lamb, includes the remainder of the sources of variation not already accounted for by the model. The number of sources of variation is presumably large and only the more important and easily measured ones are contained in the model as individual components.

Detailed explanation of the principles underlying the selection and application of the mathematical model concerning biological data, is given by Rae (1950) and Ercanbrack (1952).

After the appropriately coded observations were transferred from work sheets to International Business Machine punch cards, the IBM equipment was used in making the calculations. The IBM "Type 650" machine was used to simultaneously solve the normal equations and estimate the constants. The technique of matrix inversion was employed. In this procedure as described by McGilliard (1955) one variable from each classification is omitted in the original matrix, becoming the base from which the remaining variables of the respective classifications are expressed as deviations. In the present study the base variables were:

Classification	Base
Year of birth	1955
Age of Dam	3-year olds
Type of birth and rearing	Single lambs
Sex	Ewe lambs
Breed	Columbia X Southdale
Station	Middlebury, Vermont

The constants were then converted to correction factors and variation among the observations caused by the various environmental effects was eliminated by adjusting all observations to a common basis. The residual or error differences peculiar to each observation thus became the only remaining variation.

A total of five matrices were constructed in the process of obtaining least squares estimates. The relatively large number of traits being studied in addition to the fact that both weanling and yearling traits were measured over a 15-year period, resulted in a wide difference in numbers of records available for the different traits. Rather than discard the many weanling records in favor of simplifying the calculations, it was felt that the additional information justified the added labor involved in the computations.

B. Estimates of Heritabilities

Heritability in the narrow sense, as defined by Lush (1948), was shown in a previous section (page 11). It is considered as that fraction of the variation which is attributed to the additive or average effects of the genes in a particular population. By this definition variation attributable to non-linear gene effects associated with dominance, epistasis and hereditary and environmental interactions, is excluded from the fraction.

Heritability in the broad sense is defined by Lush also as the fraction of phenotypic variance in a trait which is caused by the differences among the genotypes of individuals in a particular population. Thus, it includes not only the additive effects of the genes but also variation due to epistasis, dominance and interaction between heredity and environment.

An estimate of heritability in the narrow sense is usually the more desirable procedure for predicting the results of a selection method because it is the additive genetic effects that contribute to the permanent gain from selection in a randomly mating population. However, as pointed out by Lush (1948), heritability estimates usually are somewhere between the narrow and broad definitions, depending on the method of calculation used. Such estimates always includes a little of the epistatic variance and sometimes a portion of the dominance variance. In addition, all, part or none of the non-linear joint effects may be included.

All methods of estimating heritability are based on resemblances among relatives of known relationship as compared to the resemblances among non-relatives. The advantages and limitation of the different methods are discussed by Lush (1948), Falconer (1960) and others.

Estimates of heritability in this study were obtained from paternal half-sib comparisons since the data conformed well to the specifications necessary for accurate estimates by this method. The accuracy of heritability estimates from half-sib data depends on the number of degrees of freedom for sires (and to a lesser degree on the number offspring per sire), on the absence of environmental correlations among the half-sibs relative to the non-sibs, and on the absence of selection among the sires. The method is considered theoretically valid if the sires are a random sample of some unselected population, (Carter and Kincaid 1959). The mating system described on page 35 indicates that the sires used were largely predetermined by the rotational nature of the breeding experiment. Therefore, the selection of sires used in the present study was limited to a particular line within a closed flock and thus should have caused little bias in the heritability estimates. The degrees of freedom were of considerable magnitude and most sires contributed sizeable numbers of offspring. Also, the half-sibs and non-sibs were treated as nearly alike as possible to minimize any possible environmental correlations between them.

The formula used was: $h^2g^2 = \dfrac{4\,\sigma_s^2}{\sigma^2 + \sigma_s^2}$ (Lush 1948)

where: σ_s^2 is the sire component of variance and σ^2 is the variance within sire progenies.

The estimates of σ^2 and σ_s^2 were obtained from analysis of variance of the adjusted data.

The theoretical relationship was shown by Fisher (1936) and Snedecor (1946) as:

Source of Variation	Degrees of Freedom	Expected Mean Squares
Among sire progenies	n-1	$\sigma^2 + k_o\,\sigma_s^2$
Within sire progenies	$\sum(k_i - 1)$	σ^2
Difference		$k_o\,\sigma_s^2$

where: σ^2 represents the variance among lambs by the same sire

σ_s^2 is the additional variance among lambs by different sires

n equals the number of sires

k_i is the number of offspring for the $_i$th sire

k_o is the average number of offspring per sire

When paternal half-sib comparisons are estimated from a randomly mating population with sire effects randomly distributed, σ^2 is expected to contain three-fourth of the additively genetic plus all the environmental variance and σ_s^2 is expected to include one-fourth of the genic variance. From these definitions it may be seen that $4\sigma_s^2$ is an estimate of the genic variance and $\sigma^2 + \sigma_s^2$ is an estimate of the phenotypic variance (additive genetic variance plus environmental and non-additive variance).

The difference between the two expected mean squares is k_o times the sire component of variance. The k_o values were calculated by use of the following formula:

$$k_o = \frac{1}{(n-1)} \left(\Sigma k_i - \frac{\Sigma k_i^2}{\Sigma k_i} \right) \quad \text{(Snedecor 1946)}$$

where:

n is the number of sires

k_i is the number of offspring for the $_i$th sire

k_o is the average number offspring per sire

According to Falconer (1960) it is of great importance to know the precision of any estimate of heritability. The precision of an estimate depends on its sampling variance, the lower the sampling variance the greater the precision, and the standard error is the square root of the sampling variance. Hazel and Terrill (1945a) have presented a method of calculating the standard error of an estimate of heritability from half-sib analysis. This method which was used in the present study, makes use of the following formula:

$$\sigma_{\hat{h}} = 4 \left[\frac{\sigma^2 \; (\sigma^2 + k_o \sigma_s^2)}{(\sigma^2 + \sigma_s^2)^2} - \sqrt{\tfrac{1}{2} (k_o - 1) k_o n} \right]$$

where: $\sigma_{\hat{h}}$ is the standard error of the heritability estimate

σ^2 is the component of variance due to lambs within sire groups

σ_s^2 is the sire component of variance

k_o is the average number of lambs per sire

n is the number of sires

thus, $\sigma_{\hat{h}}$ is four times the standard error of the half-sib correlation. It is assumed that the samples are from a non-inbred population.

C. Correlations

Phenotypic correlations - Phenotypic correlations measure the degree of association between two traits in the same individual. These correlations among the traits were obtained by calculating the product-moment coefficient of correlation. This was done for the nine traits studied using first the unadjusted data and secondly, the data after corrections for differences due to environmental factors had been made. The many sums, sums of squares and sums of products necessary in obtaining the 72 correlations were computed with the aid of the IBM machine. These quantities were used in the formula:

$$r_{xy} = \frac{\Sigma xy}{\sqrt{\Sigma x^2 \; \Sigma y^2}}$$

where: r_{xy} is the phenotypic correlation

Σx^2 is the sum of squares of one trait

Σy^2 is the sum of squares of the other trait

Σxy is the sum of products of x and y

Tests of the hypothesis that $r = 0$ were accomplished in the manner described by Snedecor (1946, p. 149) using the formula:

$$t = r \sqrt{(n-2)/(1-r^2)}, \qquad d.f. = n-2$$

<u>Genetic correlations</u> - Expressed algebraically, a genetic correlation is the ratio of the genetic covariance between the two characters and the product of their genetic standard deviations:

$$r_{G_iG_j} = \frac{\text{Cov. } G_iG_j}{\sigma G_i \; \sigma G_j}$$

where: σG_i and σG_j are the genic standard deviations for traits i and j (Hazel <u>et al</u>. 1943). Because correlations among different traits of the same individual usually contain an environmental component in addition to a genetic component, they do not necessarily provide accurate estimates of true genetic relationships among the traits unless the environmental component is removed. Hazel <u>et al</u>. (1943) suggested that estimates of genetic correlations could be obtained from paternal-half sib data by using the sire components of variance and covariance as estimates of genic variance and covariance. By this procedure the environmental component is circumvented leaving estimates of the genetic relationships which are far more accurate guides on which to base predictions of genetic progress.

The general statistical method described by Hazel (1943) and Hazel <u>et al</u>. (1943) for estimating genetic correlations was followed. The formula used was:

$$r_{G_{ij}} = \frac{\sigma s_{ij}}{\sqrt{\sigma^2_{s_i} \, \sigma^2_{s_j}}}$$

where: $\sigma_{s_{ij}}$ is the sire component of covariance and

$\sigma^2_{s_i}$ and

$\sigma^2_{s_j}$ are the sire components of variance for traits i and j.

The standard errors of the estimates of the genetic correlations were calculated according to the following formula:

$$\sigma(r_G) = \frac{1 - r_G^2}{\sqrt{2}} \sqrt{\frac{\sigma(h_x^2)\ \sigma(h_y^2)}{h_x^2\ h_y^2}} \qquad \text{(Falconer 1960)}$$

where: $\sigma_{(r_G)}$ = the standard error of the genetic correlation

$\sigma_{(h_x^2)}$ = the standard error of the heritability estimate of trait x

$\sigma_{(h_y^2)}$ = the standard error of the heritability estimate of trait y

h_x^2 = the heritability estimate of trait x

h_y^2 = the heritability estimate of trait y

RESULTS

A. Environmental Factors Affecting Weanling and Yearling Traits

Generally speaking, environmental influences are sources of variation which reduce the effectiveness of selection designed to permanently improve the performance of a flock or herd. If, however, the major environmental factors can be identified and evaluated, records can be adjusted to an equitable basis and individual performances may logically be compared from a genetical point of view.

The present study revealed substantial differences among the constants computed for the various fixed effects. Table 12 and 13 show the estimates of constants from least squares analysis. In addition, estimates of the means with their standard deviations are presented. Also, the regression of weaning weight, weaning type and condition scores and yearling body and fleece weights on age in days are evident. The estimated constants in the tables served as correction factors upon reversal of their signs and all meaningful ones were subsequently used in adjusting the data prior to calculating the genetic and phenotypic parameters.

The importance of the environmental effects can best be presented by a brief treatment of their influence on each character studied.

1. Weaning weight - Yearly differences in weaning weight were expected to be large and were found to be statistically significant ($p < .05$) in the majority of years. Lambs born in 1959 were 20 pounds heavier than those born in 1945. This difference was the greatest among any of the years and compares with a range of 25.6 pounds found by Givens (1958) in

a study including the years 1946 through 1957. No other study has compared weaning weights over such an extended period. However, small seasonal variations in weaning weight have been found by Hazel and Terrill (1945b) working with range Rambouillet lambs. Ercanbrack (1952) found a difference of 4.6 pounds in the weaning weights of Rambouillet lambs born in 1947 and those born in 1948. The same study showed a yearly variation of 8.9 pounds for Columbia and Targhee lambs in the above mentioned years. In the present study, lambs born in the years of 1958 and 1959 enjoyed a large advantage in weaning weight over lambs born in most other years. Variation among the years 1947, 1949, 1951, 1955, and 1956 did not exceed 1.5 pounds.

The age of dam classification included ewes from 2 to 9 years of age. Lambs from 2-year old ewes were lighter by 3, 5.6, 5.9, 4.2, 3.9, and 1.1 pounds respectively, than lambs from 3, 4, 5, 6, 7, and 8-year old ewes. The differences for ewes 6, 7, and 8 years old were not statistically significant while those for 2, 4, and 5 years old were significant ($p < .01$). Lambs from ewes 9 years old were lighter than those from any other age group. This agrees with the results of Sidwell and Grandstaff (1949) and Sidwell et al. (1951b). Hazel and Terrill (1945b) found slightly larger differences between lambs from 2-year old dams and mature dams (3 years old and over) than were noted in this study. They found that range Rambouillet lambs from mature ewes weighed 6.1 pounds more than lambs from 2-year old ewes. The same authors (1946d) found an 8.7 pound difference working with range Columbia, Corriedale and Targhee lambs. These differences are similar to those found by Donald and McLean 1935 in New Zealand.

The effects of type of birth and rearing were highly significant (table 12). Lambs born and raised twins were lighter than single lambs by 13.1 pounds, an amount similar to the 11.7 figure found by Givens (1958). Lambs born twins and raised as singles averaged 5.3 pounds less in weight than did single lambs. Hazel and Terrill (1945b) found that lambs born and raised as twins were 9.2 pounds lighter than singles and lambs born twins and raised as singles were at a 2.5 pound disadvantage. Ercanbrack (1952), working with Rambouillet lambs, showed that single lambs averaged 11.4 pounds heavier than twins, and twins reared as singles were 2.0 pounds lighter than single lambs. Columbia and Targhee lambs in the same study gave differences of 15.0 and 7.7 pounds respectively for twins and twins reared as singles when compared to single lambs.

Ram lambs were significantly heavier ($p < .01$) than ewe lambs. The advantage of 4.2 pounds indicated in this study is less than the 10.8 and 8.3 pounds reported by Hazel and Terrill (1946d) and Hazel and Terrill (1945b) respectively. Givens (1958) and Ercanbrack (1952) found advantages of 4.7 and 3.1 pounds respectively for wether lambs over ewe lambs.

A highly significant difference in weaning weights existed between the Columbia and Columbia X Southdale lambs. The Columbias were 4.3 pounds heavier on the average than the Columbia X Southdale lambs. The difference due to location or station was also significant ($p < .01$) with lambs born and raised at Middlebury, Vermont enjoying an average advantage of four pounds over the lambs reared at Beltsville, Maryland.

Table 12. Estimates of Constants for Fixed Effects from Least Squares Analysis, Weaning Traits

Constants	Weaning weight (lb.)	Weaning type[1] (score)	Weaning condition[1] (score)
Deviations from base due to: Year of birth			
1945	-6.5 ± 1.4**	-1.0 ± 0.25**	-1.6 ± 0.26**
1946	-2.8 ± 1.2*	-2.4 ± 0.22**	-2.3 ± 0.24**
1947	1.5 ± 1.3	-2.7 ± 0.23**	-2.6 ± 0.24**
1948	-2.8 ± 1.2*	-2.3 ± 0.23**	-2.1 ± 0.24**
1949	0.2 ± 1.0	-2.4 ± 0.20**	-2.3 ± 0.21**
1950	-4.5 ± 1.3**	-3.1 ± 0.25**	-2.9 ± 0.27**
1951	0.5 ± 1.1	-1.4 ± 0.28**	-1.1 ± 0.29**
1952	-1.3 ± 1.1	-1.9 ± 0.28**	-1.4 ± 0.29**
1953	2.3 ± 1.0*	-0.7 ± 0.20**	-0.2 ± 0.21
1954	-2.6 ± 1.0**	-0.5 ± 0.22**	-1.7 ± 0.23**
1955+	0.0	0.0	0.0
1956	1.3 ± 0.0	0.0 ± 0.20	0.1 ± 0.21
1957	2.6 ± 0.9**	-1.2 ± 0.19**	-0.7 ± 0.20**
1958	12.0 ± 0.9**	-1.3 ± 0.18**	-1.8 ± 0.19**
1959	13.5 ± 0.9**	-1.2 ± 0.18**	-1.3 ± 0.19**

1 Coded scores ranged from a possible high of 16 to a possible low of 2. See appendix A for complete explanation of coding of scores.
\+ Base effect
* Significant ($p < .05$)
** Significant ($p < .01$)

Table 12. Continued

Constants for	Weaning weight (lb.)	Weaning type (score)	Weaning condition (score)
Age of dam			
2	-3.0 ± 0.6**	-0.3 ± 0.11**	-0.3 ± 0.11**
3+	0.0	0.0	0.0
4	2.6 ± 0.6**	0.3 ± 0.11**	0.2 ± 0.12*
5	2.9 ± 0.7**	0.2 ± 0.12	0.1 ± 0.13
6	1.2 ± 0.8	-0.2 ± 0.14	-0.2 ± 0.15
7	0.9 ± 1.0	-0.3 ± 0.17	-0.2 ± 0.18
8	-1.9 ± 1.4	-0.6 ± 0.2*	-0.6 ± 0.24*
9	-3.8 ± 1.8*	-1.1 ± 0.3**	-1.0 ± 0.31**
Type of birth, rearing			
Single+	0.0	0.0	0.0
Twin-Single	-5.3 ± 0.7**	-0.6 ± 0.14**	-0.3 ± 0.14*
Twin	-13.1 ± 0.4**	-0.7 ± 0.25**	-1.6 ± 0.27**
Sex			
Ram	4.2 ± 0.4**	-0.5 ± 0.23**	-0.5 ± 0.24**
Ewe+	0.0	0.0	0.0
Breed			
Columbia X Southdale+	0.0	0.0	0.0
Columbia	4.3 ± 0.6**	-0.5 ± 0.11**	-0.7 ± 0.11**

Table 12. Continued

Constants for	Weaning weight (lb.)	Weaning type (score)	Weaning condition (score)
Station			
Middlebury, Vermont+	0.0	0.0	0.0
Beltsville, Maryland	-4.0 ± 0.5**	1.0 ± 0.14**	0.1 ± 0.15
Regression of trait on age in days	0.192 ± 0.02**	0.028 ± 0.004**	0.023 ± 0.004**
Estimate of mean	61.3 ± 11.1	13.2 ± 1.64	13.0 ± 1.7

Table 13. Estimates of Constants for Fixed Effects from Least Squares Analysis, Yearling Traits

Constants for	Yearling body weight (lb.)	Yearling type[1] (score)	Yearling condition[1] (score)
Deviations from base due to:			
Year of birth			
1946	-3.8 ± 3.8	-2.5 ± 0.28**	-0.5 ± 0.25
1947	13.1 ± 4.2**	-0.7 ± 0.31*	1.1 ± 0.28**
1948	12.8 ± 4.0**	-1.3 ± 0.29**	-0.2 ± 0.27
1949	17.5 ± 3.6**	-2.4 ± 0.27**	-1.1 ± 0.24**
1950	21.3 ± 3.4**	-1.5 ± 0.25**	-0.3 ± 0.23
1951	7.4 ± 3.5*	-0.2 ± 0.27	-1.1 ± 0.24**
1952	2.5 ± 3.4	-1.5 ± 0.31**	-0.9 ± 0.28**
1953	-1.9 ± 3.2**	-0.8 ± 0.23**	-0.7 ± 0.21**
1954	9.1 ± 3.1	-0.8 ± 0.23**	-1.0 ± 0.21**
1955+	0.0	0.0	0.0
1956	-0.8 ± 2.9	-1.1 ± 0.22**	-1.0 ± 0.19**
1957	-6.3 ± 3.3	-1.6 ± 0.25**	-0.2 ± 0.22
1958	13.8 ± 2.9**	-2.3 ± 0.22**	-2.2 ± 0.19**
1959	17.0 ± 3.1**	-2.3 ± 0.23**	-3.0 ± 0.21**
Age of dam			
2	-0.6 ± 1.8	-0.1 ± 0.14	-0.2 ± 0.13
3+	0.0	0.0	0.0
4	2.0 ± 1.9	0.1 ± 0.15	0.0 ± 0.13
5	5.6 ± 2.1**	0.0 ± 0.16	0.0 ± 0.15
6	5.0 ± 2.4*	-0.2 ± 0.18	-0.1 ± 0.16
7	11.7 ± 3.2**	-0.5 ± 0.25	-0.1 ± 0.22
8 & 9	6.5 ± 3.7	-0.3 ± 0.31	-0.3 ± 0.28

Table 13. Continued

Constants for	Yearling body weight (lb.)	Yearling type (score)	Yearling condition (score)
Type of birth & rearing			
Single+	0.0	0.0	0.0
Twin-Single	-4.9 ± 2.2**	-0.3 ± 0.17	-0.1 ± 0.15
Twin	-9.0 ± 1.4**	-0.2 ± 0.11	-0.1 ± 0.09
Sex			
Ram	16.7 ± 1.6**	-0.4 ± 0.12**	-0.3 ± 0.11**
Ewe+	0.0	0.0	0.0
Breed			
Columbia X Southdale+	0.0	0.0	0.0
Columbia	10.7 ± 2.0**	-0.1 ± 0.16	-0.7 ± 0.14**
Station			
Middlebury, Vermont+	0.0	0.0	0.0
Beltsville, Maryland	1.0 ± 1.7	0.2 ± 0.14	0.3 ± 0.13**
Regression of trait on age in days	0.095 ± 0.38*		
Estimate of mean	79.2 ± 19.7	13.3 ± 1.46	13.5 ± 1.32

Table 13. Continued

Constants for	Yearling fleece weight (lb.)	Yearling fleece[1] character (score)	Yearling staple length (cm.)
Deviations from base due to:			
Year of birth			
1946	0.5 ± 0.31	-1.0 ± 0.23**	-1.0 ± 0.54
1947	2.4 ± 0.34**	-0.6 ± 0.26**	0.9 ± 0.56
1948	3.6 ± 0.33**	0.1 ± 0.24	1.2 ± 0.55*
1949	2.3 ± 0.29**	-0.3 ± 0.22	0.5 ± 0.53
1950	3.9 ± 0.27**	-1.0 ± 0.21**	2.3 ± 0.51**
1951	1.0 ± 0.29**	1.2 ± 0.22**	-0.5 ± 0.53
1952	1.1 ± 0.27	-0.5 ± 0.20	1.5 ± 0.37**
1953	0.2 ± 0.26	0.5 ± 0.19*	-0.3 ± 0.34
1954	-0.1 ± 0.25	0.2 ± 0.19	2.1 ± 0.35**
1955+	0.0	0.0	0.0
1956	0.4 ± 0.24	0.3 ± 0.18	-0.5 ± 0.35
1957	0.3 ± 0.27	2.0 ± 0.20**	0.0
1958	1.8 ± 0.24**	-2.0 ± 0.18**	-0.5 ± 0.35**
1959	1.7 ± 0.26**	-1.7 ± 0.19**	-1.2 ± 0.43**
Age of dam			
2	0.1 ± 0.15	-0.1 ± 0.12	-0.1 ± 0.19
3+	0.0	0.0	0.0
4	0.5 ± 0.16**	-0.1 ± 0.12	0.0
5	0.8 ± 0.17**	0.0	0.0
6	0.8 ± 0.10**	-0.1 ± 0.15	-0.2 ± 0.25
7	0.9 ± 0.26**	0.1 ± 0.20	0.2 ± 0.35
8 & 9	1.1 ± 0.30**	0.2 ± 0.25	-0.1 ± 0.48

Table 13. Continued

Constants for	Yearling fleece weight (lb.)	Yearling fleece character (score)	Yearling staple length (cm.)
Type of birth & rearing			
Single+	0.0	0.0	0.0
Twin-Single	-0.5 ± 0.18**	-0.1 ± 0.14	-0.1 ± 0.20
Twin	-1.1 ± 0.11**	-0.1 ± 0.09	0.0
Sex			
Ram	1.0 ± 0.13**	0.1 ± 0.10	-0.4 ± 0.16*
Ewe+	0.0	0.0	0.0
Breed			
Columbia X Southdale+	0.0	0.0	0.0
Columbia	1.4 ± 0.16**	-0.1 ± 0.13	0.4 ± 0.33
Station			
Middlebury, Vermont+	0.0	0.0	0.0
Beltsville, Maryland	0.0	0.8 ± 0.12	-0.7 ± 0.42
Regression of trait on age in days	0.022 ± 0.003**		
Estimate of mean	8.02 ± 1.61	12.8 ± 1.19	12.0 ± 1.66

1 Coded scores ranged from a possible high of 16 to a possible low of 2. See appendix A for complete explantion of coding of scores.
\+ Base effect
* Significant ($p < .05$)
** Significant ($p < .01$)

The regression of weaning weight on age at weaning shows that lambs were gaining at an average rate of 0.192 pound per day at weaning age. This is in close agreement with the figures of 0.184 and 0.200 by Ercanbrack (1952) with Rambouillet and Columbia and Targhee lambs respectively. It is lower than the 0.448 pound per day reported by Hazel and Terrill (1946d), but similar to the figures indicated by Phillips and Brier (1940) and Phillips et al. (1940) on growth rates of lambs of similar age.

2. Weaning type score - Variation in type score due to the year in which the lamb was born was highly significant in 12 of the years studied. The year 1950 showed the greatest deviation from the base year of 1955. Lambs born in 1950 were 3.1 points lower in type score than lambs born in 1955. Since a type grade as defined in this study consists of 3 points, the 1950 lambs were inferior by a full grade compared to the 1955 lambs. Actually, the base year was one in which the majority of lambs scored highly, thus causing most other years to differ significantly from it.

Lambs from 2-year old dams scored 0.3 of a point less than lambs from 3-year old dams, the age taken for a base. Lambs from 4- and 5-year old ewes were scored better by 0.3 and 0.2 of a point respectively and lambs from 6, 7, 8, and 9-year olds were at a progressive disadvantage; those from the 9-year old group scoring poorest of any age classification. The two extreme groups, viz. lambs from the 2- and 9-year olds, differed from the base significantly ($p < .01$) while the level of significance for the variation of lambs from the 4- and 8-year old ewes was ($p < .05$). Lambs from the remaining age of dam groups were not significantly different. Hazel and Terrill (1946d) found that lambs from mature dams scored

0.25 point better than those from 2-year old dams. This is close to the 0.24 variation found by Sidwell (1954) between lambs from 2-year old dams and lambs from ewes 4 to 7 years of age.

Single lambs in this study excelled twins raised singly which in turn were scored higher than twins raised as twins, the difference in both cases being highly significant. This is in close agreement with the findings of Hazel and Terrill (1945b, 1946d) as well as those of Sidwell (1954) and Ercanbrack (1952). Ewe lambs were superior to ram lambs by 0.5 of a score, a highly significant difference and one noted also by Hazel and Terrill, Sidwell, and Ercanbrack in their studies. The Columbia X Southdale lambs were superior in type by 0.5 of a score than contemporary Columbia lambs. Lambs reared at the Beltsville Station were scored 1.0 point higher than lambs raised at the Middlebury Station, a difference significant at the 0.01 level. Type scores were better for older lambs as judged by the regression (0.028) of type score on the age of the lamb. This regression coefficient is close to the 0.020 and 0.012 figures found by Hazel and Terrill (1946d, 1945b) respectively and the value of 0.02 found by Sidwell et al. (1951b).

3. Weaning condition score - All of the environmental factors varied in the same direction and were of similar magnitude as the scores for weaning type. This close association is not surprising since type and condition have been shown to be highly correlated. Yearly differences from the base year 1955 were of high statistical significance in all but two years, 1953 and 1956. Lambs from 2-year old dams were not as fat as lambs from 3, 4, 5, 6, and 7-year old ewes but were in better

condition than lambs from 8- and 9-year old mothers. Sidwell et al. (1951b) also found that condition scores improved with age until the dams reached an age of 8 years and older with the exception that 2-year old dams had lambs with poorer condition ratings. Single lambs were scored 1.6 higher than twins raised as twins and 0.3 higher than twins reared as single lambs. The lambs born as twins but raised singly had a score advantage of 1.3 over twins raised by the same dam. Ewe lambs were superior to ram lambs by 0.5, a highly significant difference. The Columbia X Southdale lambs were fatter by 0.7 of a score than Columbia lambs, a difference of high significance. Very little difference in condition scores between lambs reared at Middlebury, Vermont and those produced at Beltsville, Maryland was apparent. As with type scores, the older lambs scored higher in condition as indicated by the regression of condition score on age of the lamb, (0.023). This regression coefficient compares closely with the 0.02 value found by Sidwell et al. (1951b). It is slightly higher than the values of 0.009 and 0.016 found by Hazel and Terrill (1945b) and (1946d) respectively.

4. Yearling body weight - Large and highly significant differences were found in the yearling body weights of sheep born in different years. Yearlings born in 1950 were 25.1 pounds heavier than yearlings born in 1946. Yearlings born in 1947, 1948, 1949, 1950, 1958, and 1959 had much higher body weights than those born in 1955 (the base year), but did not differ greatly in weight among these particular years.

Yearlings from mature ewes were heavier than those from 2-year old ewes. The greatest variation between age groups was a 12.3 pound difference in favor of yearlings from 7-year old ewes over those from 2-year old dams. Eight and 9-year old ages were grouped together in the analysis of all yearling data since each age alone lacked sufficient numbers for comparison. Differences of high significance ($p < .01$) were noted between yearlings from 3-year old dams and yearlings from 5- and 7-year old ewes. The values were 5.6 and 11.7 pounds respectively. Yearlings born and raised singly were 9.0 pounds heavier than twins and 4.9 pounds heavier than twins raised as singles, both differences being statistically significant. These values are somewhat greater than those of Price et al. (1953) who working with Navajo and Navajo crossbred ewes found differences of 6.5 and 1.5 pounds respectively for singles over twins and singles over twins raised as singles. Hazel and Terrill (1946c) found similar values of 6.0 and 0.5 pounds respectively in range Rambouillet yearling ewes. Differences in body weight at the yearling age due to age of dam are not as great as were found at weaning. This same trend of differences in the same direction but of smaller magnitude has been reported by Hazel and Terrill (1946c) and Price et al. (1953). Phillips et al. (1940) found in range sheep that singles were heavier than twins throughout the first year. Phillips and Dawson (1940) found, however, that with farm sheep the difference due to type of birth and rearing tended to disappear by the time yearling age was reached.

In this study the difference due to sex was 16.7 pounds in favor of yearling rams over yearling ewes. This is a greater difference than the 4.2 pounds found at weaning age. The Columbia yearlings were superior in weight to the Columbia X Southdales by 10.7 pounds and the yearlings grown at Beltsville were slightly heavier than those raised at Middlebury. This was a reversal of the difference found in weaning weights in favor of the Middlebury Station.

The regression of yearling body weight on age was 0.095 which is lower than the 0.192 found at weaning age. Hazel and Terrill (1946c) found a decrease in regression coefficients of an even greater size in comparing values at yearling age with weaning values.

5. Yearling type score - Variation of type score from the base year of 1955 was important in 12 of the years included in this study. Variation was in the same direction and of similar size as that noted for weaning type score. Terrill et al. (1948a) found similar results with Columbia and Targhee yearling rams over a five year span. In fact, their study showed that variation among years was the most important of all sources of variation. Age of dam and type of birth and rearing were not important sources of variation in this study, although singles received slightly better scores than twins and twins raised as singles. Price et al. (1953) and Terrill et al. (1948a) found the same to be true as did Hazel and Terrill (1946c) with the exception that the latter authors found the differences in favor of singles over twins and twins raised singly to be significant. It is of interest that twins had slightly better scores than twins raised as singles, a fact reported by Terrill et al. (1947) working with Targhee yearling ewes. Rams continued to score less than ewes at the yearling age as they did at weaning, the difference being highly significant. No significant difference was noted between the Columbia and Columbia X

Southdales, in the yearling type score, whereas at weaning age the Columbia X Southdales enjoyed a distinct advantage in type. The difference in type score between stations was not large enough to be important although the Beltsville lambs were scored slightly higher than the Middlebury lambs. The regression of type score on the age of the sheep was not computed since reports in the literature indicate that, in general, these regression coefficients lack the size to be important.

6. Yearling condition score - Yearly differences in yearling condition score were important. The range was 4.10 points from the lowest yearly average to the highest. This was a large variation even though there were 15 possible points for condition. Therefore, adjustment of condition score for years should be made. This is in agreement with the findings of Terrill *et al.* (1947, 1948a, 1948b), and Price *et al.* (1953). The age of the dam did not affect the condition of the yearlings significantly. This was not true at weaning age, when lambs from ewes 2, 4, 8, and 9 years old varied significantly in condition from lambs that were offspring of 3-year old ewes. Type of birth had no significant effect on yearling condition scores in contrast to the significant differences found at weaning age. Yearling rams scored 0.3 lower than yearling ewes, a highly significant difference, only slightly lower than that noted at weaning. The Columbia X Southdales were scored 0.7 better than Columbias in condition, a difference large enough to be significant ($p < .01$). The yearlings raised at Beltsville were 0.3 of a point fatter than those reared at Middlebury. When scored at weaning, no difference of consequence was noted between the two stations.

7. Yearling fleece weight- The range in grease fleece weights for the 14 years was 4.0 pounds. Highly significant differences were noted in 50 percent of the years studied. Terrill et al. (1948a) found a range in grease fleece weights of 5.0 and 3.4 pounds respectively for Columbia and Targhee yearling rams over the five years, 1941-1945. The same authors found a somewhat smaller range in yearling ewes of the Columbia and Targhee breeds over a four-year span, the values being 1.66 and 1.44 pounds respectively. Age of dam was of considerable importance in grease fleece weight of yearlings. Yearlings born of 2-year old dams sheared 0.1 of a pound less wool than those from 3-year old ewes, a difference closely approximating that found by Rae (1950). However, the range from 2-year old dams to 8- and 9-year olds was 1.0 pound with a progressive advantage in favor of older ewes, from age 4 upward. This was consistent with the 0.9 pound and 1.0 pound differences in favor of yearlings from mature dams over those with 2-year old dams of the Columbia breed found by Terrill et al. (1948a) working with rams and ewes respectively. The effect of type of birth and rearing on fleece weight was highly significant. Yearlings born and raised as single lambs had fleeces 1.1 pounds heavier than twins raised as twins, and produced 0.5 pound more wool than twins that were raised as singles. Terrill et al. (1947) found nearly identical differences with yearling Columbia ewes. Yearling rams sheared fleeces 1.0 pound heavier than yearling ewes and the Columbia yearlings had 1.4 pounds more wool than the Columbia X Southdales. There was no difference in fleece weights between yearlings raised at Beltsville and those reared at Middlebury. The regression of fleece weight on age

at shearing was 0.022, an average change for each extra day of age at shearing, very similar to the 0.018 found by Rae (1950) and the 0.03 found by Price et al. (1953).

8. Yearling fleece character score - As with all other traits studied, yearly differences were an important source of variation in fleece character score. The range was 4.0 points from the year with the lowest average ratings to the year with the highest. Age of dam, type of birth and rearing, sex and breed had no significant effect on fleece character scores. Yearlings raised at Beltsville, however, were scored 0.8 of a point better than those at Middlebury. The only published material on environmental influences affecting fleece character or "quality" available for comparison is the work of Rae (1950). He noted large year differences and relatively small differences in age of dam groups and type of birth and rearing. The regression of fleece quality score on age was found by Rae to be small and unimportant. Because of this, and the fact that simple logic failed to produce evidence that this regression coefficient would prove useful, it was deemed unnecessary to calculate its value.

9. Yearling staple length - The length of staple varied in yearlings by as much as 3.8 centimeters between different years. Differences of statistical significance were evident in about one-half of the years studied. Differences due to age of dam and type of birth and rearing were non-significant in this study although there was 0.3 of a centimeter difference between yearlings from 2-year old dams and those from 6- and 7-year old ewes; those from the older ewes having the longer staple.

Terrill et al. (1947) reported differences of 0.46 and -.03 centimeters for mature minus 2-year old dams, for Columbia and Targhee yearling ewes respectively. Rams had wool 0.4 of a centimeter shorter than ewes. This is a reversal of the reports of several other workers including Terrill et al. (1948a, 1947, 1948b) and Hazel and Terrill et al. (1946c) who found rams to have a longer staple than ewes. The Columbias had 0.4 of a centimeter longer staple than the Columbia X Southdales and the Middlebury sheep grew a longer stapled fleece by 0.7 of a centimeter than did those raised at Beltsville.

10. Combined sources of environmental variation - Examination of the R^2 values in table 14 reveals that the environmental effects under consideration caused a reasonable share of the variation in body traits and an even greater share of the variation in yearling fleece traits. Weaning weight also received a relatively higher share of its variation from the fixed effects applied to this study. All of the R^2 values (percent of variation accounted for) for each trait are high enough to warrant correction for the environmental factors involved here. It should be remembered however, that there is still much variation that is unaccounted for and that there may well be other important sources of environmental variation that would prove to be important in their influence on the traits studied.

B. Heritability Estimates of Weaning and Yearling Traits

The importance of reliable estimates of heritability for planning efficient breeding systems has been discussed (Wright 1939) and the usefulness of these estimates in determining the relative emphasis to

Table 14. Least Squares Analysis of Variance Due to Year of Birth, Age of Dam, Type of Birth and Rearing, Sex, Breed, and Station

Source of variation	Weaning weight			Weaning type score			Weaning condition score		
	D.F.	S.S.	M.S.	D.F.	S.S.	M.S.	D.F.	S.S.	M.S.
Regression	27	172745.94	6397.99	27	2791.61	103.39	27	2782.51	103.06
Error	2414	220658.34	91.41	1996	5133.26	2.57	1996	5678.96	2.85
Total	2441	393404.28		2023	7924.86		2023	8461.47	
	$R^2 = 0.44$		F = 69.99*	$R^2 = 0.35$		F = 40.23*	$R^2 = 0.33$		F = 36.16*

Source of variation	Yearling body weight			Yearling type score			Yearling condition score		
	D.F.	S.S.	M.S.	D.F.	S.S.	M.S.	D.F.	S.S.	M.S.
Regression	25	186351.47	7454.06	24	670.19	27.92	24	982.69	40.95
Error	1013	400706.16	395.56	922	1956.63	0.21	922	1581.00	0.17
Total	1038	587057.63		946	2626.82		946	2563.70	
	$R^2 = 0.32$		F = 18.84*	$R^2 = 0.26$		F = 132.95*	$R^2 = 0.38$		F = 240.88*

Source of variation	Yearling fleece weight			Yearling fleece character			Yearling staple length		
	D.F.	S.S.	M.S.	D.F.	S.S.	M.S.	D.F.	S.S.	M.S.
Regression	25	2698.36	107.93	24	1239.27	51.64	24	1157.98	48.25
Error	1013	2663.29	2.63	922	1321.12	0.14	641	1645.20	2.57
Total	1038	5361.66		946	2560.39		665	2803.18	
	$R^2 = 0.50$		F = 41.04*	$R^2 = 0.48$		F = 368.86*	$R^2 = 0.41$		F = 18.77*

* Significant ($p < .01$)

give each of several traits when selecting breeding animals was presented by Hazel (1943).

Heritability estimates for three weanling and six yearling traits were calculated by paternal half-sib comparisons. The analysis of variance for all traits is shown in table 15, 16, and 17. Table 18 shows the sire components, k_o values and the heritability estimates with their respective standard errors.

1. Weaning weight - The estimate of 0.14 for heritability of weaning weight found in this study lies within the range of estimates reported in the literature, although it is lower than several, particularly those relating to range sheep. Estimates such as the 0.15 reported by Felts et al. (1957), 0.07 Blackwell and Henderson (1955), and 0.07 Givens et al. (1960) were derived from data obtained on farm flocks and were similar to the value found in this analysis.

2. Weaning type - The estimate for heritability of weaning type score of 0.14 is in relatively close agreement with the estimates of 0.13 found by Hazel and Terrill (1946a), 0.07 Hazel and Terrill (1946b), 0.19 Ercanbrack (1952) and is somewhat greater than the 0.04 found by Sidwell (1954). All of the results noted in the literature as well as the value found here indicate that heritability of weaning type is relatively low.

3. Weaning condition - The estimate of 0.15 for heritability of weaning condition is not large and follows the general pattern of previous reports for this trait. Hazel and Terrill (1946b) and Ercanbrack (1952) found estimates of 0.21 and 0.25 respectively while Hazel and Terrill (1946a) and Sidwell (1954) found lower values of 0.04 and 0.11

Table 15. Analysis of Variance for Weaning Traits

Source of	Weaning weight			Weaning type score			Weaning condition score		
variation	D.F.	S.S.	M.S.	D.F.	S.S.	M.S.	D.F.	S.S.	M.S.
Between sires	66	15698.31	237.85	62	337.08	5.43	62	385.14	6.21
Within sires	2366	281056.93	118.79	1947	5068.01	2.60	1947	5496.57	2.82
Total	2432	296755.24	———	2009	5405.09	———	2009	5881.74	———
Difference			119.06			2.83			3.39

Table 16. Analysis of Variance for Yearling Body Traits

Source of	Yearling body weight			Yearling type score			Yearling condition score		
variation	D.F.	S.S.	M.S.	D.F.	S.S.	M.S.	D.F.	S.S.	M.S.
Between sires	67	37551.57	560.47	65	284.72	4.38	65	279.91	4.30
Within sires	969	364918.17	376.59	881	1723.84	1.96	881	1363.25	1.55
Total	1036	402469.74	———	946	2008.56	———	946	1643.16	———
Difference			183.88			2.42			2.75

Table 17. Analysis of Variance for Yearling Fleece Traits

Source of variation	Yearling fleece weight			Yearling fleece character			Yearling staple length		
	D.F.	S.S.	M.S.	D.F.	S.S.	M.S.	D.F.	S.S.	M.S.
Between sires	67	596.58	8.90	65	293.27	4.51	54	448.92	8.31
Within sires	969	2083.45	2.15	881	1052.05	1.19	611	1382.30	2.26
Total	1036	2680.03	—	946	1345.32	—	665	1831.22	—
Difference			6.75			3.32			6.05

Table 18. Sire Components, k_o Values, Heritability Estimates and Standard Errors

Trait	Sire component	k_o* value	Heritability	Standard error
Weaning weight	4.451	26.75	0.14	± 0.05
Weaning type	0.093	30.12	0.14	± 0.05
Weaning condition	0.113	30.12	0.15	± 0.05
Yearling body weight	12.190	15.08	0.13	± 0.07
Yearling fleece weight	0.448	15.08	0.69	± 0.13
Yearling type	0.171	14.17	0.32	± 0.10
Yearling condition	0.194	14.17	0.45	± 0.11
Yearling fleece character	0.234	14.17	0.66	± 0.14
Yearling staple length	0.505	11.99	0.73	± 0.16

* E.M.S. Between sires = $\sigma^2 + k_o \sigma_s^2$

respectively. Givens et al. (1960) reported an estimate of 0.12 for heritability of market grade (a composite score of type and condition).

4. Yearling body weight - Relatively few estimates of heritability for yearling body weight appear in the literature. The estimate of 0.13 found in this study differs considerably from the 0.40 found by Terrill and Hazel (1943). It is also considerably less than the 0.36 found by Morley (1955) who used the method of parent-offspring regression. Using a different set of data and method of analysis, Morley (1955) reported an estimate of 0.09 which is close to the one found in this study. These estimates, however, were made under varying conditions with sheep of different breeds. Therefore, careful consideration should be given any comparisons between them.

5. Yearling type - The estimate of heritability for yearling type was 0.32, a value larger than the estimates reported by most other workers. In fact, the estimates reported for this trait range only from 0.12 of Terrill and Hazel (1943) to the 0.17 of Rae (1950).

6. Yearling condition - Heritability of yearling condition was estimated as 0.45, being approximately three times as great as the corresponding value determined at weaning. Kyle and Terrill (1953) found similar values of 0.45 and 0.39 for Targhee and Columbia yearlings respectively.

7. Yearling fleece weight - Heritability of yearling fleece weight was estimated to be 0.69. This is higher than other estimates reported in the literature to date. Several estimates have approached this figure including the 0.65 found by Kyle and Terrill (1953). The majority, however,

have been in the vicinity of 0.40.

8. Yearling fleece character - The term "fleece character" is one which describes certain features that contribute to the quality of the fleece. The estimate of 0.66 for the heritability of this trait found in the present study was high relative to other estimates reported previously. Only three other estimates have been noted in the literature, 0.14 by McMahon (1943) and by Rae (1948) and 0.22 by Rae (1950). It is difficult to compare these estimates in view of the fact that the characteristic is scored in a subjective manner, the standards may vary, the scorers were different and the sheep were of different breeds.

9. Yearling staple length - Of all the heritability estimates made in this study, that of yearling staple length was the highest being 0.73. Other estimates have been high also as attested to by the values of 0.56 and 0.52 found by Morley (1955), 0.42 by Blackwell and Henderson (1955) and 0.86 by Kyle and Terrill (1953). The range of estimates for this trait is very wide and dictates that caution be observed in the interpretation of these values. However, in the majority of reports the estimates have been high.

C. Phenotypic Correlations Among Weanling and Yearling Traits

The phenotypic correlations were calculated by the product-moment method before and after adjustment of the data. Table 19 shows the 36 phenotypic correlations calculated after each record was corrected for differences due to environmental factors. Appendix C compares the correlations based on unadjusted and adjusted records. In some instances the corrections for these fixed environmental effects caused an increase in the size of the correlation coefficients and in some a decrease. In others there was little change. In four instances it caused a reversal of sign from negative to positive and in one instance a change from positive to negative.

The correlations in table 19 show that the heaviest lambs also scored the best for body type and condition. The lambs with the best type scores were also those rated highest for condition or fat covering. These findings are consistent with those from the literature summarized in table 4, page 23.

Correlations among yearling body traits were much lower than those observed at weaning with the exception of the relationship between yearling type and yearling condition which was 0.68. Although this is a high correlation it is lower than the corresponding value at weaning. Yearling body weight and yearling type were positively correlated to a moderate degree, and the same was true of body weight and condition. The values of these correlation coefficients were 0.24 in both instances, a figure somewhat below the 0.49 and 0.42 found by Terrill *et al.* (1950). Yearlings that were best in type also possessed slightly longer staple wool. Also, the better conditioned yearlings had better fleece character. The degree of relationship between condition and staple length, and fleece character and staple length was negligible. Yearlings with the heaviest fleece also had the longest fiber, a fact noted also by Terrill *et al.* (1950). They found this correlation to be 0.30 compared to the 0.27 found here. However, heavy fleeces appeared to be detrimental to fleece character, a negative correlation

Table 19. Phenotypic Correlations Among Weanling and Yearling Traits

	Weaning type	Weaning condition	Yearling body weight	Yearling fleece weight	Yearling type	Yearling condition	Yearling fleece character	Yearling staple length
Weaning weight	0.65**	0.62**	0.22**	0.26**	0.20**	0.10**	0.02	0.10**
Weaning type		0.82**	0.06	0.15**	0.15**	0.10**	-.01	0.09*
Weaning condition			0.13**	0.14**	0.16**	0.14**	0.02	0.05
Yearling body weight				0.26**	0.24**	0.24**	-.02	0.06
Yearling fleece weight					0.05	-.02	-.13**	0.27**
Yearling type						0.68**	0.26**	0.07
Yearling condition							0.28**	0.02
Yearling fleece character								0.0033

** and * Distinguish estimates which differ significantly from zero at the 1 and 5 percent levels of probability, respectively.

of -.13 being evident. The typiest sheep were also ranked the highest in fleece character, the correlation between the two traits being 0.26. Rae (1950) found this correlation to be 0.12 for New Zealand Romney Marsh sheep. The heaviest yearlings grew the most wool, the correlation between body and fleece weight being 0.26, which compares favorably with Morley's (1954) 0.36. Correlations among all other yearling traits were insignificant.

In general, weanling traits were not highly correlated with yearling traits although some relationships were high enough to be important. Weaning weight and yearling body weight showed a correlation of 0.22 while the correlation between weaning weight and yearling fleece weight was 0.26. Thus, the selection of lambs on weaning weight alone should result in larger yearlings with heavier fleeces. Correlation coefficients among the other weanling and yearling traits ranged from -.01 (the only negative correlation) to 0.16 between weaning condition and yearling type. These correlations are quite consistent with those found by Terrill _et al_. (1950) although they are slightly smaller in most cases.

D. Genetic Correlations Among Weanling and Yearling Traits

Phenotypic correlations between different traits of the same individual may contain a large environmental component as well as a genetic component. For this reason they do not provide an accurate estimate of the actual genetic relationships involved. The suggestion of Hazel (1943) of correlating traits between close relatives, was followed in this analysis. The sire components of variance and covariance were used as estimates of genic variance and covariance, thus circumventing the environmental component and obtaining a more reliable estimate of true breeding value. The statistical method used has been described in a previous section. Table 20 shows the genetic variances and covariances used for calculating the genetic correlations.

The results obtained by this method are shown in table 21. None of the correlations exceeded unity but the majority of them were larger than the corresponding phenotypic relationships. The same trend of larger genetic correlations as compared with phenotypic ones was noted by Sidwell (1954) and by Swiger and Hazel (1961) working with beef cattle. Ercanbrack (1952) found that about one-half of the genetic correlations exceeded the corresponding phenotypic ones.

Not all of the genetic correlations were positive. Selection for type at weaning will result in sheep lighter in weight as yearlings. Selecting yearlings on the basis of body weight will automatically result in retrogression of fleece character and to a small extent, length of staple. Negative correlations also existed between yearling fleece weight and yearling type, condition and fleece character. Yearling staple length was negatively correlated with fleece character and yearling condition.

Fortunately from a selection standpoint, all but three of the correlations between weanling and yearling traits were positive in sign and several were fairly large. Selecting the heaviest lambs at weaning should bring improvement in yearling body weight, type, condition, fleece character and staple length. A positive relationship also exists between weaning type and yearling type, condition and staple length.

Table 20. Genetic Variances and Covariances Used for Calculating Genetic Correlations

Degrees of freedom	Trait	$\sigma^2_{G_1}$	Trait	$\sigma^2_{G_2}$	$\sigma_{G_1 G_2}$
2014	Weaning weight	4.1819	Weaning type	0.0951	0.3179
	Weaning weight	4.1819	Weaning condition	0.1136	0.4638
	Weaning type	0.0951	Weaning condition	0.1136	0.0769
837	Weaning weight	7.1464	Yearling body weight	13.9422	1.7999
	Weaning weight	7.1464	Yearling fleece weight	0.4868	0.0539
	Weaning type	0.2054	Yearling body weight	13.9422	-.5576
	Weaning type	0.2054	Yearling fleece weight	0.4868	0.0112
	Weaning condition	0.1733	Yearling fleece weight	0.4868	0.0382
	Weaning condition	0.1733	Yearling body weight	13.9422	0.0957
	Yearling body weight	13.9422	Yearling fleece weight	0.4868	2.0262
813	Weaning weight	7.2394	Yearling type	0.4101	0.4101
	Weaning weight	7.2394	Yearling condition	0.2221	0.4202
	Weaning weight	7.2394	Yearling fleece character	0.2608	0.1858
	Weaning type	0.2129	Yearling type	0.1768	0.0536
	Weaning type	0.2129	Yearling condition	0.2221	0.0301
	Weaning type	0.2129	Yearling fleece character	0.2608	-.0205
	Weaning condition	0.1744	Yearling type	0.1768	0.0356
	Weaning condition	0.1744	Yearling condition	0.2221	0.0208
	Weaning condition	0.1744	Yearling fleece character	0.2608	-.0246
	Yearling body weight	14.5999	Yearling type	0.1768	0.0049
	Yearling body weight	14.5999	Yearling condition	0.2221	0.0329
	Yearling body weight	14.5999	Yearling fleece character	0.2608	-1.6737
	Yearling fleece weight	3.2757	Yearling type	0.1768	-.1374
	Yearling fleece weight	3.2757	Yearling condition	0.2221	-.1969
	Yearling fleece weight	3.2757	Yearling fleece character	0.2608	-.3224
	Yearling type	0.1768	Yearling condition	0.2221	0.1788
	Yearling type	0.1768	Yearling fleece character	0.2608	0.1110
	Yearling condition	0.2221	Yearling fleece character	0.2608	0.1535

Table 20. Continued

Degrees of freedom	Trait	$\sigma^2_{G_1}$	Trait	$\sigma^2_{G_2}$	$\sigma_{G_1G_2}$
	Weaning weight	10.1917	Yearling staple length	0.4860	1.1592
	Weaning type	0.3112	Yearling staple length	0.4860	0.2281
	Weaning condition	0.2069	Yearling staple length	0.4860	0.1473
	Yearling body weight	34.6885	Yearling staple length	0.4860	-.0425
522	Yearling fleece weight	0.5754	Yearling staple length	0.4860	0.1972
	Yearling type	0.2467	Yearling staple length	0.4860	0.0505
	Yearling condition	0.3499	Yearling staple length	0.4860	-.0680
	Yearling fleece character	0.3669	Yearling staple length	0.4860	-.1299

Table 21. Genetic Correlations Among Weanling and Yearling Traits

	Weaning type	Weaning condition	Yearling body weight	Yearling fleece weight	Yearling type	Yearling condition	Yearling fleece character	Yearling staple length
Weaning weight	0.49 ± 0.21	0.67 ± 0.13	0.18 ± 0.28	0.03 ± 0.06	0.36 ± 0.19	0.33 ± 0.19	0.14 ± 0.18	0.52 ± 0.14
Weaning type		0.74 ± 0.11	-.33 ± 0.27	0.04 ± 0.18	0.28 ± 0.21	0.14 ± 0.20	-.09 ± 0.19	0.59 ± 0.13
Weaning condition			0.06 ± 0.29	0.13 ± 0.17	0.20 ± 0.21	0.11 ± 0.20	-.12 ± 0.18	0.46 ± 0.15
Yearling body weight				0.80 ± 0.08	0.00 ± 0.28	0.02 ± 0.24	-.86 ± 0.06	-.10 ± 0.24
Yearling fleece weight					-.18 ± 0.17	-.23 ± 0.15	-.35 ± 0.12	0.37 ± 0.13
Yearling type						0.90 ± 0.04	0.52 ± 0.13	0.15 ± 0.18
Yearling condition							0.64 ± 0.10	-.17 ± 0.16
Yearling fleece character								0.31 ± 0.14

The fattest lambs at weaning were positively correlated with yearlings better in fleece character, type, condition and staple length. The highest positive correlations were between yearling body weight and yearling fleece weight and yearling type and yearling condition.

E. Comparisons Between Columbia and Columbia X Southdale Sheep

A comparison of the performance of the Columbia breed and the Columbia X Southdale strain of sheep, in the traits studied, is of interest although a complete evaluation of the two must await further investigation. Table 22 shows the unadjusted means of the weaning and yearling traits.

The differences between breeds were of importance in the case of weaning weight, yearling body weight, yearling condition score, yearling fleece weight and yearling staple length. In all of the above cases except that of yearling condition, the Columbia was superior. The Columbia X Southdale enjoyed a slight advantage in weaning type score, weaning condition score, yearling type score, and yearling fleece character score.

Table 22. Unadjusted Means of Weaning and Yearling Traits for Columbia and Columbia X Southdale Sheep

Trait	Mean			
	Columbia	Number of records	Columbia X Southdale	Number of records
Weaning weight (lb.)	64.5	360	57.1	2082
Weaning type score*	10.7	334	10.9	1690
Weaning condition score*	10.2	334	10.6	1690
Yearling body weight (lb.)	97.6	147	86.7	892
Yearling type score*	11.8	127	12.0	820
Yearling condition score*	11.6	127	12.7	820
Yearling fleece weight (lb.)	10.6	147	9.2	892
Yearling fleece character score*	12.4	127	12.7	820
Yearling staple length (cm.)	12.9	41	12.2	625

* See Appendix A for explanation of scores

DISCUSSION

The interpretation of the results of this study are important for several reasons. First, because the findings, if wisely used, will prove valuable in determining future plans and procedures in the selection and development of the Columbia X Southdale strain of sheep. Secondly, the phenotypic and genetic parameters estimated may further substantiate or refute similar estimates by others working with farm sheep and thus contribute to the degree of confidence which may be placed on such estimates. Thirdly, certain correlations determined in this study between weanling and yearling traits have not previously been investigated and thus provide new information to be added to the accumulation of knowledge concerning relationships between economic characters in farm sheep.

Any conclusions drawn from examining the estimates of the environmental factors influencing the weanling and yearling traits and the phenotypic and genetic parameters calculated in this analysis should be tempered by the realization that they are not necessarily constants applicable to all flocks. Nevertheless, the results obtained here may provide evidence of what can be expected in other flocks reared under similar conditions. Therefore, even though the usefulness of these estimates and those of the other parameters estimated may be limited in the sense of yielding absolute perfection when applied to other farm flocks, much benefit may be realised when these results are used with discretion.

Environmental Effects

The estimates of the environmental differences found in table 12 and 13 indicate that the year in which a lamb is born may have an important effect on all traits studied including those at yearling age. This information may be more important in ram selection than in ewe selection where most comparisons will be between ewes born in the same year. Large differences between years occur often enough to warrant adjustment for this effect, as pointed out by Terrill et al. (1947, 1948a, 1948b) and Sidwell et al. (1951). Some of the variation among years may possibly be attributed to changes in mental standards where traits that were scored subjectively are concerned. Subjective scores of such traits as body type depend to a large extent on mental images of a composite nature and are subject to fluctuations from time to time and person to person.

The age of the dam was an important source of variation in weaning weight, yearling body weight, and yearling fleece weight. With respect to weaning weight, lambs from ewes 2 years of age or over 7 years of age were lighter than lambs from ewes between these ages. Bonsma (1939) and Barnicoat et al. (1949) have both shown that milk production is greater in ewes more advanced than 2 years of age. Sidwell (1954) found that ewes older than 7 years probably did not produce as much milk as younger ewes and that 2-year old dams had not reached their peak of production, conclusions also reached in the present study. The lambs that were larger at weaning because of the age of their dams enjoyed a distinct weight advantage as yearlings indicating that once these lambs were ahead in size they likely had a competitive advantage that they maintained even without their mother's influence. It is concluded that adjustments for differences due to the age of the dam are indicated where weaning weight, yearling body weight, and yearling fleece weight are concerned.

The fact that single lambs were heavier at weaning than twins may have been due, in part, to the smaller birth weights of twins. Phillips and Dawson (1940) showed that a significant relationship existed between birth weight and subsequent growth rate. Twins appear to be severely handicapped since they are forced to share the milk supply of the mother post-natally. Barnicoat et al. (1949) have shown with Romney sheep, that ewes with twin lambs secrete about a third more milk than ewes with singles. Therefore, a twin lamb receives about two-thirds of the amount of milk received by a single lamb providing he is equally as vigorous a nurser as his twin. This increased milk production does not persist in the event one twin dies since twins raised as singles do not surpass single lambs in weaning weight. The present results indicate that the handicap suffered by twins is not overcome by yearling age except in the case of type and condition scores.

The lambs in this study had obviously passed their peak stage of gain at weaning since the regression of weight on weaning age was only 0.192 pound per day. This value is far from sufficient to account for the average weaning weight of 61.3 pounds. However, it is of sufficient magnitude to warrant its use in adjusting weaning weight if there is a wide range in ages at weaning.

The importance of correcting for environmental factors may be seen by an example of a particular combination of circumstances. Two lambs are to be compared with respect to weaning weight.

Lamb A	Lamb B
Dam = 5-year old	Dam = 2-year old
Single lamb	Twin lamb
Ram lamb	Ewe lamb
Columbia	Columbia X Southdale
Born at Middlebury	Born at Beltsville

Using the correction factors obtained we would expect Lamb A to be heavier by 5.9 pounds because of the age of its dam, by 13.1 pounds because it was a single instead of a twin, by 4.2 pounds because it was a ram instead of a ewe, 4.3 pounds because it was a Columbia rather than a Columbia X Southdale, and 4.0 pounds because it was raised at Middlebury rather than Beltsville. Thus, Lamb A could weigh 31.5 pounds more than Lamb B at a given age due to the combination of environmental circumstances listed. Without these corrections the genetic merits of Lamb B might well be overlooked in any selection program.

Not all flocks will have detailed records available for the development of adjustment factors for use in selecting breeding animals. The results of this study indicate that fairly large flocks in this category may improve the accuracy of selection by sorting lambs into groups according to sex, age of dam (at least into 2-year old versus older ewes), age of the lamb and selecting the same proportion from each group. Phillips and Dawson (1940) proposed a similar method to overcome these environmental differences.

Heritability Estimates

The heritability estimate of weaning weight found in this study was lower than several estimates reported in the literature, particularly those relating to range sheep. Apparently environment plays a more important part in determining the weaning weight of farm sheep than it does in those reared under range conditions. Although weaning weight is not highly heritable as indicated in this study, it is positively correlated with yearling body weight both phenotypically and genetically and is a valuable criterion in selection designed to improve size within a flock.

Weaning type and condition were found to be lowly heritable. It is clear that both type and condition can be influenced rather widely by nutrition and other environmental factors. Mutton conformation is the result of an extremely complex system of simpler traits which interact with each other. For this reason there has been no system of linear measurements developed which can replace the subjective method of the experienced animal husbandman of comparing individual animals with a mental standard. Stonaker and Lush (1942) working with Poland China swine suggested that selection for conformation was comparable to selection for an intermediate in many visible characteristics. With such low heritabilities, type and condition will respond very slowly to any attempts at genetic improvement by means of phenotypic selection alone. According to Dickerson and Hazel (1944) progress in traits with such low heritabilities will be more rapid if progeny testing is used. However, the length of time required to accurately evaluate sires by progeny testing may limit the rate of progress as compared to a system of selection based on rapid turnover of ram generations as described by Terrill (1955). In actual practice it would be seldom that type and condition would be the only or the major factors in selecting lambs at weaning.

Heritability of yearling body weight was low (0.13). This value was slightly less than that found for weaning weight (0.14). It has been suggested by Hazel and Terrill (1945a) that the heritability of body weight increases from weaning to yearling age. This is implied from the findings of Terrill and Hazel (1943) who showed that the heritability of body weight in yearling Rambouillet ewes was 0.40, a larger value than the 0.30 found by the same authors in Rambouillet lambs at weaning. The results of this study do not bear this out. Apparently there is much to learn about the changes in heritability occurring with age for traits in sheep although it is well established that certain genes manifest themselves only at a certain age or stage of development.

The increase in heritability estimate of type found at the yearling age as opposed to weaning age may well be the result of the lamb becoming free of certain environmental influences, particularly the maternal influence. The fact that experience indicates that fewer errors are made in selecting typier sheep at the yearling age than at weaning tends to bear this out.

The majority of heritability estimates of fleece weight have been high indicating that fleece weight is a relatively strongly inherited characteristic presenting an excellent opportunity for progress on the basis of mass selection for this trait, providing accurate measurements (fleece weights) are taken. It is interesting to speculate on the causes of the genetic variance of wool production. Schinckel (1960), on the basis of his study of variation in feed intake of grazing sheep, has postulated that a significant proportion of the genetic variance in wool production may be a function of genetic variability in feed intake as well as of variability in efficiency.

Heritability estimates of all three fleece characteristics studied were higher than many estimates for these traits reported in the literature. A contributing factor to the relatively large amount of gentic variance was thought to be the fact that the data were drawn predominantly from the cross-bred strain, the Columbia X Southdale.

The heritability estimates presented here are thought to be reasonably accurate. The standard errors of the estimates are not excessive, indicating that the sampling variances of the estimates were not unreasonably high.

Based on the estimates obtained here, mass selection for yearling fleece weight, yearling fleece character and yearling staple length should result in rapid progress in these traits. However, some genetic antagonisms were apparent among these traits which might tend to slow the rate of improvement somewhat. It should be recognized that changes in the heritability of a trait may occur over a period of time involving selection for that trait. According to Lush (1948) the change would usually be slow unless most of the genetic variability was caused by only a few genes and selection was intense.

Correlations

1. Phenotypic correlations - The phenotypic correlations among weaning and yearling traits are of interest from a predictive standpoint. If an easily measured weaning trait is highly correlated with an economically important yearling trait it is possible to be more accurate in selecting at a younger age providing there are no important genetic antagonisms present. Only one negative correlation was found between weaning and yearling traits. It may be concluded therefore, with this exception, that selecting the heaviest lambs with the best type and condition at weaning will cause at least slight improvement in all yearling traits studied.

It is of interest to compare the phenotypic correlations with the genetic correlations. The phenotypic and genetic correlations between yearling body weight and yearling type are 0.24 and zero respectively. This indicates that the phenotypic correlation is caused by environmental factors (assuming that non-additive genetic factors are unimportant), which stimulate both increased body weight and improvement in type. With such a correlation existing, selection for heavier yearlings should automatically improve type. If however, the correlations between weaning type and yearling body weight are examined, they are found to be on the order of 0.06 (phenotypic) and -.33 (genetic). Therefore, it is concluded that if these are true relationships, selecting typier lambs at weaning on the basis of their phenotype will be genetically detrimental to establishing heavier yearlings in the flock.

2. Genetic correlations - The estimates of genetic correlations

are useful in predicting genetic gains that may result from positive genetic relationships between traits or possible deterioration in traits negatively correlated with others. Sampling errors are usually large and for this reason genetic correlations often lack precision. The standard errors of the estimates in this study indicate that little reliance can be placed on some of the values but for others they show that the calculated relationships may be quite accurate. Since a positive genetic correlation between two traits results in simultaneous progress for both traits when selection for either is applied, much progress can be made in improving a particular trait without detriment to overall merit if the trait is positively correlated with most others. The higher the heritability of the trait the faster will be the progress. A good example of this is the work of Neale (1946) in New Mexico. He selected only for staple length and made considerable progress without noting deterioration in other traits. The results of the present study indicate that staple length is positively correlated with all other traits except yearling body weight (noted also by Karam, 1953) and yearling condition and fleece character.

The most important genetic correlation limiting genetic improvement as determined in this study is that between yearling body weight and yearling fleece character. The negative correlation between yearling weight and fleece character is large enough to warrant consideration if quality of fleece should become a factor necessitating major attention for improvement. In the interpretation of the correlations between characters it must be remembered that the correlation coefficients in themselves do not give the necessary information to distinguish between the cause and effect of the relationship.

SUMMARY

Estimates of heritability of the important economic characters in Columbia and Columbia X Southdale sheep at weaning and yearling ages were obtained as well as the phenotypic and genetic correlations among these traits. Information concerning the effects of year of birth, age of dam, type of birth and rearing, sex, breed, and station on the weaning and yearling traits was acquired.

Data were available on 2442 lambs from 1707 ewes for weaning weight analysis. The lambs were predominantly of the Columbia X Southdale strain. The Columbia X Southdale lambs were raised at Middlebury, Vermont and Beltsville, Maryland, while the Columbias were reared at the Middlebury Station only. Numbers of records for the other traits were not as large, many of the lambs having been culled before yearling age.

Three weanling traits and six yearling traits were considered on each individual. The traits were scored or measured at about 140 days of age for the weanlings. Yearling measurements were made when the sheep were approximately 13 months old. The nine traits considered were: weaning weight, weaning type, weaning condition, yearling body weight, yearling type, yearling condition, yearling fleece weight, yearling fleece character, and yearling staple length.

The traits most influenced by the environmental effects (table 12 and 13) were weaning weight, weaning type, weaning condition, yearling body weight, and yearling fleece weight. The year of birth was the most consistent cause of environmental differences of any of the effects studied.

Heritabilities (table 18) of weaning weight, weaning type, weaning condition, and yearling body weight were found to be 0.14, 0.14, 0.15 and 0.13 respectively. Heritability values for yearling type, condition, fleece weight, fleece character and staple length were 0.32, 0.45, 0.69, 0.66 and 0.73 respectively. The estimates were obtained by paternal half-sib analysis.

The 36 phenotypic correlations (table 19) were all of a positive nature with the exception of four and only one of these negative relationships, between yearling fleece weight and fleece character, was statistically significant. Correlations of the greatest magnitude were found among the weanling body traits. The yearling traits were not highly correlated with the exception of type and condition (0.68).

The genetic correlations (table 21) revealed genetic antagonisms which might impede genetic progress if ignored in selection procedures. Negative genetic correlations were found between yearling body weight and weaning type, yearling fleece character and yearling staple length. Yearling fleece weight was negatively correlated with yearling condition, Yearling type and yearling fleece character. Staple length was negatively correlated with yearling condition and fleece character. The majority of all traits were positively correlated and weaning weight showed a positive relationship with every other trait.

The comparison between the Columbia and Columbia X Southdale sheep showed the Columbia's to rank heavier in weaning weight, yearling weight, yearling fleece weight and longer in yearling staple length. The Columbia X Southdale's ranked higher in weaning type, condition, yearling type, condition and fleece character scores.

No attempt has been made in this study to set economic values on the traits studied nor to develop a selection index, although such an index could logically be constructed as an extension of this investigation.

LITERATURE CITED

Ali, K. T. 1952. The heritability of and the effects of some environmental factors on the birth weight, weaning weight and the grease fleece weight of sheep. Univ. of Minn. Pub. No. 3434.

Bailey, C. M., A. B. Chapman, A. L. Pope and L. L. Felts. 1961. Selection of lambs under farm conditions. J. Animal Sci. 20:680. (Abstr.).

Balch, D. J. 1956. Tailored sheep. Vermont Farm and Home Sci. 1(3):8-10.

Barnicoat, C. R., A. G. Logan and A. D. Grant. 1949. Milk secretion studies with New Zealand Romney ewes. J. Agr. Sci. 39:44-45, 237-248.

Blackwell, R. L. and C. R. Henderson. 1955. Variation in fleece weight, weaning weight and birth weight of sheep under farm conditions. J. Animal Sci. 14:831-843.

Blunn, Cecil T. and James O. Grandstaff. 1945. Comparison of the yield of side samples from weanling and yearling sheep. J. Animal Sci. 4:122-127.

Bonsma, F. N. 1939. Factors influencing the growth and development of lambs with special reference to crossbreeding of Merino sheep for fat lamb production in South Africa. Univ. Pretoria Pub., Ser. 1, Agr. No. 48.

Carter, R. C. and C. M. Kincaid. 1959. Estimates of genetic and Phenotypic parameters in beef cattle. III. Genetic and phenotypic correlations among economic characters. J. Animal Sci. 18:331.

Chapin, Miriam. 1959. Sheep in Vermont. Vermont Life 13(3):4-17.

Cockerham, C. Clark. 1949. Estimates of repeatability and heritability in sheep. Unpublished M. S. Thesis. N. Carolina State College Library, Raleigh, N. C.

Dickerson, G. E. 1955. Genetic slippage in response to selection for multiple objectives. Cold Spr. Harb. Symp. Quant. Biol. 20:213-224.

Dickerson, G. E. and L. N. Hazel. 1944. Effectiveness of selection on progeny testing performance as a supplement to earlier culling in livestock. J. Agr. Res. 69:459-476.

Donald, H. P. and J. W. McLean. 1935. The growth rate of lambs in Canterbury. A preliminary study of the variation in the growth-rate of lambs in Canterbury. New Zealand J. Sci. and Tech. 17:497-519.

Ercanbrack, S. K. 1952. Selection indexes for range Rambouillet, Columbia and Targhee lambs. Unpublished Ph.D. Thesis. Iowa State College Library, Ames, Iowa.

Falconer, D. S. 1960. Introduction to quantitative genetics. The Ronald Press Company, New York.

Felts, V. L., A. B. Chapman and A. L. Pope. 1957. Estimates of genetic and phenotypic parameters for use in a farm ewe selection index. J. Animal Sci. 16:1048 (Abstr.).

Fisher, R. A. 1918. The correlation between relatives on the supposition of Mendelian inheritance. Tran. Roy. Soc. Edinburgh 52:399-433.

Fisher, R. A. 1936. Statistical methods for research workers.(6th ed.) Oliver & Boyd, Edinburgh, London.

Givens, C. S., Jr. 1958. A selection index for weanling traits in spring lambs. Unpublished M. S. Thesis. Virginia Polytechnic Institute Library, Blacksburg, Va.

Givens, C. S., Jr., R. C. Carter and J. A. Gaines. 1960. Selection indexes for weanling traits in spring lambs. J. Animal Sci. 19:134-139.

Goot, H. 1945. Hairiness in wool. Part II. Yearly changes in hairiness in New Zealand Romney Marsh sheep. New Zealand J. Sci. and Tech. Sect. A, 27:173-187.

Grandstaff, J. O. 1948. Comparison of Corriedale X Navajo and Romney X Navajo crosses. J. Animal Sci. 7:455-465.

Grandstaff, James O. and H. W. Wolf. 1947. Relation of kemp and other medullated fibers to age in the fleeces of Navajo and crossbred lambs. J. Animal Sci. 6:133-140.

Hale, R. W. 1961. Heritabilities and genetic correlations of egg production and other characters in a White Wyandotte flock. Animal Production 3:73-87.

Hammond, J. 1932. Growth and development of mutton qualities in the sheep. Oliver and Boyd, Edinburgh, London.

Hardy, John I. 1943. Sampling fleeces for determining average wool fineness. U. S. Dept. Agr. Circ. 680.

Hazel, L. N. 1943. The genetic basis for constructing selection indexes. Genetics. 28:476-490

Hazel, L. N. 1946. A note on the covariance analysis of multiple classification tables with unequal subclass numbers. Biometrics Bul. 2:21-25.

Hazel, L. N., M. L. Baker and C. F. Reinmiller. 1943. Genetic and environmental correlations between the growth rates of pigs at different ages. J. Animal Sci. 2:118.

Hazel, L. N. and C. E. Terrill. 1945a. Heritability of weaning weight and staple length in range Rambouillet lambs. J. Animal Sci. 4:347-358.

Hazel, L. N. and C. E. Terrill. 1945b. Effects of some environmental factors on weanling traits of range Rambouillet lambs. J. Animal Sci. 4:331-341.

Hazel, L. N. and C. E. Terrill. 1946a. Heritability of type and condition in range Rambouillet lambs as evaluated by scoring. J. Animal Sci. 5:55.

Hazel, L. N. and C. E. Terrill. 1946b. Heritability of weanling traits in range Columbia, Corriedale and Targhee lambs. J. Animal Sci. 5:371-377.

Hazel, L. N. and C. E. Terrill. 1946c. Effects of some environmental factors on fleece and body characteristics of range Rambouillet yearling ewes. J. Animal Sci. 5:382-388.

Hazel, L. N. and C. E. Terrill. 1946d. Effects of some environmental factors on weanling traits of range Columbia, Corriedale and Targhee lambs. J. Animal Sci. 5:318-325.

Henderson, C. R. 1948. Estimation of general, specific and maternal combining abilities in crosses among inbred lines of swine. Unpublished Ph.D. Thesis. Iowa State College Library, Ames Iowa.

Hill, J. A. 1921. Studies in the variation and correlation of fleeces from range sheep. Wyo. Agr. Exp. Sta. Bul. 127.

Hundley, W. S., Jr. 1956. Heritability and correlation of some economic characters in mutton type sheep. Unpublished M. S. Thesis. Virginia Polytechnic Institute Library, Blacksburg, Va.

Jones, J. M., W. H. Dameron, S. P. Davis, B. L. Warwick and R. E. Patterson. 1944. Influence of age, type, and fertility in Rambouillet ewes on fineness of fiber, fleece weight, staple length, and body weight. Texas Agr. Exp. Sta. Bul. 657.

Jones, J. M., Paul Homeyer, S. P. Davis, W. H. Dameron, and B. L. Warwick. 1936. A comparison of fleeces from B and C type Rambouillet ewes. Proc. Am. Soc. An. Prod. 29:155-158.

Karam, H. A., A. B. Chapman and A. L. Pope. 1953. Selecting lambs under farm flock conditions. J. Animal Sci. 12:148-164.

Kincaid, C. M. and R. C. Carter. 1958. Estimates of genetic and phenotypic parameters in beef cattle. I. Heritability of growth rate estimated from response to sire selection. J. Animal Sci. 3:675-683.

Kyle, W. H. and C. E. Terrill. 1953. Heritabilities and repeatabilities of fleece and body traits of Rambouillet, Targhee, and Columbia sheep born in 1951. Mimeo. Presented at meetings of Am. Soc. An. Prod., November 27-28.

Lush, J. L. 1935. The inheritance of productivity in farm livestock. Part V. Discussion of Preceding Contributions. Emp. J. Exp. Agr. 3:25-30.

Lush, J. L. 1941. Intra-sire correlations or regressions of offspring on dam as a method of estimating heritability of characteristics. Proc. Am. Soc. An. Prod. 34:293-301.

Lush, J. L. 1945. Animal breeding plans. (3rd ed.) The Iowa State College Press. Ames, Iowa.

Lush, J. L. 1948. The genetics of populations. (Mimeo.) Iowa State College, Ames, Iowa.

Lush, J. L. 1949. Heritability of quantitative characters in farm animals. Proc. 8th Int. Congress Genet. Stockholm, Hereditas, Suppl. Vol. pp. 356-375.

MacNaughton, W. N. 1957. Repeatability and heritability of birth, weaning, and shearing weights among range sheep in Canada. Iowa State College J. Sci. 31:465-467 (Abstr.).

Marshall, F. R. 1949. The making of the Columbia sheep. National Wool Grower. 39(4):9-32.

McGilliard, L. D. 1955. Off-diagonal elimination procedures for solving simultaneous equations. An. Husb. Dept., Iowa State College, Ames, Iowa. (Mimeo.).

McMahon, P. R. 1943. The inheritance of multifactor characters in sheep. Proc. New Zealand Soc. An. Prod. (Mimeo.).

Morley, F. H. W. 1950. Selection for economic characters in Merino sheep. Unpublished Ph.D. Thesis. Iowa State College Library, Ames, Iowa.

Morley, F. H. W. 1955. Selection for economic characters in Australian Merino sheep. Aust. J. Agr. Res. 6:77-90.

Neale, P. E. 1946. Corrective sheep breeding. New Mexico Agr. Exp. Bul. 334.

Nelson, R. H. and G. Venkalatachalam. 1949. Estimates of heritability of birth weights and weaning weights of lambs. J. Animal Sci. 8:607-608 (Abstr.).

Pohle, E. M. 1942. Relationship between weanling and yearling fleece characters in range sheep. J. Animal Sci. 1:229-235.

Pohle, E. M. and L. N. Hazel. 1944. Clean wool yields in small samples from eight body regions as related to whole fleece yields in four breeds of sheep. J. Animal Sci. 2:159-165.

Pohle, E. M., L. N. Hazel and H. R. Keller. 1945. The influence of location and size of sample in predicting whole-fleece clean yields. J. Animal Sci. 4:104-112.

Pohle, E. M. and R. G. Schott. 1943. Wool fineness in eight sampling regions on yearling Rambouillet ewes. J. Animal Sci. 2:197-208.

Phillips, R. W. and G. W. Brier. 1940. Estimating weights of lambs at a constant age. U. S. Dept. Agr. Circ. 541.

Phillips, R. W. and W. M. Dawson. 1937. The relation of type and time of birth and birth weight of lambs to their survival, growth and suitability for breeding. Proc. Am. Soc. An. Prod. 30:276-306.

Phillips, R. W. and W. M. Dawson. 1940. Some factors affecting survival, growth and selection of lambs. U. S. Dept. Agr. Circ. 538.

Phillips, R. W., R. G. Schott, and D. A. Spencer. 1945. The genetics, physiology and economic importance of the multinipple trait in sheep. U. S. Dept. Agr. Tech. Bul. 909.

Phillips, R. W., J. A. Stoehr and A. W. Brier. 1940. Growth in Corriedale and Rambouillet sheep under range conditions. Proc. Am. Soc. An. Prod. 33:173-181.

Price, D. A., G. M. Sidwell and J. O. Grandstaff. 1953. Effects of some genetic and environmental factors on yearling traits of Navajo and Navajo crossbred ewes. J. Animal Sci. 12-697-703.

Rae, A. L. 1948. Some aspects of progeny testing in sheep. Proc. New Zealand Soc. An. Prod. 8:97-104.

Rae, A. L. 1950. Genetic variation and covariation in productive characters of New Zealand Romney Marsh sheep. Unpublished Ph.D. Thesis. Iowa State College Library, Ames, Iowa.

Rasmussen, K. 1942. The inheritance of fleece weights in range sheep. Sci. Agr. 23:104-116.

Rice, V. A., F. N. Andrews, E. J. Warwick and J. E. Legates. 1957. Breeding and improvement of farm animals. (5th ed.) McGraw-Hill Book Company, Inc., New York.

Schinckel, P. G. 1960. Variation in feed intake as a cause of variation in wool production of grazing sheep. Aust. J. Agr. Res. 2:585-594.

Serra, J. A. 1948. Génétique du mouton. Publ. Junta, Pecuar. Lisbon. Series A No. 1.

Sidwell, G. M. 1954. A selection index for Navajo crossbred range lambs. Unpublished Ph.D. Thesis. Iowa State College Library, Ames, Iowa.

Sidwell, G. M. and J. O. Grandstaff. 1949. Size of lambs at weaning as a permanent characteristic of Navajo ewes. J. Animal Sci. 8:373-380.

Sidwell, G. M., J. O. Grandstaff and D. A. Price. 1951a. Genetic and environmental factors affecting staple length in Navajo and Navajo crossbred weanling lambs. J. Animal Sci. 10:278-283.

Sidwell, G. M., D. A. Price and J. O. Grandstaff. 1951b. Genetic and environmental factors affecting type and condition in Navajo and Navajo crossbred weanling lambs. J. Animal Sci. 10:455-461.

Snedecor, G. W. 1946. Statistical Methods. (4th ed.) The Iowa State College Press, Ames, Iowa.

Spencer, D. A. 1955. Personal letter describing the Southdale strain of sheep; on file at the Dept. of Animal & Dairy Science, University of Vermont, Burlington, Vermont.

Spencer, D. A., J. I. Hardy, and Mary J. Brandon. 1928. Factors that influence wool production with range Rambouillet sheep. U. S. Dept. Agr. Tech. Bul. 85.

Stonaker, H. H. and Jay L. Lush. 1942. Heritability of conformation in Poland China Swine as evaluated by scoring. J. Animal Sci. 1:99-105.

Swiger, L. A. 1961. Genetic and environmental influences on gain of beef cattle during various periods of life. J. Animal Sci. 20:183-188.

Terrill, C. E. 1955. Improvement of sheep through selection. Sheep and Goat Raiser. June, pp. 8-9.

Terrill, C. E. 1957. Personal communication.

Terrill, C. E. and L. N. Hazel. 1943. Heritability of yearling fleece and body traits of range Rambouillet ewes. J. Animal Sci. 2:358-359 (Abstr.).

Terrill, C. E. and L. N. Hazel. 1946. Heritability of face covering and neck folds in range Rambouillet lambs as evaluated by scoring. J. Animal Sci. 5:170-179.

Terrill, C. E., W. H. Kyle and L. N. Hazel. 1950. Correlations between traits of range Rambouillet rams. J. Animal Sci. 9:640 (Abstr.).

Terrill, Clair E., Elroy M. Pohle, L. Otis Emik and Lanoy N. Hazel. 1945. Estimation of clean-fleece weight from grease-fleece weight and staple length. J. Agr. Res. 70:1-10.

Terrill, C. E., G. M. Sidwell and L. N. Hazel. 1947. Effects of some environmental factors on yearling traits of Columbia and Targhee ewes. J. Animal Sci. 6:115-122.

Terrill, C. E., G. M. Sidwell and L. N. Hazel. 1948a. Effects of some environmental factors on yearling traits of Columbia and Targhee rams. J. Animal Sci. 7:181-189.

Terrill, C. E., G. M. Sidwell and L. N. Hazel. 1948b. Effects of some environmental factors on traits of yearling and mature Rambouillet rams. J. Animal Sci. 7:311-319.

U. S. Dept. Agr. Bureau of Animal Industry. Range-sheep-breeding investigation Score-Record Book. A. H. Form-534.

U. S. Dept. Agr., Agr. Res. Adm. 1946. Research Line Project Outline. ARA Form No. 1. Rev. March 4.

Verges, J. B. 1939. Effect of nutrition on the carcass quality of Suffolk cross lambs. Suffolk Sheep Soc. Yearbook, pp. 27-37.

Wallace, L. R. 1948. The growth of lambs before and after birth in relation to the level of nutrition. J. Agr. Sci. 38:93-153.

Warwick, B. L. and T. C. Cartwright. 1957. Heritability of weaning weight of milk lambs. J. Animal Sci. 16:1025 (Abstr.).

Western Sheep Breeding Laboratory. 1946. (9th Ann. Rept.) Unpublished research. Dubois, Idaho.

Wright, S. 1921. Systems of mating. Genetics 6:111-178.

Wright, Sewall. 1939. Genetic principles governing the rate of progress of livestock breeding. Proc. Am. Soc. An. Prod. 32:18-26.

Yates, F. 1934. The analysis of multiple classification tables with unequal numbers in the different classes. J. Am. Stat. Assn. 29:51-66.

The two page vita has been removed from the scanned document. Page 1 of 2

The two page vita has been removed from the scanned document. Page 2 of 2

APPENDIX A

System of Coding for Subjective Scores

Scores for weaning type, weaning condition, yearling type, yearling fleece character were recorded according to the system developed by the United States Sheep Experiment Station (U.S. Dept. of Agr. Bureau of Animal Industry, A. H. Form-534). As explained in Part C, Section III. this system consists of units ranging from 1 to 5 with the most desirable animals being scored 1 and the most inferior ones being scored 5. Each unit is further refined by the inclusion of a plus or minus rating making possible 15 different scores.

These scores were coded prior to analysis of the data in order to give the highest scoring animals the highest numerical rating for the purpose of simplifying the interpretation of results. The scores were coded as follows:

Score recorded	Coded score
1+	16
1	15
1-	14
2+	13
2	12
2-	11
3+	10
3	9
3-	8
4+	7
4	6
4-	5
5+	4
5	3
5-	2

In the interpretation of results, therefore, the highest numerical scores indicate the greatest merit for the trait in question.

APPENDIX B

Unadjusted and Adjusted Means

Trait	Number of records	Mean	
		Unadjusted	Adjusted
Weaning weight	2433	58.25 ± 12.69[1]	61.26 ± 11.05[1]
Weaning type score	2010	10.92 ± 1.73	13.16 ± 1.64
Weaning condition score	2010	10.55 ± 2.00	12.96 ± 1.71
Yearling body weight	1037	88.27 ± 23.77[1]	79.18 ± 19.71[1]
Yearling type score	947	11.98 ± 1.41	13.34 ± 1.45
Yearling condition score	947	12.53 ± 1.41	13.53 ± 1.32
Yearling fleece weight	1037	9.37 ± 2.27[1]	8.02 ± 1.61[1]
Yearling fleece character score	947	12.70 ± 1.41	12.76 ± 1.19
Yearling staple length	666	12.25 ± 2.05[2]	12.00 ± 1.66[2]

For scoring system, see Appendix A
1 In pounds
2 In centimeters

APPENDIX C

Phenotypic Correlations Among Weanling and Yearling Traits Calculated From Unadjusted and Adjusted Data

	Weaning type	Weaning condition	Yearling body weight	Yearling fleece weight	Yearling type	Yearling condition	Yearling fleece character	Yearling staple length
Weaning weight (Unadjusted)	0.51	0.48	0.44	0.48	0.07	-.12	-.18	0.09
(Adjusted)	0.65	0.62	0.22	0.26	0.20	0.10	0.02	0.10
Weaning type		0.85	0.08	0.05	0.19	0.12	0.09	-.0033
		0.82	0.06	0.15	0.15	0.10	-.01	0.09
Weaning condition			0.08	0.03	0.18	0.15	0.12	0.03
			0.13	0.14	0.16	0.14	0.02	0.05
Yearling body weight				0.47	0.09	0.02	-.20	0.23
				0.26	0.24	0.24	-.02	0.06
Yearling fleece weight					-.08	-.05	-.35	0.47
					0.05	-.02	-.13	0.27
Yearling type						0.63	0.38	0.14
						0.68	0.26	0.07
Yearling condition							0.39	0.24
							0.28	0.02
Yearling fleece character								-.015
								0.0033

ESTIMATES OF GENETIC AND PHENOTYPIC PARAMETERS
IN COLUMBIA AND COLUMBIA X SOUTHDALE SHEEP

Donald James Balch

The primary purpose of the study was to obtain estimates of heritabilities of the important economic characters in Columbia and Columbia X Southdale sheep at weaning and yearling ages as well as the phenotypic and genetic correlations among these traits. Information was acquired concerning the effects of year of birth, age of dam, type of birth and rearing, sex, breed, and station on the weanling and yearling traits considered.

Data were available on 2442 lambs from 1707 ewes for weaning weight analysis. The lambs were predominantly of the Columbia X Southdale strain. The Columbia X Southdale lambs were raised at Middlebury, Vermont and Beltsville, Maryland, while the Columbias were reared at the Vermont Station only. Numbers of records for the other traits were not as large, many of the lambs having been culled before yearling age.

Three weanling traits and six yearling traits were considered on each individual. The traits were scored or measured at about 140 days of age for the weanlings. Yearling measurements were made when the sheep were approximately 13 months old. The nine traits evaluated were: weaning weight, weaning type, weaning condition, yearling body weight, yearling type, yearling condition, yearling fleece weight, yearling fleece character, and yearling staple length.

The traits most influenced by the environmental effects were weaning weight, weaning type, weaning condition, yearling body weight, and

yearling fleece weight. The year of birth was the most consistent cause of environmental differences of any of the effects studied.

Heritabilities of weaning weight, weaning type, weaning condition, and yearling body weight were found to be 0.14, 0.14, 0.15 and 0.13 respectively. Heritability values for yearling type, condition, fleece weight, fleece character and staple length were 0.32, 0.45, 0.69, 0.66 and 0.73 respectively. The estimates were obtained by paternal half-sib analysis.

The 36 phenotypic correlations were all of a positive nature with the exception of four and only one of these negative relationships, between yearling fleece weight and fleece character, was statistically significant. Correlations of the greatest magnitude were found among the weanling body traits. The yearling traits were not highly correlated with the exception of type and condition (0.68).

The genetic correlations revealed genetic antagonisms which might impede genetic progress if ignored in selection procedures. Negative genetic correlations were found between yearling body weight and weaning type, yearling fleece character and yearling staple length. Yearling fleece weight was negatively correlated with yearling condition, yearling type and yearling fleece character. Staple length was negatively correlated with yearling condition and fleece character. The majority of all traits were positively correlated and weaning weight showed a positive relationship with every other trait.

The comparison between the Columbia and Columbia X Southdale sheep showed the Columbias to rank heavier in weaning weight, yearling weight, yearling fleece weight and longer in yearling staple length. The Columbia X Southdale ranked higher in weaning type, condition, yearling type, condition and fleece character scores.

The estimates of genetic parameters obtained in the study form important guidelines for the development of future selection procedures, thus making possible more rapid progress in the improvement of the flocks studied.