ESTIMATES OF SOME SOURCES OF VARIATION IN THE RATE OF GAIN OF CROSSBRED MILK LAMBS AT DIFFERENT AGES

By

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INTRODUCTION

A large portion of the commercial sheep industry in Oklahoma and adjacent areas consists of the production of "spring" milk-fed fat lambs. The success of this type enterprise depends upon the use of ewes that will breed out of season (spring) and the availability of a succulent pasture as a source of cheap feed. The most desirable type of lamb is one that grows rapidly to market weight and possesses sufficient finish to bring a top or near top market price.

The individual lamb's growth is strongly influenced by its dam's milk supply and mothering ability, especially during the early stages of the lamb's life. On the basis of this maternal influence on a lamb's growth, it appears that the weight of a lamb at some early age might be a good indication of its dam's productivity. Likewise, a later weight of the same lamb might be a good index of its own ability to grow as it becomes less dependent on its dam and is able to utilize sources of nutrients other than its dam's milk.

Due to differences in sex, type of rearing (single or twin), type of birth (single or twin) and birth weight, lambs of equal genetic merit may differ considerably in their individual weights. It is also possible that a lamb of inferior genetic merit may out weigh a superior lamb because of these environmental factors. These differences in lamb weights cause the breeder to make mistakes in culling the less productive ewes and in the selection of the most desirable lambs for replacements.

It is the purpose of this study to obtain a measure of the effect of certain environmental factors on the weights of lambs at different ages. The sources of variation studied were breed of dam, sex, birth type (single or twin), type of rearing (single or twin) and birth weight.

REVIEW OF LITERATURE

Many factors influence the weight of an individual lamb at a particular age. By the judicious use of improved statistical methods, many of these factors can be measured to determine how much importance should be attributed to a particular source of variation.

Phillips and Dawson (1940) proposed three methods whereby differences due to sex, type of birth and time of birth could be at least partially overcome in the selection of breeding animals. One, separate the lambs into groups according to sex, type of birth and time of birth and make selections within these groups. Two, make selections at a standard age using adjustments for sex and birth factors. Three, postpone selection until a later age when these differences become more nearly equalized and are less important.

Hazel and Terrill (1945) (1946a) reported that 33 to 49.5 percent of the variation in the body weight of 2135 Rambouillet, 478 Columbia, 238 Corriedale and 366 Targhee lambs could be accounted for by differences due to sex, age of dam, birth type, age at weaning and percent inbreeding of these lambs reared under range conditions. These workers suggested that by considering the more important sources of variation, the breeder will be able to increase the improvement expected from selection.

Price et al. (1953) accounted for 47.8 percent of the variation in the body weights of 917 Navajo and Navajo crossbred yearling ewes. Some of the major sources of variation reported were age of dam, breeding groups, type of birth and rearing, differences between years and the age of the ewe when the weights were taken.

Weaning weights of 1295 lambs from 463 ewes were analyzed by Blackwell and Henderson (1955). These lambs were reared under farm flock conditions in the Northeastern section of the United States. Differences in weights due to sex, breed, age of ewe, type of birth and rearing and the age of the lamb at weaning were estimated by least squares analysis. These factors were found to be significant sources of variation.

Coefficients of determination were calculated by deBaca and co-workers (1956) as a result of estimates of certain factors effecting the 120 day weights of 280 crossbred lambs. The effect of breed of sire, breed of dam, the interaction between sire and dam breeds, birth type, sex, the interaction between birth type and sex were estimated by least squares analysis. The resulting coefficients of determination ranged from .45 to .70. When the effect of birth weight was removed in addition to the other effects, the resulting coefficients of determination ranged from .68 to .78. All of these coefficients were highly significant.

Effect of Breed

Sheep breeding is perhaps unique in that many breeds which are currently popular in a particular area were developed to satisfy that particular environment. Crossbreeding is also a common breeding practice of many commercial sheep breeders.

A comparison of Hampshire and Rambouillet rams as sires of market lambs was reported by Joseph (1931). Under range conditions the Rambouillet sired lambs did better in hard years, but the Hampshire sired lambs were better adapted for the early fat lamb market during good years. Hultz et al. (1935) divided 100 Western yearling ewes into several lots and mated a different breed of ram to each lot. The rams were rotated each year in an attempt to determine which ram breed sired the most desirable type market lamb. Age for age the Suffolk sired lambs gained from 15 to 20 pounds more than the other crossbred lambs. The Southdown sired lambs processed the most finish and the most desirable carcass at market time.

Miller (1935) bred 120 grade Rambouillet and 80 Romney-Rambouillet ewes to Hampshire, Suffolk, Shropshire, Southdown, Romney and Rambouillet rams. Comparisons of the ewe groups showed that the Rambouillet ewes sheared heavier fleeces and produced a higher percent lamb crop. The Rambouillet ewes also produced a heavier lamb at market time but this was principly due to the fact that they bred earlier in the season so consequently their lambs were older at market time. The Suffolk and Hampshire rams sired the heaviest lambs at market time and were the most profitable. The Southdown and Shropshire sired lambs were of higher quality but lighter in respect to carcass weight.

Christian and Henning (1949) found that three breed cross ewes (Hampshire X Dorset-Merino and Dorset X Corriedale-Merino) raised superior quality and faster growing lambs than two breed cross ewes when bred to Southdown and Shropshire rams.

The Targhee breed is a good example of a breed developed to fulfill the requirements of mountain range conditions. Terrill (1947) described the Targhee as a polled white faced sheep of intermediate size and better mutton conformation than most fine wool breeds. In an effort to find other suitable crosses to increase the number of Targhee sheep, comparisons were made between 599 Targhee lambs and 415 crossbred lambs. Comparisons between 439 Targhee yearling and 262 crossbred yearling ewes were also reported. The author found that Columbia rams mated to Rambouillet ewes produced lambs which met the requirements of this environment whereas matings between Targhee rams and Rambouillet ewes produced lambs which tended to be wool blind and shear a less desirable fleece and also lacked carcass conformation and finish.

Hazel and Terrill (1946a) determined the differences in weaning weight due to breed effect of 478 Columbia, 238 Corriedale and 366 Targhee lambs by analysis of variance techniques. The Columbia lambs were significantly heavier at weaning than the Targhee and Corriedale lambs by 7.2 and 8.8 pounds, respectively. The difference between the Targhee and Corriedale lambs was not significant.

Grandstaff (1948) mated Corriedale and Romney rams to old type Navajo ewes. A total of 817 matings resulting in an average of 89 percent pregnancies in each cross were studied. The Corriedale crosses excelled in the percentage of lambs born and reared and the rate of gain between birth and weaning. The differences between average weaning weight (3.86 pounds) and the pounds of lamb produced per ewe (15.2 pounds) in favor of the Corriedale crosses were highly significant. Price et al. (1953) investigated some of the factors influencing the yearling traits of 917 ewes retained from 1325 ewe lambs. The analysis revealed that breed differences were an important source of variation and accounted for 9.4 percent of the variation in body weight of these yearling ewes based on the difference between twelve different crossbred groups.

Comparisons of reciprocal crosses of two breeds of Egyptian sheep were reported by Asker et al. (1954). The differences between body weight of the crosses at birth and 4 months were statistically significant. These workers concluded that the differences were influenced mainly by the differences in body size and milk production of the dams.

deBaca and coworkers (1956) found that some of the variation in the 120 day weights of 280 crossbred lambs could be attributed to the interaction between the breed of sire and breed of dam. The breed interaction effect was not significant in all crosses but tended to increase when wider crosses were made. They concluded that some of this increase may have been due to heterosis.

Winters *et al.* (1946) maintained performance records on 603 ewes to study some of the factors effecting ewe productivity. The results of the study indicated that there are rather definite breed differences. In general, crossbreds performed better than the average of the breeds in the cross. Miller and Daily (1951) reported that Shropshire, Hampshire and Columbia ewes produced 19 percent more lamb per 100 pounds of ewe when mated to another breed. The average total productivity was 16 percent more for the ewes used in the 555 crossbred matings. The crossbred lambs had a lower mortality rate and were heavier than the purebred lambs. These workers concluded that the increased productivity as a result of crossbreeding was likely due to differences in breed size and heterosis.

Effect of Birth Type and Rearing

Most lambs are reared by their own dams in the same manner as they are born, that is singles as singles and twins as twins, consequently the effects of birth type and rearing will be considered together. However, it is not possible to consider these two factors as a single unit, for if one of a pair of twins dies or is reared by a different ewe, its mate must be considered as being raised as a single.

Hammond (1932) reported that at birth, singles were 29 percent heavier than twins. He also reported that as the lambs become older the differences between singles and twins becomes less important.

Phillips and Dawson (1937) (1940) stated that in the selection of breeding animals, singles are favored over twins even though no conscious effort has been made to favor the single lambs. Single lambs in this study of 1864 birth weights were significantly heavier at birth and were more vigorous at birth. Single lambs were also noted to grow faster during earlier life. Venkatachalam <u>et al</u>. (1949) investigated the births of 483 lambs representing 6 different breeds. These workers noted that there was a highly significant increase in the percent death losses among twin births as compared to single births. The incidence of death loss was 15 percent higher among the twins. Sidwell (1956) compared single and twin lambs born and reared under range conditions. These data were collected over a 6 year period and a total of over 5800 lambs were studied. Single lambs were significantly heavier than twins at weaning. There was also a higher mortality rate among the twin lambs.

Kean and Henning (1949) reported the average daily gain of 317 twin lambs and 443 single lambs to be 0.45 pound per day and 0.60 pound per day, respectively. These lambs were raised during the early spring as hothouse lambs. Thomson and McDonald (1956) examined the relationship between birth and weaning weight of 688 lambs. When the twins were both of the same sex, the lamb heaviest at birth was also heaviest at weaning in over 50 percent of the cases. When the twins were of mixed sexes, the lamb heaviest at birth was heaviest at weaning in 80 percent of the cases when the male was heaviest at birth, and in 50 percent of the cases when the female was heavier at birth. These differences were statistically significant. Botkin et al. (1956) used the 140 day weaning weight of 1020 Rambouillet lambs and the 200 day weaning weight of 480 Rambouillet lambs reared under range conditions to investigate some of the factors influencing the weaning weights of these lambs. They found that the single lambs weaned at 140 days of age were 14 pounds heavier than the twins and that the singles weaned at 200 days were 8 pounds heavier than twins. This indicates that birth type differences and rearing differences tend to become smaller as the lambs grow older.

U.S.D.A. workers Hazel and Terrill (1945) estimated the differences due to birth type and rearing on the weaning weights of 2183 range Rambouillet lambs by a method of fitting constants by least squares analysis. Singles were found to be 9.2 pounds heavier than twins reared as twins and 2.4 pounds heavier than twins reared as singles at 120 days. Type of birth accounted for 12.2 percent of the variation in weaning weights of these lambs. From this groups of lambs, 932 were studied as yearling ewes by Hazel and Terrill (1946b). The constants obtained for the difference between single and twins reared as twins and for the difference between singles and twins reared as singles were 6.0 and 0.5 pounds, respectively. These results would indicate that the rearing differences were less important at the yearling age than at the weanling age. A similar investigation was conducted by Hazel and Terrill (1946a) on 478 Columbia, 238 Corriedale and 366 Targhee lambs weaned at 120 days. Singles were reported to be 11.7 pounds heavier than twins reared as twins and 5.1 pounds heavier than twins reared as singles. Part of the ewe lambs reported in this study in addition to ewe lambs retained in subsequent years were studied as yearlings by Terrill et al. (1947). A total of 406 Columbia and 290 Targhee yearling ewes were studied. Type of birth had an importand effect on body weight accounting for 7 percent of the total variation in the Columbia ewes and 13 percent of the variation in Targhee yearling ewes. Constants calculated for the differences between singles and twins reared as twins and twins reared as singles for the Columbia ewes were 7.12 and 2.37 pounds, respectively. The constants estimated for the Targhee ewes were 4.70 pounds for the difference between singles and twins reared as twins and 7.42 pounds between singles and twins reared as singles. No explanation was given for the apparent depressing effect of the twins reared as singles among the Targhee ewes.

By analysis of variance techniques, Blackwell and Henderson estimated the effects due to birth type and rearing on the weaning weights of 1295 lambs. They reported that type of birth and rearing have a significant effect on the weaning weights of lambs. Single lambs were 5.38 ± 1.13 pounds heavier than twins reared as single and 8.29 ± 0.899 pounds heavier than twins reared as twins. Differences due to birth type and rearing on 485 Dorset lambs were single minus twins reared as twins 7.89 ± 1.154 pounds. The difference due to type of birth on birth weight was 1.85 ± 0.094 in favor of the single birth type in the Corriedale, Hampshire and Shropshire data. Results from the Dorset birth weights indicated a difference of 1.20 ± 0.133 pounds in favor of the single birth type.

Estimates of the effect of birth type and rearing on 280 crossbred spring lambs was reported by deBaca et al. (1956). These workers obtained estimates in favor of single lambs ranging from 0.84 to 5.98 pounds in weaning weight. A non-significant interaction between birth type and sex was reported. Birth type differences were not consistent between sexes. Bogart and coworkers (1957) calculated a constant for the effect of birth type on birth weight. These estimates ranged from 1.02 to 2.40 pounds in favor of the single birth type. These authors concluded that the effect on birth weight due to birth type was the most consistent of the factors studied.

Effect of Sex

When comparisons are made between ewes on the basis of the weight of their lambs at particular age, the sex of the lamb may be an important consideration in these comparisons.

Mumford (1901) reported that males were 16 percent heavier than females at birth. The male lambs made slightly better gains than females from birth to 7 weeks.

Phillips and Dawson (1937) (1940) investigated the effect of sex on birth weight and subsequent gains of 1864 lambs. The analysis indicated that males were significantly heavier than females at all ages. Male lambs that were heavier at birth survived better than lighter male lambs. A similar trend was noted among the female lambs but the difference was not significant.

Bonsma (1939) stated that male lambs were significantly heavier at birth and from 3 to 6 pounds heavier than females at 18 weeks of age.

Using the information obtained on 882 lambs representing 10 breeds and crosses over a 10 year period, Kean and Henning (1949) compared the effects of sex on birth weight and rate of gain. The males were 0.6 pounds heavier at birth than females. The average daily gain for male and female lambs were 0.54 and 0.51 pounds per day, respectively.

Guyer and Dyer (1954) obtained inconsistent results from their data on 139 Hampshire lambs. The male lambs were found to be slightly heavier than females at birth. The comparisons between wethers and females at 63 and 112 days of age were inconsistent within seasons but when the data of two seasons were pooled, the males were slightly heavier.

Extensive studies on range sheep were reported by Hazel and Terrill (1945). Data on 2183 Rambouillet lambs reared under range conditions were available for these investigations. By a method of least squares analysis constants were obtained to estimate the differences between sexes at weaning. Ram lambs were 8.3 pounds heavier than females at 120 days. Hazel and Terrill (1946a) studied some weanling traits of 478 Columbia, 238 Corriedale and 366 Targhee lambs reared under range conditions and reported a difference of 10.8 pounds in favor of the males at a weaning age of 120 days. Blackwell and Henderson (1955), working with farm flock in the Northeastern United States, reported that by fitting constants for the effect of sex and birth weight and weaning weight, the males were 0.54 pounds heavier at birth and 4.38 pounds heavier at weaning than the females based on 2158 birth weights and 1295 weaning weights. In a study of the 120 day weaning weights of 280 crossbred lambs, deBaca et al. (1956) estimated constants for sex ranging from 3 pounds in favor of the females to 3 pounds in favor of the wethers. These estimates were adjusted for the effects of breed of sire, breed of dam, breed of sire and ewe interaction, birth type and type of rearing. Bogart et al. (1957) analyzed the birth weights of 280 lambs. Constants ranging from .28 $\pm$ .27 to .44 $\pm$ .08 were calculated by least squares analysis in favor of the male lambs. These constants were adjusted for breed of sire, breed of dam, breed of sire breed of dam interaction and birth type.

Effect of Birth Weight

The importance of the birth weight of lambs in relation to their weight, vigor at birth and subsequent gains has been investigated by several workers.

Mumford (1901) concluded that lambs which were heavier at birth exhibited a tendency to grow faster up to 7 weeks.

Hammond (1932) found a correlation coefficient of 0.52 between one week weights and twenty week weights of lambs.

Phillips (1936) reported that lambs which are heavier at birth have a better chance of surviving and are heavier at 4, 6 and 12 months later. This study was based on the analysis of 110 Shropshire lambs. He also noted that only 50 percent of the lambs weighing 6 pounds or less at birth survived to the age of one month.

Bonsma (1939) obtained a highly significant correlation of 0.41 (147 d.f.) between birth weight and the weight at 12 weeks indicating that birth weight is associated with subsequent weight differences.

Phillips and Dawson (1937) (1940) analyzed the birth weights of 508 Hampshire, 521 Shropshire and 835 Southdown lambs. They found that lambs which were heavier at birth tended to be heavier at later ages. Each additional pound at birth resulted in 2 to 4 pounds heavier lamb weights at 90 days. As the lambs grew older the differences due to birth weight decreased in importance.

Guyer and Dyer (1954) correlated birth weight and gain of 151 Hampshire lambs and found the correlation to be 0.65 ($P < 0.01$). However, when milk intake was held constant by partial correlation, the correlation coefficient (0.11) was non-significant.

Results reported by Thomson and McDonald (1956) indicated that when the weaning weights of 688 lambs were regressed on their birth weights, for each additional pound at birth, there was a 2 to 4 pound increase in weaning weight. A similar figure was reported by deBaca and coworkers (1956). They found that for each additional pound at birth of 280 crossbred lambs, there was an increase of 2.5 to 6.0 pounds at a weaning age of 120 days.

Terrill (1944) investigated the effect of gestation length on birth weight and subsequent growth. He reported that lambs from a longer gestation tended to be heavier at birth and exhibit a slightly faster rate of gain immediately following birth. The survival rate was also noted to be slightly in favor of a longer gestation.

Birth weight was reported by Venkatachalam *et al.* (1949) to be an important factor in the survival and vigor of lambs. The percent death losses rose sharply when the birth weight of the lamb was much below the breed average. Lambs of the large mutton breeds were noted to have a lower survival rate than the lighter breeds.

Wallace (1948) reported that the level of nutrition during the last six weeks of pregnancy has a very profound effect on the birth weight and vigor of lambs, especially twins.

Carter and Henning (1951) studied 1056 lambs to determine the effect of heterosis on birth weight. The comparisons were made on the basis that with heterosis, the birth weight of the crossbred lamb should be greater than the arithmatic mean of the breeds crossed. The data indicated that there was little, if any, heterosis. However, the difference of all the purebred Hampshire lambs and all the purebred Southdown lambs was 1.6 pounds. The difference in birth weight of the lambs sired by these two ram breeds when mated to Dorset-Merino ewes was 0.057 pounds.

This indicates that the ewe may have a greater influence on the birth weight of her offspring than her contribution of 50 percent of the genes to that offspring.

Various other workers have investigated the breed of sire effect on lamb birth weights. Kincaid (1943) divided 150 ewes into to equal groups. One group was bred to Hampshire rams, the other group to Southdown rams. The rams were compared on a switch back trial the following season. Lambs sired by the Hampshire rams averaged 1.05 pounds heavier than those sired by Southdown sires, the difference was highly significant. No attempt was made to estimate the differences between sires of the same breed. Neville et al. (1955) compared the birth weight of lambs sired by 10 Hampshire rams, 10 Suffolk rams and 10 Southdown rams which were mated to 72 Western ewes over a two-year-period. During the second season male lambs sired by the Suffolk rams were significantly heavier than the male lambs sired by the Hampshire and Southdown rams, the latter two groups showed little difference. Jamison and coworkers (1956) compared the sire effect on 967 lamb birth weights by 70 sires representing 7 breeds. The differences between sire breeds were small but in a few cases the differences were significant.

Some Other Sources of Variation

Many research workers have reported that the age of dam influences the rate of gain of the lamb. Bonsma (1939) reported that lambs from later parturitions were comparatively heavier than first born lambs at birth, 12 and 18 weeks of age. Hazel and Terrill (1945) reported that in an investigation of 2183 Rambouillet lambs reared by dams of different ages, that age of dam accounted for 3.1 percent of the variation observed in the weaning weights of these lambs. A constant fitted for the differences between 2-year old dams and mature dams (3-years old or older) was 6.1 pounds in favor of the older dams. A similar study by Hazel and Terrill (1946a) found a difference of 8.7 pounds in favor of the mature ewes based on the weaning weights of 1082 range lambs. A later study of 932 yearling ewes by Hazel and Terrill (1946b) showed a 2.6 pound difference in body weight of these ewes in favor of the ewes from mature dams. Terrill _et al._ (1947) reported on the difference between body weights of yearling ewes due to differences in the age of dam. The 406 Columbia ewes reared by mature dams were 4.6 pounds heavier than the ewes reared by 2-year old dams. Among the 290 Targhee yearling ewes, those reared by mature dams were 0.60 pound heavier than the ewes reared by 2-year old dams. Sidwell and Grandstaff (1949) collected data over a 10-year period on the life time production of 414 Navajo ewes. They reported that 2-year old ewes reared the lightest lambs, the 4-to 7-year old ewes, the heaviest, and the 3-year old and 8-to 11-year old group weaned intermediate weight lambs. An important year effect was noted in these life time production records. The weaning weights in 1939 and 1946 were 5.2 pounds below average and the 1941 weaning weights were 6.9 pounds heavier than average.

Blackwell and Henderson (1955) estimated the age of dam on a linear and curvilinear basis. The effect of age of dam in the lamb weaning weights among the Hampshire, Shropshire and Corriedale ewes was curvilinear, reaching a maximum production at approximately five years of age. The age of dam effect was less important upon the weaning weights of the Dorset lambs. The effect of age of dam on birth weight was curvilinear in all the ewe breeds studied. These authors noted that years were an important source of variation on the birth weight and weaning weights of the lambs. The yearly fluctuations were essentially random about the general mean. These variations from year to year were attributed to weather conditions which effected the quality and quantity of forage available and the general health of the flock from year to year.

Hammond (1932) observed lamb growth over a 10-year period and found a large variation in growth rates between years. He attributed this variation to inbreeding of the flock and the quality of roughage available. During the years of little rainfall, the forage available was fibrous and unpalatable.

Blunn (1944) weighed 739 Navajo lambs at monthly intervals from birth to 20 weeks of age from 1938 to 1941 inclusive. Highly significant differences between the mean weights of the 4 years were found for weights at all ages except birth weight. Analysis of variance showed most of the variation (84 to 92 percent) in the mean body weights was due to between year differences. During years of light rainfall, the lamb weights were lighter than average.

Variation in weighing conditions and methods may be a source of considerable variation between weights of the same animal. Bonsma (1939) concluded that the two main sources of error in lamb birth weights were the weight of the fluids if the lamb isn't dry, and the amount of milk consumed by the lamb prior to its first weighing. Bean (1948) concluded that there was no justification for a 3-day average weight based on 3 consecutive daily weights to increase the accuracy of individual lamb weights. Baket et al. (1947) stated there was no advantage in taking weights on 3 consecutive days to estimate weaning weights of calves. A single weight taken under uniform conditions will be just as accurate as most three day averages.

The level of milk production of the ewe has a strong influence on the growth rate of her lamb. However, milk production records on ewes of the "non-milk" breeds are difficult to determine due to the large amount of time and labor involved. Fuller and Klienheinz (1901) reported that by weighing the lamb immediately before and after nursing to determine the amount of milk produced is much more satisfactory than hand milking. This method of weighing the lamb before and after nursing has been used extensively by other research workers to obtain milk production estimates. Ritzman (1917a) compared the effect of whole milk and skim milk on lamb growth. He concluded that the chief advantage of whole milk was its capacity to promote fattening simultaneously with growth. Bonsma (1939) obtained lactation records on 70 Merino ewes and found lamb gains to be highly correlated with the milk production of the ewe. The lactation was broken into periods and the following correlation coefficients between milk consumption and lamb live weight gains were calculated.

1st Period (1st 14 days)	$r = 0.882$
2nd Period (2 - 5 weeks)	$r = 0.784$
3rd Period (5 - 8 weeks)	$r = 0.516$
4th Period (8 -11 weeks)	$r = 0.397$
Total Period (11 weeks)	$r = 0.812$

Using the first lactation as a base of 100, he found the comparative increases in the 2nd, 3rd and 4th lactations to be 120, 125 and 136, respectively, indicating that there is a marked increased in subsequent lactations. There was also a highly significant correlation between the body weight of the ewe within a breed and the amount of milk produced ($r = 0.512$ 111 d.f.). In a later study Bonsma (1944) compared several dam-daughter lactations. These comparisons were based on 16 Merino dam-daughter comparisons and 17 Blackhead Persian dam-daughter comparisons. The daughters were all sired by mutton type rams. In every case an increase was noted in the daughter's production record varying from 21 to 190 percent with the Merino ewes with an average increase of 89 percent. With the Blackhead Persian ewes the comparative increase varied from 91 to 402 percent with an average increase of 199 percent. The author stated that the lambs from the crossbred ewes sired by mutton type rams grew faster and were significantly heavier than lambs from purebred ewes sired by mutton type rams. Therefore, the author concluded that crossbred ewes were generally superior to purebred ewes for this type of fat lamb production. However, there were no reciprocal comparisons of the breeds used in these data.

Wallace (1948) reported that the level of nutrition of the ewe, especially during the last 6 weeks of pregnancy, has a profound effect on the total milk production of the ewe. The results of 48 lactations were used in this study. Ewes rearing twins produced more milk than ewes rearing singles within the treatment groups. The ewe that produces an abundant amount of milk early in her lactation aids the growth of her lamb in two ways. One, each additional pound of milk that a lamb consumes between birth and 28 days was found to increase the lamb's live weight at one month by 1/4 pound. Two, the larger, faster growing lambs are able to start utilizing supplemental feed approximately a week earlier than lighter lambs. This ability to utilize supplemental feed at an earlier age allows the heavier lamb to maintain its growth rate as its dam's milk production declines. The author obtained a multiple correlation coefficient of 0.9794 between the lamb's 112 day weight and the amount of milk and supplemental feed consumed by the lamb, thus accounting for 96 percent of the variation in the 112 day weight of the individual lambs. The author also suggested that it may be possible to determine the milk production of a ewe indirectly on the basis of the amount of gain of its lamb at some early age since approximately 38 percent of the total milk produced during the ewe's lactation occurs during the first month.

Guyer and Dyer (1954) estimated the milk production of 54 Hampshire ewes fed on different planes of nutrition. The ewes receiving supplemental concentrates during pregnancy produced more milk than the non-supplemented ewes. The increase in the level of milk production of ewes rearing twins was significantly greater than the ewes raising singles. The milk consumption of suckling lambs was studied by Burris and Baugus (1955) on 18 single lambs and 5 pairs of twins from 23 aged Hampshire ewes. They obtained a correlation between milk consumption and average daily gain of the lambs from birth to 4 weeks of 0.90 and from birth to 16 weeks of 0.83. The average daily gain of the lambs from birth to 16 weeks was also significantly correlated with the weight of the ewe ($r = 0.67$), with birth weight of the lamb ($r = 0.61$) and with udder width ($r = 0.54$). As the lambs grew older, the correlations between growth and milk production by 4 week periods declined rapidly.

The most extensive research on the aspects of milk production of ewes are those reported by Barnicoat and coworkers (1949) (1956). Lactation records on 200 Romney ewes collected over a 5 year period provided the data for these reports. Some of the important factors influencing milk production are age of ewe, time of lambing, health of the ewe, number of lambs suckled, genetic factors and the level of nutrition.

Experiments with over 50 ewes on controlled feed intake demonstrated the following facts. One, feeding during pregnancy was important for maintaining milk yield during the latter part of lactation. Two, feeding during lactation was a primary factor influencing both the initial yield and total milk yield. Three, maximum yield was obtained by liberal feeding during late pregnancy and throughout lactation. Correlations between milk consumption and lamb growth were found to be the highest during the 4th and 6th week period (0.62 to 0.98). This is mainly because the lambs are able to consume more milk during this period when the ewe's daily production is the highest. The authors stated that the appetite of the lamb determines the milk yield and, consequently, correlations between yield and lamb growth tend to be low during the 9-12 week period. These workers found that the lambs could be successfully weaned at two months of age without upsetting their rate of gain if lush pasture is available to maintain the growth rate. A close relationship was found to exist between the live weight gain of the lambs and the amount of milk ingested from birth to 6 weeks of age even though there was a large amount of variation in growth rates. When the lactation records were reduced to an equal milk consumption basis, the variation in lamb weight gains from birth to 6 weeks was found to be almost entirely due to differences in the quantity of milk. Thus, the authors concluded that a ewe's milk production could be estimated rather accurately on the basis of her lamb's live weight gain from birth to 6 weeks. A repeatability estimate of 0.388 based on 4 consecutive lactations of 19 ewes was obtained. Estimates based on the actual records and by the indirect method of estimating a ewe's milk production were in close agreement. The authors concluded that the results of one lactation can be regarded as a satisfactory indication of a ewe's life time production and the low producing ewes culled on this basis. If two years records are used, then it's possible to increase the accuracy of culling by about 20 percent.

Adjusting Weights to a Constant Age

When comparisons are made between lambs, difference in age may be an important source of variation. Consequently, it is often desirable to make comparisons on an equal age basis. Obviously the most accurate method would be to weigh each lamb when it reaches the desired age. However, under most conditions it is neither practical or possible to weigh each lamb when it reaches the desired age. Various methods have been devised to adjust body weight to a constant age.

Bywaters and Willham (1935) noted that when a straight line was fitted to the growth curves of pigs from approximately 19 to 32 weeks that the lines intersected the age axis at approximately the same point. They concluded that by dividing the pigs weight by its age, less the age intercept, a useful estimate of its growth rate could be obtained. They also stated that this method makes no allowances for differences in feeding and management.

In order to compare pig litters raised on different farms and weighed at different ages, Whatley and Quaife (1937) fitted a straight line to two years data and obtained an age intercept. From this intercept a formula was developed to adjust the litter weights to a constant age of 56 days. To speed up the process of adjusting the weights, a table of factors can be worked out in advance. These workers stated that caution should be used in applying these factors to weights obtained at ages which deviate greatly from 56 days due to the change in the slope of the growth curve.

A formula based on the age intercept method was developed by Phillips and Brier (1940) to adjust lamb weights to a constant age of 20 weeks. Although the age intercepts for the various groups of lambs used in the study were rather divergent, this intercept method was more accurate than using average weekly gains. They found that instead of an even rate of growth of the type found in average growth curves, the individual lamb often has considerable fluctuations above and below a smooth curve. The authors stated that there is a need for more date on the growth of sheep of different types under various conditions before the most accurate application of the age intercept method can be made.

In order to analyze the effect of inbreeding on the body weight of dairy heifers, Baker et al. (1942) corrected the weights to a constant age. The unadjusted weights were plotted, then a small amount of free-hand smoothing of the curve was done to remove random error in the weights. From this curve an equation was derived and the necessary correction factors obtained. Baker (1944) found that this method of free-hand smoothing of the unadjusted data worked satisfactorily to estimate the weights of chickens.

Working with weaning weights of range beef calves, Koger and Knox (1945) fitted a form equation derived from the calf growth data to a nomograph. The nomograph was found to be a fast and convenient method of adjusting the weaning weights of calves to a constant age. They further stated that the merit of this method of weight adjustment lies in the fact that if there is no trend in the size of the regression coefficient with the variation in weight at a given age and the lines of regression do not converge, no error will be introduced by using the nomograph. If the age intercept method is used, and the lines don't converge, then error may be introduced. The use of the nomograph is based on the assumption that linear growth has occurred between the adjusted age and actual age.

Johnson and Dinkel (1951) studied the growth curve of 297 grade and purebred Hereford calves under range conditions. These data showed that growth was essentially linear up to 155 days of age then dropped off gradually. They adjusted the weights taken between 120 and 155 days to a standard age of 155 days. Two sets of factors were developed for the period of 155 to 225 days of age which were used to adjust the weights to a standard age of 190 days. The authors cautioned that these correction factors may not be satisfactory under conditions of management different from those under which these correction factors were obtained.

Lush and Kincaid (1943) used a quadratic equation to obtain correction factors to adjust the weights of swine to a constant age of 154 days.

Taylor and Hazel (1955) compared six different methods of correcting the weights of swine to a constant age. They found the age intercept method and the linear interpolation method to be the most accurate. The linear interpolation method has slight disadvantage of requiring two weights at ages which bracket the constant age to which all the weights are being adjusted. If growth is linear during the period between the two weights, then the linear interpolation is by far the most accurate method of weight adjustment. A set of tables can be made up in advance which make the method of adjustment faster and more convenient.

Blackwell and Henderson (1955) measured some of the factors effecting the weaning weights of lambs under farm flock conditions. To remove the variation in weaning weights due to differences in age of weaning, they added the age of lamb at weaning into the mathmatical model used to measure the other factors effecting the weaning weights of lambs. The regression of weaning weight on weaning age ranged from 0.13 to 0.27 pound per day.

During a study of weaning weights of crossbred spring lambs, deBaca *et al.* (1956) found that the average weaning age was approximately 120 days. Based on the assumption that growth was linear from birth to 135 days, the weaning weights were corrected to a constant age of 120 days. To obtain the adjusted 120 day weight, these workers subtracted the birth weight of the lamb from its actual weight, divided this figure by the lamb's actual age, then multiplied by 120 and added the birth weight, the resulting figure was used as the adjusted weight.

MATERIALS AND METHODS

The lamb weights used in this study were obtained from the experimental sheep flock (Project S-908) at the Ft. Reno Experiment Station. The lambs were born during the late falls of 1955 and 1956 and were unselected except for death losses.

The dams of these lambs were grade Rambouillet and grade Rambouillet X Panama-Rambouillet ewes which were purchased as yearlings during April and May 1955 in the Del Rio, Texas area. All of the lambs were sired by purebred Dorset rams which were purchased from private breeders in Oklahoma. The ewes were first bred during late May, June and early July 1955 as yearlings and bred again during late May, June and early July 1956 as two-year olds.

The flock was managed according to the usual practice of the commercial breeders in Oklahoma. During the winter months the ewes were grazed on wheat pasture and received supplemental alfalfa hay during inclimate weather. After lambing the flock was divided into bands, one band made up of ewes rearing lambs, and one band of ewes not rearing any lambs. During the 1956-57 season the ewes rearing twins were separated from those rearing singles. All of the lambs had free access to creep feed consisting of two parts cracked sorghum (kafir) grain and one part chopped alfalfa hay (good quality). The lambs were separated from their dams only during the time of weighing.

The birth weight of the lambs was recorded to the nearest one-half pound in 1955 and to the nearest one-tenth pound in 1956. These weights were taken as soon as possible after the lamb was dry. The lambs were reweighed when the older lambs in the flock were approximately 40 to 45 days of age. After that the lambs were weighed at approximately two week intervals until they reached a market weight of about 90 to 92 pounds. In both years there were a few lambs which were born late in the season and were marketed at slightly less than 90 pounds. Each lamb was identified by a number which was usually the same as its dam's number. The number was stamped on a metal ear tag and was also paint branded on the lamb's back to make identification easier. In the case of twins during the 1955-56 season, one twin was usually assigned its dam's number and its mate was assigned a different number. During the 1956-57 season both twins received their dam's number except the number of one of the twins had a bar (-) before it. The method used during the 1956-57 season was found to be more satisfactory since it readily permitted comparison between full-sibs without needing to check the record book to identify them. All of the lambs were docked during the first week after birth. The ram lambs were all castrated between one and four weeks of age.

The distribution of these lambs according to year of birth, breed, sex, birth type, and type of rearing is presented in Table 1.

The weights of the lambs were adjusted to different ages so that breed of ewe, sex, type of birth, type of rearing and birth weight could be estimated. The weights were adjusted to the following ages: 45, 60, 75, 90, 105, 120, and 135 days. Since some of the lambs reached market weight and were sold, it was not possible to continue the study beyond 135 days of age. The method used to adjust the weights to a constant age was the linear interpolation method. Taylor and Hazel (1955) stated that this method was the most accurate method when growth is linear between the two weights. The procedure used to adjust the weights to a constant age is explained in more detail in Appendix A.

TABLE I NUMBER OF LAMBS USED IN THIS STUDY ASSEMBLED ACCORDING TO BREED, SEX, TYPE OF BIRTH, TYPE OF REARING AND YEAR

Breed*	Sex	Type of Birth and Rearing	1956	1957
D X RPR	Male	Single as a single	15	21
		Twin as a single	4	3
		Twin as a twin	7	12
	Female	Single as a single	11	23
		Twin as a single	4	2
		Twin as a twin	3	15
		Single as a twin	0	1
D X R	Male	Single as a single	26	26
		Twin as a single	4	1
		Twin as a twin	6	27
	Female	Single as a single	33	27
		Twin as a single	0	0
		Twin as a twin	6	23
TOTAL			119	181

* D X RPR = Dorset X (Rambouillet X Panama-Rambouillet)
D X R = Dorset X Rambouillet

Due to confounding of age of dam and year effects, it was necessary to analyze the data on a within year basis. The least squares method of obtaining constants was used to contend with the multiple classification and unequal subclass numbers as outlined by Anderson and Bancroft (1952). Each observation of an adjusted weight was assumed to be the sum of the influences or effects of the other variables as follows:

$$Y_{ijkmx} = M + B_i + T_j + S_k + R_m + W_x + e_{ijkmx}$$

where

Y_{ijkmx} = the adjusted weight of the lamb

M = a constant for all lambs, the mean

B_i = a constant for the i^{th} ewe breed

T_j = a constant for the j^{th} birth type (single or twin)

S_k = a constant for the k^{th} sex (wether or female)

R_m = a constant for the m^{th} type of rearing (single or twin)

W_x = a constant for the x^{th} birth weight, a covariable

e_{ijkmx} = error or failure of the above constants to estimate the adjusted weight of the lamb.

These computations were facilitated by the use of International Business Machines. The arrangement of the model was such that the effect of birth weight was removed last. The procedure used to set up these data for analysis is explained in more detail in Appendix B.

RESULTS AND DISCUSSION

Rather apparent differences were noted in the rate of gain of the lambs reared in two different seasons. During the 1955-56 season the rate of gain started to slow down slightly at approximately 60 days and started to increase again at approximately 120 days. Thus, when the mean lamb growth curve (Figure 1) was plotted, it took on a non-linear appearance. The exact cause of this change in rate of gain is not known. However, many of the lambs reared during this period lost weight and some of them were noted to be stiff in their rear legs. During the 1956-57 season the lamb growth curve was essentially linear from birth to 120 days and then the rate of gain declined slightly. On an age for age basis, the lambs reared during the 1956-57 season were comparatively heavier than those reared during the 1955-56 season. It is impossible to determine how much of the difference in weight of the lambs between seasons is due to the age of dam or to the difference between years. Hammond (1932), Blunn (1944), Sidwell and Grandstaff (1949) and Blackwell and Henderson (1955) have reported that the year in which the lambs are reared is an important source of variation in their body weights. Bonsma (1939), Hazel and Terrill (1945) (1946a), Sidwell and Grandstaff (1949) and Blackwell and Henderson (1955) have reported that lambs reared by three-year old ewes are heavier at weaning than lambs reared by two-year old ewes.

Bonsma (1939), Wallace (1948), Guyer and Dyer (1954) and deBaca

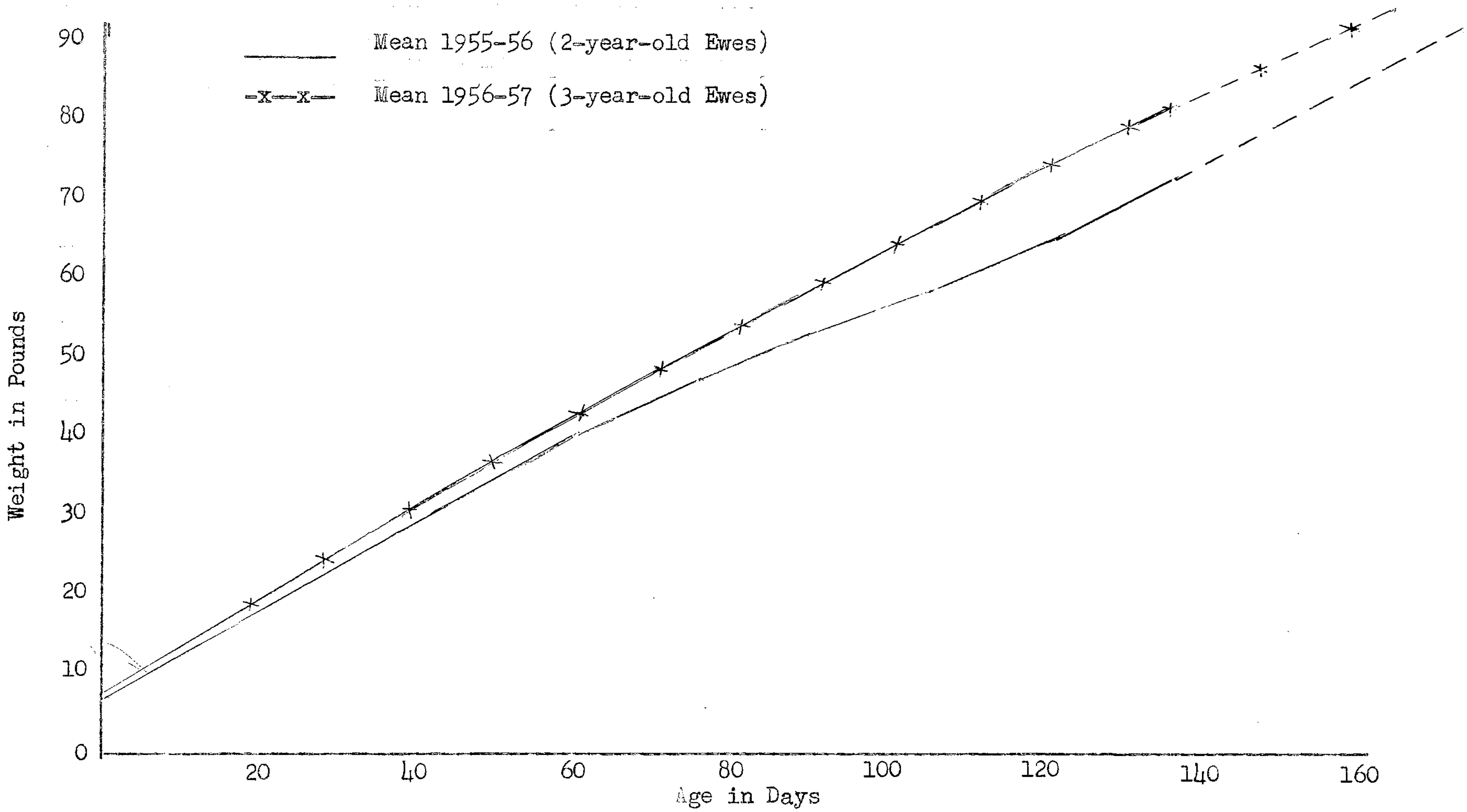

FIGURE 1. MEAN LAMB GROWTH CURVES, 1955-56 and 1956-57

et al. (1956) have reported that lamb growth is essentially linear from birth to approximately 135 days of age. This evidence in addition to the fact that the lamb growth in 1956-57 was very linear would lead to the conclusion that the fluctuations in rate of growth during the 1955-56 season were probably due to within year environmental differences. It is impossible to estimate how much bias in the 1955-56 estimates can be attributed to this atypical environment. There is also ample opportunity for sampling error since there were rather a small number of lambs within certain classes (see Table I). This is especially true in the cases of the number of twin birth types, the number of twins reared as singles and the number of twins reared as twins. If this unusual environmental factor was independent of age and occurred at a particular date, then the estimated differences between classes may be biased considerably due to difference in the average birth date of the different classes.

As the mean body weight of the lambs increased, the variance also increased but not at the same relative rate. Coefficients of variation (Snedecor, 1956) were calculated for each adjusted age and are presented in Table II on page 33. More detailed coefficients of variation on a within breed basis are presented in Appendix C. In the 1955-56 season these coefficients ranged from 18.8 percent at 45 days to 14.5 percent at 135 days. During the 1956-57 season these coefficients ranged from 20.0 percent at 45 days to 13.5 percent at 135 days. This decrease in size of the coefficients of variation as the lambs grew older indicates that the relative variation among the lambs was less as they grew heavier.

Simple correlation coefficients were also calculated between

TABLE II COEFFICIENTS OF VARIATION* FOR THE LAMB WEIGHTS AT DIFFERENT AGES

	45 Day Wt.	60 Day Wt.	75 Day Wt.	90 Day Wt.	105 Day Wt.	120 Day Wt.	135 Day Wt.
1956	18.8%	17.5%	17.0%	17.1%	16.5%	15.3%	14.5%
1957	20.0%	18.4%	17.1%	15.9%	14.8%	14.1%	13.5%

* $C.V. = \frac{\text{standard deviation}}{\text{mean}} \times 100$

weights at different ages and are presented in Tables III and IV on page 35. The correlations between weights at adjacent constant ages ranged from .911 to .980 in 1955-56 and from .972 to .986 in 1956-57. Correlations between adjacent constant ages would be expected to be high since in some instances the same unadjusted weight may have been used to calculate adjusted weights at two different ages. However, correlations between more distant ages may be of some value in a selection program. Correlations between birth weight and subsequent weights declined from .581 to .479 in 1955-56 and from .661 to .571 in the 1956-57 season. Correlations between birth weight and subsequent weights in 1956-57 declined rather slowly. Correspondingly higher correlations were noted during the 1956-57 season which again indicates the increased linearity of growth during that season. These correlations between birth and subsequent weights are similar to the correlation of 0.52 between the one week weight and the twenty week weights of lambs calculated by Hammond (1932).

Estimated Regression Coefficients

A multiple regression equation was calculated for each of the different ages. The normal equations obtained by the least squares procedure are not independent. Therefore, in order to obtain a solution for these equations, certain restrictions were made, namely, the Rambouillet X Panama-Rambouillet breed of ewe, the twin birth type, the female sex, and the twin rearing type were set equal to zero. Thus, the regression coefficient estimates for breed of ewe, birth type, sex and type of rearing are the differences between the breed of ewe, birth type, sex and rearing type effects. A particular multiple regression

TABLE III SIMPLE CORRELATION COEFFICIENTS BETWEEN WEIGHTS AT DIFFERENT AGES 1955-56 DATA

	45 Days	60 Days	75 Days	90 Days	105 Days	120 Days	135 Days
Birth	.581	.540	.529	.496	.518	.479	.486
45 Days		.961	.900	.806	.746	.691	.691
60 Days			.930	.847	.775	.713	.720
75 Days				.911	.817	.748	.740
90 Days					.914	.835	.806
105 Days						.939	.909
120 Days							.980

TABLE IV SIMPLE CORRELATION COEFFICIENTS BETWEEN WEIGHTS AT DIFFERENT AGES 1956-57 DATA

	45 Days	60 Days	75 Days	90 Days	105 Days	120 Days	135 Days
Birth	.661	.619	.598	.586	.586	.571	.579
45 Days		.979	.963	.940	.921	.901	.898
60 Days			.979	.957	.943	.925	.914
75 Days				.972	.962	.949	.934
90 Days					.981	.967	.956
105 Days						.981	.976
120 Days							.986

coefficient can be interpreted as the average change in body weight for each unit change in its corresponding variable when the other variables are not changed. It should be kept in mind when considering these estimates for the effect of breed of dam, birth type, sex, type of rearing and birth weight on the lamb weights at different ages, that there is a high correlation between the weights at different ages. This is primarily due to the fact that the same lambs were used within each season to obtain the regression coefficients at different ages. The estimated regression coefficients for the mean, breed of ewe, and birth type are presented in Table V on page 37. The estimates for sex, type of rearing and birth weight are presented in Table VI on page 39. The effect of sex, type of rearing and birth weight independent of the other variables are presented graphically in Appendix D.

The effect of breed of ewe on the lamb weights at different ages was estimated as the difference between the Rambouillet and the Rambouillet X Panama-Rambouillet ewes. The results of these estimates were rather conflicting. During the 1955-56 season the Rambouillet ewes reared the heavier lambs. The maximum differences between breeds were at 75 and 90 days. The differences amounting to 2.6 ± 1.2 pounds at 75 days and 3.7 ± 1.4 pounds at 90 days were statistically significant at the 5 percent level. The results of the 1956-57 analysis showed a slight difference ranging from 0.02 to 0.32 pounds in favor of the Rambouillet X Panama-Rambouillet ewes. The difference between breeds of ewes was non-significant and only a minor source of variation in the 1956-57 data. No estimates of the difference between Rambouillet ewes and Panama ewes were found in the literature.

The effect of birth type was estimated as the difference between

TABLE V THE ESTIMATED REGRESSION COEFFICIENTS AND STANDARD ERRORS FOR THE MEAN, BREED OF EWE, AND BIRTH TYPE
1955-56 and 1956-57

Season	Age in Days	Mean[a] $b_{1\cdot 23456}$	Breed of Ewe[d] $b_{2\cdot 13456}$	Birth Type[d] $b_{3\cdot 12456}$
1955-56	45	13.8689 ± 1.4807	1.1489 ± 0.7544	1.4100 ± 1.2306
	60	20.5762 ± 1.8969	1.5810 ± 0.9664	1.5371 ± 1.5765
	75	25.1609 ± 2.2748	2.5944 ± 1.1589*	0.7123 ± 1.8905
	90	30.2738 ± 2.7825	3.6634 ± 1.4175*	-1.0321 ± 2.3124
	105	34.0313 ± 3.0000	2.6100 ± 1.5284	-2.3520 ± 2.4932
	120	42.6168 ± 3.2531	1.5145 ± 1.6573	-2.8265 ± 2.7036
	135	48.9633 ± 3.4494	1.3306 ± 1.7573	-3.0239 ± 2.8666
1956-57	45	15.5396 ± 1.4336	-0.0675 ± 0.6582	2.8745 ± 1.7520
	60	22.5674 ± 1.7836	-0.1156 ± 0.8188	2.3566 ± 2.1797
	75	29.2065 + 1.9913	-0.0653 ± 0.9142	3.2179 ± 2.4335
	90	35.8363 ± 2.2133	-0.0224 ± 1.0161	2.7876 ± 2.7048
	105	42.5523 ± 2.4336	-0.1106 ± 1.1173	3.1358 ± 2.9740
	120	49.2240 ± 2.6665	-0.3203 ± 1.2241	1.2986 ± 3.2587
	135	54.7029 ± 2.7616	-0.1952 ± 1.2679	0.9303 ± 3.3749

[a] The unadjusted means are presented in Appendix C.

[d] Differences between classes.

* Significant at the 5 percent level.

lambs born as twins and lambs born as singles. This difference actually represents the difference between single lambs reared as singles and twin lambs reared as singles. During the 1955-56 season the differences were initially in favor of the single birth type but declined steadily as the lambs grew older. At 90 days the twin birth type surpassed the single birth type and was 3.0 ± 2.8 pounds heavier at 135 days. The 1956-57 data indicated a difference fluctuating from approximately 2.4 to 3.2 pounds in favor of the single birth type until the lambs were 105 days old, then the differences between birth types dropped sharply from 3.1 ± 2.9 at 105 days to 0.9 ± 3.4 pounds at 135 days. The standard errors of the differences in birth type were comparatively higher than those calculated for the difference between breed of ewe and sex. The differences between birth types were not significant at any age during either season. Hazel and Terrill (1945) (1946a) reported that single lambs were from 2.5 to 5.1 pounds heavier than twins reared as singles.

The effect of sex was estimated as the difference between males and females. During the 1955-56 season the males were significantly ($P<0.05$) heavier than females at 45 and 135 days of age. There was a general trend towards an increased difference in favor of the male lambs as the weight and age increased. Although the differences were greater at later ages than at 45 days, they were not significant due to the increased size of the standard error. The difference in favor of the males was highly significant ($P<0.01$) at all ages during the 1956-57 season. These differences increased steadily from 1.9 ± 0.6 at 45 days to 5.1 ± 1.3 pounds at 135 days. The differences in the 1956-57 data were in close agreement with the difference of 4.3 pounds in favor of the males reported by Blackwell and Henderson (1955). The estimates reported by Hazel and

TABLE VI THE ESTIMATED REGRESSION COEFFICIENTS AND STANDARD ERRORS FOR SEX TYPE OF REARING AND BIRTH WEIGHT 1955-56 and 1956-57

Season	Age in Days	Sex[d] $b_{4\cdot 12356}$	Type of Rearing[d] $b_{5\cdot 12346}$	Birth Weight $b_{6\cdot 12345}$
1955-56	45	1.4251 ± 0.7176*	5.6657 ± 1.3808**	1.4830 ± 0.2037**
	60	1.6848 ± 0.9193	6.5526 ± 1.7689**	1.6300 ± 0.2609**
	75	2.0862 ± 1.1024	7.4573 ± 2.1213**	1.8615 ± 0.3129**
	90	1.7526 ± 1.3485	7.7655 ± 2.5947**	2.0563 ± 0.3827**
	105	2.2703 ± 1.4539	8.3318 ± 2.7976**	2.4239 ± 0.4126**
	120	2.9115 ± 1.5766	6.6982 ± 3.0336*	2.3923 ± 0.4474**
	135	3.6084 ± 1.6717*	6.7257 ± 3.2166*	2.6065 ± 0.4744**
1956-57	45	1.9215 ± 0.6608**	2.6214 ± 1.7186	1.9593 ± 0.2104**
	60	2.4905 ± 0.8221**	3.8192 ± 2.1382	2.1238 ± 0.2618**
	75	3.2952 ± 0.9178**	3.8519 ± 2.3872	2.1738 ± 0.2923**
	90	3.5216 ± 1.0202**	4.3013 ± 2.6533	2.3320 ± 0.3249**
	105	4.3461 ± 1.1217**	2.6342 ± 2.9174	2.6065 ± 0.3572**
	120	4.4513 ± 1.2291**	4.3865 ± 3.1966	2.7772 ± 0.3914**
	135	5.0599 ± 1.2729**	4.6119 ± 3.3106	2.9582 ± 0.4054**

[d] Difference between classes.

* Significant at 5 percent level.

** Significant at 1 percent level.

Terrill (1945) (1946a) were considerably larger, ranging from 8 to 10 pounds in favor of the males under range conditions.

During the 1955-56 season the type of rearing was a very important source of variation in the lambs' weights. The lambs reared as singles were significantly heavier than the lambs reared as twins at all ages. The differences fluctuated from 5.6 ± 1.4 to 8.3 ± 2.8 pounds in favor of the single lambs. Type of rearing was found to be less important during the 1956-57 season. The single lambs ranged from 2.6 ± 1.7 to 4.6 ± 3.3 pounds heavier than the lambs reared as twins, but these differences were not significant. The standard errors of the difference between types of rearing were comparatively large during both seasons. These results are in agreement with the results obtained by deBaca et al. (1956). These workers also reported that adjusting for birth weight greatly reduced the variation in 120 day weights due to the type of birth and rearing.

Difference in birth weight was the largest single source of variation of any of the factors measured. To estimate the effect of birth weight, the lamb's birth weight was used as a covariable. The regression of subsequent weights on birth weight was highly significant ($P < 0.01$) at all ages during both seasons. The regression coefficients ranged from 1.5 ± 0.2 to 2.6 ± 0.5 and from 1.9 ± 0.2 to 2.9 ± 0.4 in 1955-56 and 1956-57, respectively. In 1955-56 the differences in birth weight alone accounted for 23 to 34 percent of the variation (r^2) in the age adjusted weights. In 1956-57 differences in birth weights were estimated to account for 33 to 44 percent of the variation in the lamb weights at different ages. The regression of subsequent weights on birth weight were about equal to the estimates reported by deBaca et al. (1956) and

Thomson and McDonald (1956). The regression coefficients reported by Phillips and Dawson (1940) for 90 day weights on birth weight were similar to the results found at the same age in this study.

Coefficients of Determination

After the regression coefficients were obtained, it was possible to calculate coefficients of determination (R^2). This is done by dividing the total sums of squares removed by regression (SSR) by the unadjusted population sums of squares. These coefficients (see Table VII) estimate the amount of or percent of the variation in body weight which was accounted for by the effects that were measured. The coefficients were found to decrease steadily as the lambs increased in age. The coefficients obtained during the 1955-56 season were somewhat less than those calculated at the corresponding ages in the 1956-57 season which would indicate that the unmeasured sources of variation were of greater importance during the 1955-56 season. These estimates ranged from .58 to .29 in 1955-56 and from .59 to .43 in 1956-57. The coefficients of determination calculated by deBaca et al. (1956) were considerably higher but more sources of variation were taken into consideration in their study.

Application of Results

A large portion of the phenotypic expression of a lamb's body weight is due to environmental factors. Consequently, estimates of the magnitude of some of these environmental effects will enable the breeder to make adjustments for them and improve the accuracy of selection. Under systems of management where the lambs are raised for a fat lamb market, it is necessary to make the selection of replacements before the lambs go to

TABLE VII COEFFICIENTS OF DETERMINATION OR THAT PORTION OF THE TOTAL VARIATION IN THE LAMB WEIGHTS AT DIFFERENT AGES ACCOUNTED FOR BY THE VARIABLES STUDIED

1955-56 and 1956-57 DATA

	45 Day Wt.	60 Day Wt.	75 Day Wt.	90 Day Wt.	105 Day Wt.	120 Day Wt.	135 Day Wt.
1955-56	.5781**	.5167**	.4761**	.3838**	.3696**	.2934**	.3020**
1956-57	.5905**	.5343**	.5240**	.4929**	.4564**	.4275**	.4357**

** $P < 0.01$

market. The results of this study indicate that the magnitude of the environmental effects change as the lambs grow older and heavier. Therefore, if a breeder used the same correction factors for lambs differing in age, error may be introduced. For example, using the 1956-57 data, the difference between males and females increases steadily from 1.9 pounds at 45 days to 5.0 pounds at 135 days.

When selecting lambs for replacements, the best results would probably be obtained with selection at older ages when the maternal influence of the dam is less important. As the lamb grows older it becomes less dependent on its dam, thus, its weight at a later age is a better indication of its own ability to grow.

Selection of lambs within a flock is but one of the uses of these correction factors. Some recent work by Barnicoat et al. (1956) indicates that the milk production of a ewe can be estimated fairly accurately on the basis of the amount of body weight gain of her lambs between birth and six weeks of age. To use this method it is necessary to make adjustments for the differences between twins and singles. On the basis of their lamb's gain, the less productive ewes could be culled from the flock.

If more than one ram is used in the flock, it is possible to compare the rams on the basis of their progeny. Since the rams will not sire the same number of males and females or twins and singles, it would be necessary to make adjustments for these differences.

SUMMARY

The weights of 300 lambs reared in 1955-56 and 1956-57 were adjusted to constant ages of 45, 60, 75, 90, 105, 120 and 135 days. The effects of breed of ewe, birth type, sex, type of rearing and birth weight on the variation in body weight at these different ages were estimated by least squares analysis. Each estimate of a source of variation or partial regression coefficient can be interpreted as the average change in body weight for each unit change in its corresponding variable when the other variables are not changed. The data were analyzed on a within year basis because the same ewes were bred each season and the effect of age of ewe and year could not be separated.

The results indicate that there was little difference in the rate of gain of the lambs due to differences in breed of ewe. Differences in lamb weights due to birth type or the difference between single lambs reared as singles and twin lambs reared as singles were not conclusive. Male lambs were heavier than female lambs at all ages. The most important differences were obtained 1956-57 when the males were approximately 5 pounds heavier than the females at 135 days. The differences between sexes were significant at all ages in 1956-57. Lambs reared as singles were from 6 to 8 pounds heavier than the lambs reared as twins in 1955-56. The difference due to type of rearing ranged from 2 to 4 pounds in favor of the single lambs in 1956-57, but the differences were not significant. The difference in birth weight was the most important source of variation in the lamb

weights at different ages. Regression of subsequent weights on birth weight increased steadily from 1.48 at 45 days to 2.60 pounds at 135 days during 1955-56. The regression of the corresponding weights in 1956-57 increased from 1.95 pounds at 45 days to 2.96 pounds at 135 days of age. Birth weight differences accounted for from 34 to 44 percent of the variation in body weight at 45 days and from 22 to 33 percent at 135 days.

Coefficients of determination R^2 indicated that from 29 to 59 percent of the variation in lamb weights at different ages could be accounted for by the factors studied. These coefficients were highly significant (P 0.01) at all ages during both seasons. Therefore the accuracy of selection can be improved by making adjustments for these sources of variation.

These estimates can be used as correction factors when selecting lambs for replacements, culling the less productive ewes on the basis of their lamb's growth and in the progeny testing of rams.

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A P P E N D I X

APPENDIX A

ADJUSTING WEIGHTS TO A CONSTANT AGE

The method used to adjust the lamb weights to a constant age was the linear interpolation method. This method is considered to be the most accurate when linear growth has occurred between the two weights. Adjustment by this method can be facilitated if the unadjusted weights are conveniently arranged. Appendix Table VIII shows the method used to handle these data. Each lamb is readily identified by number, birth type, sex and rearing.

TABLE VIII AN EXAMPLE OF THE DATA DEMONSTRATING THE MANNER IN WHICH THE DATA WERE ARRANGED PREPARATORY TO ADJUSTING THE WEIGHTS TO A CONSTANT AGE

Lamb No.	Sex	Birth Type Rear.	Birth Wt.	Birth Date	12/5 (340) Wt.	Age	12/20 (355) Wt.	Age	1/2 (2) Wt.	Age	1/14 (14) Wt.	Age	1/ (30 Wt.
15	F	T.T.	7.0	300	31	40	41	55	48	68	51	80	63
-15	W	T.T.	6.5	300	28	40	38	55	46	68	52	80	58
20	F	S.S.	5.3	307	23	33	31	48	38	61	44	73	51
30	W	S.S.	7.6	309	24	31	35	46	39	59	45	71	53
-55	F	T.S.	4.8	296	19	44	28	59	33	72	38	84	44

The general formula used to adjust the weights may be written as follows:

$$\text{Adjusted Wt.} = \frac{(W_1 - W_2)}{(A_1 - A_2)} \times (\text{Constant Age} - A_1) + W_1$$

where

A_1 = next actual age younger than the constant age

A_2 = next actual age older than the constant age.
W_1 = actual weight at age A_1
W_2 = actual weight at age A_2
$A_2 - A_1$ = number of days between weights
$W_2 - W_1$ = number of pounds gained or lost during the period between weights

The differences between ages A_2 and A_1 ranged from 12 to 15 days inclusive. The difference between weights W_2 and W_1 ranged from 1 to 15 pounds inclusive. Therefore, it was possible to calculate a set of adjustment cards (Appendix Tables IX and X) in advance to speed up the process of weight adjustment. These weight adjustment cards were transferred readily to a wheel so that the number of pounds to add to W_1 could be read directly from the wheel for any amount of gain from 1 to 15 pounds at interval between weights from 12 to 16 days inclusive.

Appendix Figure 2 shows a portion of the under half of the weight adjustment wheel. In this figure a gain of 5 pounds ($W_2 - W_1$) was used for the different periods between weights ($A_2 - A_1$). Each different possible amount of gain for the different periods between weights was calculated in a similar manner. The pounds to be added were rounded off to the nearest pound. Appendix Figure 3 shows a portion of the cover of the weight adjustment wheel for adjusting weights to a constant age of 60 days. Several windows were cut in the cover to reduce the amount of turning necessary to find the correct amount of gain and the correct number of days between weights. To adjust the weights to a different age it is only necessary to make a new cover for that particular age. If a lamb lost weight during the period between weights, the adjusted weight is calculated in the same manner except the figure obtained on the weight adjustment wheel is subtracted from W_1 instead of adding the figure to W_1.

TABLE IX ADJUSTMENT CARD FOR 14 DAY PERIOD BETWEEN WEIGHTS

Adj. Age minus Act. Age	POUNDS GAIN BETWEEN WEIGHTS 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
13	1	2	3	4	5	6	6	7	8	9	10	11	12	13	14	15
12	1	2	3	3	4	5	6	7	8	8	9	10	11	12	13	14
11	1	2	2	3	4	5	5	6	7	8	9	9	10	11	12	12
10	1	1	2	3	4	4	5	6	6	7	8	9	9	10	10	11
9	1	1	2	3	3	4	4	5	6	6	7	8	8	9	10	10
8	1	1	2	2	3	3	4	4	5	6	6	7	7	8	9	9
7	1	1	2	2	2	3	3	4	4	5	5	6	6	7	7	8
6	0	1	2	2	2	3	3	3	4	4	5	5	6	6	6	7
5	0	1	1	1	2	2	2	3	3	4	4	4	5	5	5	6
4	0	1	1	1	1	2	2	2	3	3	3	3	4	4	4	5
3	0	0	1	1	1	1	1	2	2	2	2	3	3	3	3	3
2	0	0	0	1	1	1	1	1	1	1	2	2	2	2	2	2
1	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1

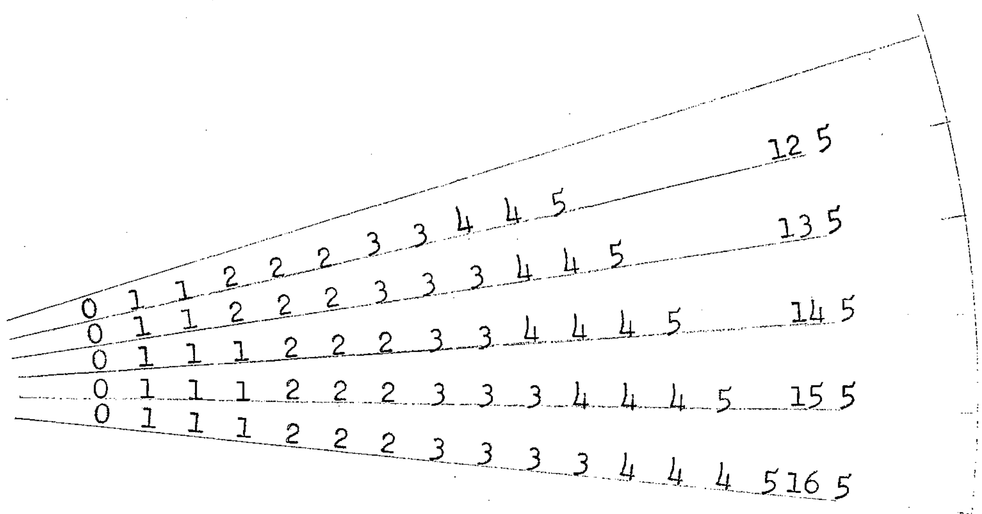

FIGURE 2

A PORTION OF THE UNDER HALF OF THE WEIGHT ADJUSTMENT WHEEL SHOWING A GAIN OF 5 POUNDS DURING A 12, 13, 14, 15, and 16 DAY PERIOD BETWEEN WEIGHTS

TABLE X ADJUSTMENT CARD FOR A 16 DAY PERIOD BETWEEN WEIGHTS

Adj. Age minus Act. Age	POUNDS GAIN BETWEEN WEIGHTS														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
15	1	2	3	4	5	6	7	8	8	9	10	11	12	13	14
14	1	2	3	4	4	5	6	7	8	9	10	11	11	12	13
13	1	2	2	3	4	5	6	7	7	8	9	10	11	11	12
12	1	2	2	3	4	5	5	6	7	8	8	9	10	11	11
11	1	1	2	3	3	4	5	6	6	7	8	8	9	10	10
10	1	1	2	3	3	4	4	5	6	6	7	8	8	9	9
9	1	1	2	2	3	3	4	5	5	6	6	7	7	8	8
8	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8
7	0	1	1	2	2	3	3	4	4	4	5	5	6	6	7
6	0	1	1	2	2	2	3	3	3	4	4	5	5	5	6
5	0	1	1	1	2	2	2	3	3	3	3	4	4	4	5
4	0	1	1	1	1	2	2	2	2	3	3	3	3	4	4
3	0	0	1	1	1	1	1	2	2	2	2	2	2	3	3
2	0	0	0	1	1	1	1	1	1	1	1	2	2	2	2
1	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1

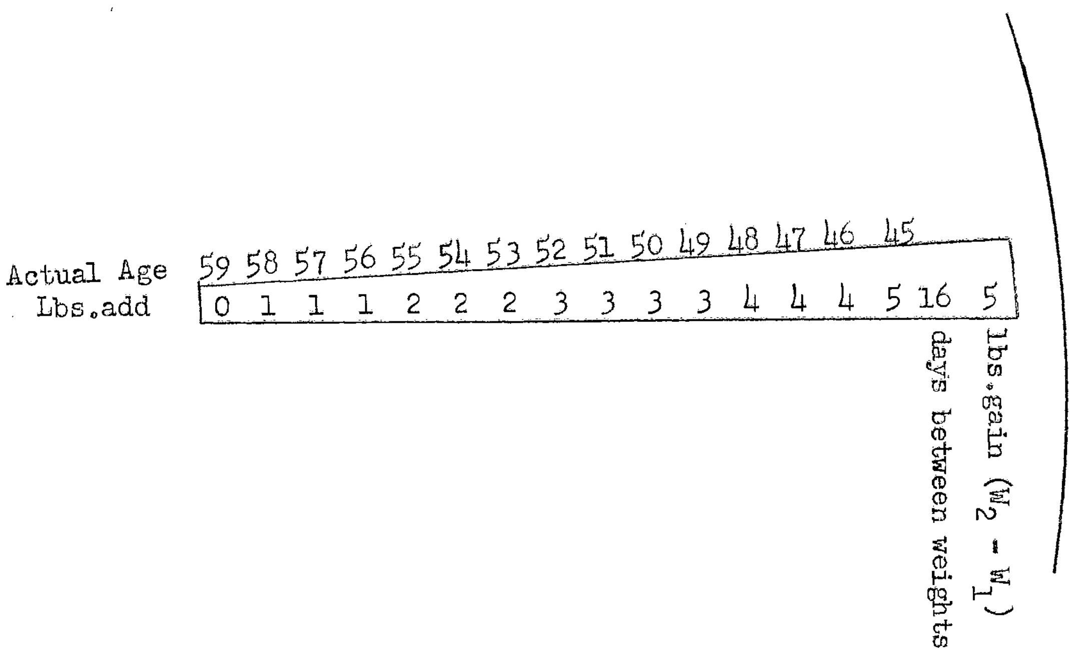

FIGURE 3

A PORTION OF THE WEIGHT ADJUSTING WHEEL SHOWING THE POUNDS TO ADD TO OBTAIN AN ADJUSTED 60 DAY WEIGHT

APPENDIX B

PREPARATION OF THE DATA FOR ANALYSIS

International Business Machines were used to facilitate the calculations necessary to obtain the estimates of the effects of breed, birth type, sex, type of rearing and birth weight on the adjusted lamb weights. Before the data could be analyzed on the IBM computer, it was necessary to punch the required information on IBM cards. Each card represented an individual lamb and contained the following information about that lamb:

1. Year the record was made.
2. Dam number.
3. Column for the mean.
4. Breed, D X R or D X RPR.
5. Birth type, single or twin.
6. Sex, wether or ewe.
7. Type of rearing, single or twin.
8. Birth weight.
9. Adjusted 45 day weight.
10. Adjusted 60 day weight.
11. Adjusted 75 day weight.
12. Adjusted 90 day weight.
13. Adjusted 105 day weight.
14. Adjusted 120 day weight.
15. Adjusted 135 day weight.
16. Market weight.
17. Market age.
18. Lamb identification number.

The lamb number consisted of four digits. The first digit identified the lamb as a twin or single, 1 for the first twin, 2 for the second twin and 0 for a single lamb. These cards represented an X matrix. A sample of the method in which the cards were punched is presented in Appendix Table XI. By the use of the IBM computor it was possible to obtain all the sums of squares and cross-products for all the variables needed to assemble the X'X matrices and their corresponding X'Y matrices. The X'X matrices were singular in nature and the singularities had to be removed before a solution could be obtained. This was done by removing the last column and the last row of each of the classifications for breed, birth type, sex, and type of rearing. The X'X matrices and their corresponding X'Y matrices are presented in Appendix Tables XII and XIII. Another way to remove the singularities in the matrices would be to make the restriction that the sum of the breed, birth type, sex, and rearing effects are each equal to zero. However, the size of the matrix would be larger and require a larger amount of calculation to invert.

TABLE XI A PORTION OF THE X MATRIX EACH LINE REPRESENTS ONE IBM CARD CONTAINING AN INDIVIDUAL LAMB'S IDENTIFICATION AND ADJUSTED WEIGHTS AT DIFFERENT AGES

Year	Ewe No.	Mean	Breed		B.Type		Sex		Rear-ing		Bir. Wt.	45 Day Wt.	60 Day Wt.	75 Day Wt.	90 Day Wt.	105 Day Wt.	120 Day Wt.	135 Day Wt.	Mkt. Wt.	Mkt. Age	Lamb No.
			D X R	D X RPR	Single	Twin	Male	Female	Single	Twin											
56	008	1	0	1	0	1	0	1	1	0	070	034	044	052	058	069	076	086	092	144	0008
56	013	1	0	1	1	0	1	0	1	0	050	028	030	036	043	051	059	069	092	178	0013
56	071	1	0	1	0	1	1	0	0	1	060	022	028	036	043	049	061	070	090	167	1071
56	071	1	0	1	0	1	1	0	0	1	060	023	031	039	048	055	067	074	093	167	2071
56	110	1	1	0	1	0	1	0	1	0	040	027	037	046	052	056	064	071	098	188	0110
57	055	1	0	1	0	1	0	1	0	1	049	014	021	028	034	041	047	052	079	196	1055
57	055	1	0	1	0	1	0	1	1	0	048	019	028	034	040	046	054	059	083	196	2055
57	109	1	1	0	1	0	1	0	1	0	097	042	051	060	070	080	089	097	099	139	0109
57	201	1	1	0	0	1	0	1	0	1	058	028	036	046	054	063	068	072	092	176	1201
57	201	1	1	0	0	1	1	0	0	1	055	028	034	043	054	062	068	076	092	162	2201

TABLE XII THE 6x6 X'X MATRIX AND THE 7 X'Y MATRICES FROM 1956 DATA

Mean	Breed D X R	Birth Type Sin.	Sex Male	Rear-ing Sing.	Birth Wt.	45 Day Wt.	60 Day Wt.	75 Day Wt.	90 Day Wt.	105 Day Wt.	120 Day Wt.	135 Day Wt.
119	75	85	62	97	772.5	3640	4697	5540	6240	6867	7623	8559
	75	59	36	63	502.5	2363	3045	3604	4070	4434	4872	5457
		85	41	85	575.5	2760	3537	4143	4617	5043	5537	6203
			62	49	414.0	1939	2496	2948	3307	3660	4080	4592
				97	644.0	3112	3994	4689	5243	5746	6322	7084
					5402.25	24353	31297	36873	41468.5	45647.5	50498.5	56658.5

TABLE XIII MATRIX INVERSE, THE C_{ij} OR $(X'X)^{-1}$ MATRIX FROM THE 1956 DATA

.15023593	-.0162113	.0192573	-.0138441	-.0498364	-.0150248
	.0389920	-.0121030	.0035814	.0078369	-.0012281
		.1037623	.0068412	-.0867979	-.0028588
			.0352862	-.0021169	.0015341
				.1306414	.0002325
					.0028422

TABLE XIV THE 6x6 MATRIX AND THE 7 X'Y MATRICES FROM 1957 DATA

X'X						X'Y						
Mean	Breed D X R	Birth Type Sing.	Sex Male	Rear-ing Sing.	Birth Wt.	45 Day Wt.	60 Day Wt.	75 Day Wt.	90 Day Wt.	105 Day Wt.	120 Day Wt.	135 Day Wt.
181	104	98	90	103	1267.5	6014	7613	9044	10473	11964	13376	14652
	104	53	54	54	738.5	3454	4369	5193	6017	6882	7683	8425
		98	47	97	740.7	3597	4497	5313	6094	6862	7626	8318
			90	51	658.5	3127	3953	4701	5427	6213	6927	7595
				103	764.6	3742	4691	5544	6366	7167	7981	8709
					9391.31	43451.4	54773.1	64891.5	74983.1	85535.3	95488.2	104525.5

TABLE XV MATRIX INVERSE, THE C_{ij} OR $(X'X)^{-1}$ MATRIX FROM THE 1957 DATA

.1106013	-.0107743	.0305374	-.0006052	-.0286805	-.0141084
	.0233109	-.0042986	-.0009561	.0072604	-.0005639
		.1651746	.0091608	-.1486738	-.0053478
			.0234968	-.0068957	-.0016515
				.1589441	.0025684
					.0023830

APPENDIX C

TABLE XVI MEAN LAMB BODY WEIGHTS, STANDARD DEVIATIONS AND COEFFICIENTS OF VARIATION FOR THE DIFFERENT CONSTANT AGES
1955-56 DATA

UNADJUSTED FOR THE SOURCES OF VARIATION OTHER THAN AGE

Breed		Birth Weight	45 Day Wt.	60 Day Wt.	75 Day Wt.
D X RPR	$\bar{x}$	6.14	29.02	37.55	44.00
n = 44	s	1.65	6.20	7.18	8.02
	C.V.	26.9 %	21.4 %	19.1 %	18.2 %
D X R	$\bar{x}$	6.70	31.50	40.60	48.05
n = 75	s	1.88	5.31	6.50	7.54
	C.V.	28.1 %	16.9 %	16.0 %	15.7 %
Combined	$\bar{x}$	6.49	30.58	39.47	46.55
Weights	s	1.81	5.76	6.89	7.93
n = 119	C.V.	27.9 %	18.8 %	17.5 %	17.0 %

Breed		90 Day Wt.	105 Day Wt.	120 Day Wt.	135 Day Wt.
D X RPR	$\bar{x}$	49.31	55.29	62.52	70.50
n = 44	s	8.71	9.37	10.45	11.09
	C.V.	17.7 %	16.9 %	16.7 %	15.7 %
D X R	$\bar{x}$	54.26	59.12	64.90	72.76
n = 75	s	8.63	9.41	9.30	9.99
	C.V.	15.9 %	15.9 %	14.3 %	13.7%
Combined		52.44	57.70	64.05	71.92
Weights		8.95	9.54	9.77	10.42
n = 119		17.1 %	16.5 %	15.3 %	14.5 %

TABLE XVII MEAN LAMB BODY WEIGHTS, STANDARD DEVIATIONS AND COEFFICIENTS OF VARIATION FOR THE DIFFERENT CONSTANT AGES 1956-57 DATA

UNADJUSTED FOR THE SOURCES OF VARIATION OTHER THAN AGE

Breed		Birth Weight	45 Day Wt.	60 Day Wt.	75 Day Wt.
D X RPR	$\bar{x}$	6.87	33.24	42.12	50.01
n = 77	s	1.69	6.43	7.73	8.46
	C.V.	24.6 %	19.3 %	18.4 %	16.9 %
D X R	$\bar{x}$	7.10	33.21	42.00	49.93
n = 104	s	1.69	6.82	7.80	8.67
	C.V.	23.8 %	20.5 %	18.6 %	17.4 %
Combined	$\bar{x}$	7.00	33.22	42.06	49.96
Weights	s	1.69	6.64	7.74	8.55
n = 181	C.V.	24.1 %	20.0 %	18.4 %	17.1 %

Breed		90 Day Wt.	105 Day Wt.	120 Day Wt.	135 Day Wt.
D X RPR	$\bar{x}$	57.87	66.00	73.94	80.87
n = 77	s	9.21	10.06	10.63	11.38
	C.V.	15.9 %	15.2 %	14.4 %	14.1 %
D X R	$\bar{x}$	57.85	66.17	73.87	81.05
n = 104	s	9.26	9.63	10.29	10.58
	C.V.	16.0 %	14.5 %	13.9 %	13.1 %
Combined	$\bar{x}$	57.86	66.10	73.90	80.95
Weights	s	9.21	9.78	10.41	10.90
n = 181	C.V.	15.9 %	14.8 %	14.1 %	13.5 %

APPENDIX D

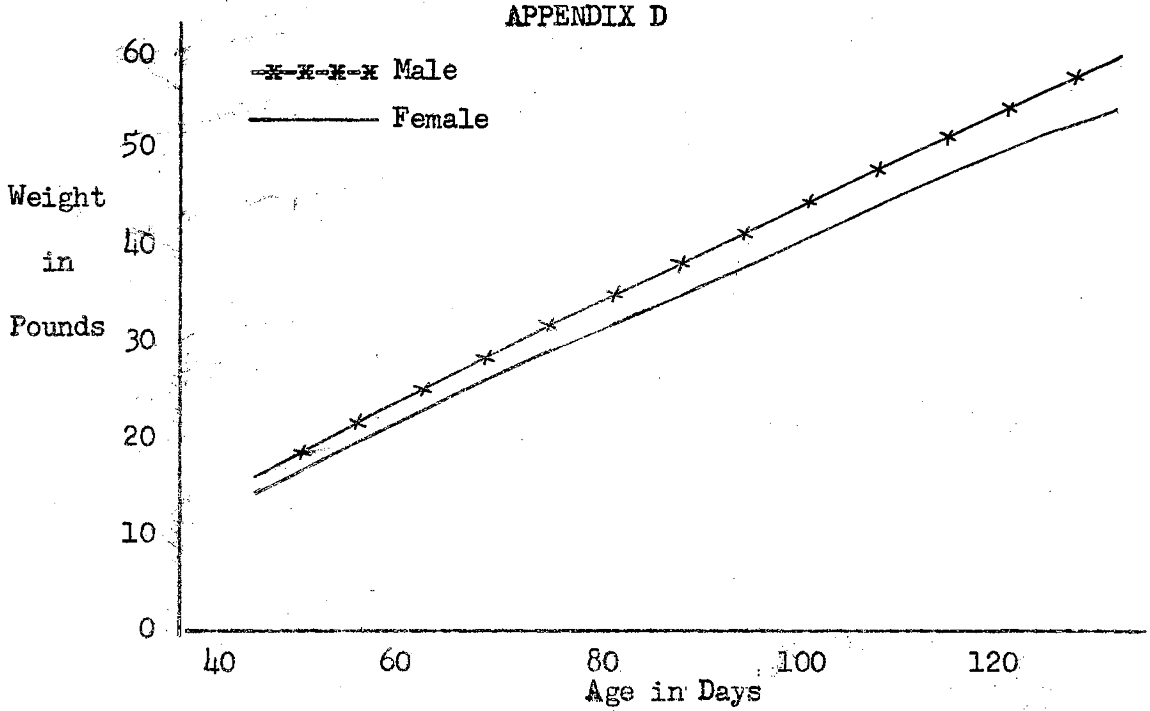

FIGURE 4 THE MEAN IN COMBINATION WITH THE EFFECT OF SEX INDEPENDENT OF THE OTHER SOURCES OF VARIATION
1956-57 DATA

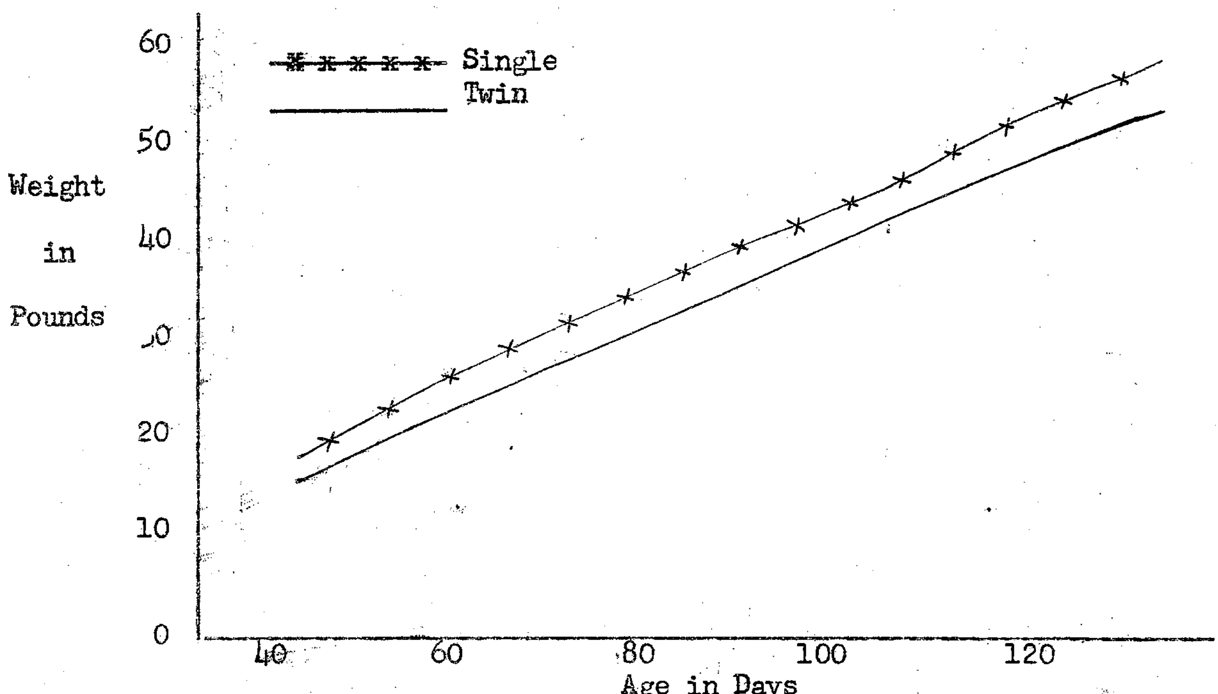

FIGURE 5 THE MEAN IN COMBINATION WITH THE EFFECT OF TYPE OF REARING INDEPENDENT OF THE OTHER SOURCES OF VARIATION
1956-57 DATA

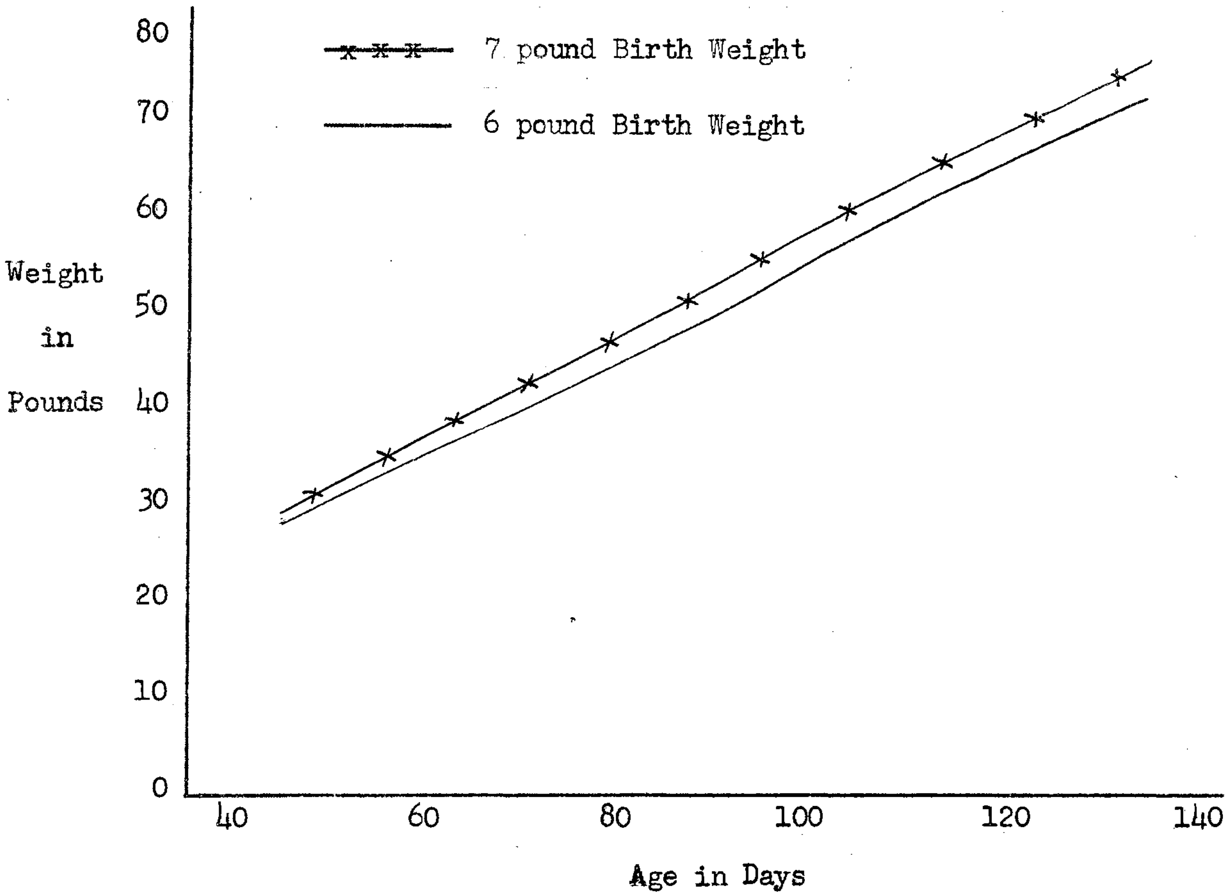

FIGURE 6 THE MEAN IN COMBINATION WITH THE EFFECT OF BIRTH WEIGHT INDEPENDENT OF THE OTHER VARIABLES 1956-57 DATA

VITA

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