SELECTION OF LAMBS THAT YIELD THE GREATEST EXPERIMENTAL EFFICIENCY IN GROWTH STUDIES FROM APPROXIMATELY FIFTY TO NINETY POUNDS

By

Don G. Brothers

Bachelor of Science
Texas Technological College
Lubbock, Texas
June, 1957

Master of Science
Oklahoma State University of Agriculture and
Applied Science
Stillwater, Oklahoma
May, 1959

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the Oklahoma State University of Agriculture and
Applied Science in partial fulfillment of the
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Thesis Approved:

Joe V. Whiteman
Thesis Adviser

E.J. Turman

Robert D Morrison

Allen D. Tillman

J A Whatley Jr.

Dean of Graduate School

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INTRODUCTION

The magnitude of the experimental error is probably the most profound problem confronting the statistical analysis of an experiment with animals. This fact exists because many sources of variation influence animal response and large numbers for experimental use are often unavailable, too costly or facilities for large numbers are limited. Therefore, more information is needed concerning the selection of experimental material that yields the smallest experimental error and consequently the greatest experimental efficiency.

Both physical and statistical control have been employed in attempts to reduce experimental error. These include selection of homogenous units, stratification of units into sub-populations of similar individuals, use of covariance analysis and use of correction factors. Increasing numbers has also been used to increase the degrees of freedom and reduce the standard error of the mean, but this practice does not reduce the experimental error.

Twin pairs have some sources of variation in common that random groups of animals do not. This has led to the establishment of monozygotic cattle twins as valuable experimental units for certain experiments. Also litter mates in swine (seldom monozygotic) are known to yield greater experimental efficiency in some types of experiments than pigs from different litters. Monozygotic twins in sheep are rare, but dizygotic twins occur frequently. These dizygotic twins have several sources of variation in common that random groups of lambs do not.

Brothers (1959) investigated average daily gain of lambs from 50 to 90 pounds and found that the variation within like-sexed twin pairs was less than the variation within groups of randomly selected lambs of the same sex. However, in experiments where more than two treatments are imposed one may have difficulty in obtaining adequate numbers of twin pairs for the experiment which requires some form of the incomplete block design. Also twin efficiency value estimates do not take into consideration the loss of degrees of freedom that occurs when the pairing design is employed. Therefore, further work is needed to establish which of the known sources of variation should be held constant when one is selecting lambs for experiments in which twin pairs as experimental units are not completely suitable.

It was the purpose of this study to determine the increase in experimental efficiency one may expect to obtain when various known sources of variation are held constant by selecting lambs within one or more classifications of these known variables. The criterion for measurement was average daily gain from approximately 50 to 90 pounds.

REVIEW OF LITERATURE

Rate of growth in lambs is influenced by both genetic and environmental sources of variation. Many of these sources are known. A particular sample of lambs can reflect differences due to any number of these known sources. This depends on how many sources of variation the lambs under consideration do not have in common.

Factors Affecting Growth Rate of Lambs

Hazel and Terrill (1945a) used data from 2183 Rambouillet lambs weaned at an average weight of 69 pounds. Ram lambs were heavier than ewe lambs, lambs from mature ewes were heavier than lambs from two-year-old ewes and singles were heavier than twins reared twin or singly ($P < .01$). The regressions of weaning weight on age at weaning ($b = 0.41$) and on percent inbreeding ($b = -0.38$) were also significant ($P < .01$). A significant difference due to year was not found. The factors considered accounted for 49.5 percent of the total variation in weaning weight. Hazel and Terrill (1946a) also studied records from 478 Columbia, 238 Corriedale and 366 Targhee lambs weaned at an average age and weight of 120 days and 73 pounds, respectively. Ram lambs gained faster than ewe lambs, and singles gained faster than twins reared twin or singly ($P < .01$). Lambs from two-year-old dams gained slower than lambs from mature dams ($P < .01$). Regressions of weaning weight on age at weaning ($b = 0.45$) and weaning weight on percent inbreeding (b = -0.30) were also highly significant. Columbia lambs were heavier than Corriedale and Targhee lambs at weaning.

Price et al. (1953) used 917 Navajo and Navajo crossbred ewes to study the effect of various factors on yearling body weight. Ewes from two-year-old dams were lighter than ewes from dams three-years-old and older and singles were heavier than twins reared twin or singly ($P < .01$). Effect due to year and the regression of body weight on yearling age were also significant ($P < .01$). These factors and the difference between breeding groups accounted for about 48 percent of the total variation in body weight. Botkin et al. (1956) studied data from 1020 Rambouillet lambs weaned at an average age of 128 days and 480 lambs weaned at an average age of 202 days. Rams were 9 pounds heavier than ewes when weaned at 128 days and 15 pounds heavier than ewes when weaned at 202 days. Single lambs were 14 pounds heavier than twin lambs when weaned early but only 8 pounds heavier than twins when weaned late. Age of dam had little influence on weaning weight. Karan et al. (1953) also found that wether lambs and single lambs were significantly heavier at 155 days of age than ewe and twin lambs, respectively.

deBaca et al. (1956) estimated the influence of various variables on weaning weight at 120 days of age from 280 crossbred lambs. Birth weight was the most influential of all the variables studied. The regression of weaning weight on birth weight (b = 2.50 to 5.96) was high and significant ($P < .01$). Lambs born as singles were 17 pounds heavier at weaning than those born twin. However, when adjustments for birth weights were made this difference was eliminated. Wethers were consistently heavier than ewe lambs although this difference was not always significant.

Phillips and Dawson (1937) presented data on 829 Southdown lambs reared under farm conditions. Multiple regression analysis revealed that singles were heavier at three months of age than twins. Birth weight was also a significant factor affecting three month weight. However, these factors were of little importance when weight at one year of age was considered. Phillips *et al.* (1940) studied growth rate of 262 Corriedale and 322 Rambouillet lambs raised under range conditions. Singles were heavier than twins and ram lambs out gained ewe lambs throughout the first year. Terrill *et al.* (1947) investigated body weights of 406 Columbia and 290 Targhee yearling ewes also raised under range conditions. The ewes averaged 402 days of age when body weight was taken. Type of birth and rearing accounted for 7 to 13 percent of the total variation. Columbia single ewes weighed 7.12 pounds more than twins and 2.37 pounds more than twins raised singly. Corresponding differences for Targhees were 4.70 and 7.42 pounds, respectively. Age of dam (mature vs. two-year-old) had an important effect on body weight in Columbias but was not significant for Targhees. Variation due to year was significant ($P < .01$).

Kean and Henning (1949) collected records on 882 hot house lambs of 10 breeds and cross breeds. Males were 0.6 pound heavier than females, and singles were 1.4 pounds heavier than twins at birth. Males and singles outgained females and twins, respectively, to about 36 pounds when the lambs were marketed. Birth weight varied between breeds and crossbreeds, and it had a tendency to be positively correlated with average daily gain. Burris and Baugus (1955) reported that average daily gain of lambs to 16 weeks of age is correlated with weight of the ewe (r = 0.67) and birth weight of the lamb (r = 0.61). However, the multiple regression equation revealed the partial regressions of average daily gain on body weight of the ewe and on birth weight of the lamb were not significant when milk consumption of the lamb was considered as an independent variable in the model.

Bogart et al. (1957) used 280 crossbred lambs in a study to determine factors affecting birth weight. Birth type contributed the most consistent of all effects on birth weight. Singles were from 1.92 to 2.40 pounds heavier at birth than were twins. Ram lambs were consistently heavier than ewe lambs but this difference was not significant. There was no consistent difference in lambs by Suffolk and Southdown rams, but lambs from Border Leicester-cross ewes were significantly heavier than those from Cheviot-cross ewes.

Harrington et al. (1958) estimated the effect of breed of dam, birth type, sex, rearing type and birth weight on the variation in body weight at 45, 60, 75, 90, 105, 120 and 135 days of age for 300 crossbred lambs. Birth weight was the most important source of variation in lamb weights at all ages. Males were also heavier than females at all ages but this difference was not always significant. Single lambs had a tendency to be heavier than twins reared twin or singly, but these sources of variation became less important as the lambs grew older. All factors studied accounted for 29 to 59 percent of the total variation in lamb weights at different ages. Harrington et al. (1960b) also investigated the effect of birth weight, breed of dam, type of birth and rearing, sex and sire on variation in rate of gain from 50 to 90 pounds. These factors accounted for 38 percent of the total variation. Of this, 21 percent was removed by birth weight and 9 percent by sire.

Cassard and Weir (1956) determined factors affecting lamb weights at birth, 70, 120 and 240 days of age and their inclusive growth rates from purebred Suffolk records. Sex was not significant at birth but was in all weights and rates of growth thereafter. Singles were heavier than twins at birth and grew faster to 70 days but slower from 70 to 120 days than twins. All weight difference in females due to birth type was lost by 240 days; however this was not so with males. Age of dam influenced 70 and 120 day weights and growth to 70 days (curvilinear). Heritability estimates for weights ranged from 0.09 at birth to 0.41 at 120 days. Estimates for the three inclusive growth rates were 0.40, 0.18 and 0.63.

Blackwell and Henderson (1955) studied the variation in 1295 weaning weight records of lambs from 560 ewes. The data were collected from 1930 to 1952. A significant ($P < .01$) difference was found between Corriedale (62 lb.) Hampshire (71 lb.) and Shropshire (55 lb.) breeds and between years. Males gained faster than females and singles gained faster than twins reared twin or singly ($P < .05$). The effect of age of dam was curvilinear, reaching a maximum at about five years of age. Regression of weaning weight on age of lamb at weaning ($b = 0.13$ to 0.27) was significant ($P < .05$). Sidwell and Grandstaff (1949) collected data from 1,506 lambs representing the lifetime production of 414 Navajo ewes. The lambs were sired by various sire breeds. Year, age of ewe, breed of sire, type of birth and rearing and sex were all found to be significant ($P < .01$) factors affecting weight at weaning at about 60 pounds. These factors and the regression of weaning weight on weaning age ($b = 0.37$) accounted for 56 percent of the total variation. Brothers and Whiteman

(1960) used 330 crossbred lambs in a study which indicated birth weight, breed of dam, type of birth and rearing, sex, year and sire accounted for 35 percent of the total variation in average daily gain from 50 to 90 pounds. Of this, 8 percent of the variation was removed by sire and 27 percent by factors other than sire.

Sidwell (1956) reported Navajo crossbred ewes had heavier lambs than Navajo ewes and singles were heavier than twins ($P < .01$) at weaning. Jamison et al. (1956) studied the effect of breed of sire on body weight from data on 967 grade lambs sired by 60 rams of seven breeds. Differences in birth weight among breeds were small but significant in some cases. Data from 1125 lambs were also analyzed by Jamison et al. (1961) who reported that singles were 1.88 pounds heavier than twins and ram lambs were 0.36 pound heavier than ewes at birth. Breed of sire was also found to influence birth weight when seven breeds and breed crosses were analyzed. However, not all differences due to breed of sire were significant. Kincaid (1943) used Hampshire and Southdown sires in a "switchback" scheme of breeding on two equal groups of native ewes. Hampshire sired lambs averaged 1.05 pounds heavier at birth than Southdown sired lambs. An average annual increase of 0.63 pound in birth weight of lambs as the ewe increased in age from two to six years was observed. No significant departure from linearity was found. Male lambs were slightly heavier at birth but the difference was not significant.

Dameron et al. (1949) reported significant differences within and between Rambouillet sire groups on rate of gain of their lambs on test. Relatively high heritability for this trait was indicated when 96 rams from 12 sire groups were used. Hazel and Terrill (1945b) estimated heritability of weaning weight to be 0.269 $\pm$ .045 by the half-sib correlation method and 0.339 $\pm$ .007 by the intra-sire regression of offspring on dam. The average estimate was 0.30 $\pm$ .04. The data consisted of 2183 lambs and 892 dam-offspring pairs. Hazel and Terrill (1946b) also reported heritability of weaning weight to be 0.17 $\pm$ .05 when heritabilities from Columbia, Corriedale and Targhee breeds computed by half-sib correlation and offspring-dam regression methods were appropriately weighted. The data for the half-sib correlations were 1711 lambs by 99 sires, and the offspring-dam regression data were 798 pairs. Nelson and Venkatachalam (1949) found significant differences in weaning weight of lambs due to differences in sex, type of birth and age of dam. Lambs from mature ewes were heavier than those from two-year-old ewes. Heritability of weaning weight was 0.33 $\pm$ .12. Handley and Carter (1956) reported heritability estimates of rate of gain from birth to weaning obtained from 943 lambs sired by Hampshire and Southdown rams out of grade ewes. Heritability estimates were 0.37 $\pm$ .15 for Hampshire and 0.04 $\pm$ .14 for Southdowns. Harrington _et al_. (1960a) reported from data on 671 crossbred lambs. Heritabilities were 0.11, 0.38 and 0.36 for average daily gain from birth to 50 pounds, 50 to 90 pounds and birth to 90 pounds, respectively.

The preceding literature review indicates that many factors affect rate of gain among lambs. These include birth weight, sex and birth and rearing type of the lamb, year of the trial and age of dam. Also genetic differences associated with breed of sire and dam as well as genetic differences within breeds (heritability) affect lamb growth.

Some of these variables are correlated and, consequently, the effect of one may be dependent on one or more other variables.

Physical and Statistical Control of the Known Sources of Variation

Both physical and statistical control of variables have been employed in attempts to combat the various known sources of variation established in the preceding section. Physical control is usually used when uniform groups of animals are desired to begin an experiment or when uniform groups are desired to compare particular measurements on such as in selection. Statistical control has been devised to make corrections for known sources of variation so that groups of animals from different classifications of variables may be compared on some common basis. However, Koch and Clark (1955) state that statistical control of a variable may not remove all variation for each individual due to the variable but only the average effect of the variable on all individuals.

Phillips and Dawson (1940) found that birth and rearing type, sex, breed, birth weight and time of birth had varying degrees of influence on lamb weights at three, six and 12 months of age. They suggested that selection should be improved by: (1) dividing lambs into similar groups at time of selection and selecting only within these groups; (2) selecting at a standard age rather than a standard date and correcting for the known sources of variation; or (3) delaying selection until an age when differences disappear which they admit is probably not too practical. Hazel and Terrill (1945a) also reported that sex, age of dam, year, breeding group, type of birth, age at weaning and percent inbreeding affected lamb weaning weights and suggested that selection should be more accurate if lambs were sorted into various groups or if weaning weights were adjusted for these variables before selection.

Correction of weights to a standard age occupies much of the literature concerning correction factors. Whatley and Quaife (1937) adjusted pig weights to a standard age of 56 days. Linear growth was assumed and a multiplicative correction was employed since the observed weight was multiplied by an age correction term. This method was extended by Phillips and Brier (1940) who found it to be satisfactory to correct lamb weights to a constant age of 20 weeks and by Botkin and Whatley (1953) to adjust beef calves to a standard weaning age of 210 days. Lush and Kincaid (1943) later used a quadratic equation to describe the growth of pigs at 154 days.

Johnson and Dinkel (1951) adjusted calf weights to a standard age of 190 days and found that linear correction factors obtained by the method of Whatley and Quaife (1937) were slightly more accurate than the quadratic corrections obtained by the method of Lush and Kincaid (1943).

Hazel and Terrill (1945a) suggested that corrections for variables could be made by adding the mean difference between two variables to the inferior of the two. Gregory _et al_. (1950) corrected birth weights of beef calves for sex differences by adding the mean difference in birth weight between heifer and bull calves to the birth weights of all heifer calves. Koch and Clark (1955) recommended additive corrections for sex of calf and age of dam differences in order to standardize birth weights and weaning weights. These correction factors were simply the mean difference between heifers and bulls when the weights were taken.

Botkin and Whatley (1953) adjusted birth weights and weaning weights of beef calves for the effect of sex of calf, age of dam and year by the use of additive corrections. This type of correction for age of dam removed 82 percent of the variation in weaning weight and 62 percent of the variation in birth weight due to differences in age of dam. Rollins and Guilbert (1954) standardized early rate of growth and weaning weight of beef calves for sex, year and season of birth and age of dam. The additive correction factors used were established simultaneously by the least squares solution of an equation containing additional sources of variation not corrected for.

Botkin (1952) suggested the use of a percentage correction factor to convert one sex to the equivalent of the other because sex difference increases with age. Koch et al. (1959) used both additive and multiplicative corrections for the influence of sex on birth weights and daily gains from birth to weaning. However, the results were inconclusive as to which is more efficient. Taylor and Hazel (1955) examined six possible methods of adjusting pig weights to a standard age of 154 days and concluded a combination of both additive and multiplicative factors yield the most satisfactory method to make this correction.

Minyard and Dinkel (1960) corrected 2351 calf weaning weight records by two methods for age and sex of calf. Age of calf was more efficiently corrected by a multiplicative factor than by an additive factor. This method removed 90 percent of the variation due to age of calf. A multiplicative correction also was more effective than an additive correction for sex adjustment. However, neither method reduced the between sex variance to a non-significant level.

Marlowe and Gaines (1958) obtained constants by least squares analysis for the effects of sex of calf, season of birth and age of dam on preweaning gain of beef calves. A second group of calf data was corrected for these sources of variation by multiplicative correction factors derived from the constants determined. Sub-group means of the corrected data were satisfactorily equalized leading to the conclusion that these multiplicative correction factors were acceptable.

This section indicates that researchers recognize the need to control known sources of variation by either physical or statistical control. Various sources of variation have been corrected for by statistical control. Both additive and multiplicative correction factors have been used. However, the data are insufficient to establish which kind of correction is best suited for each source of variation.

Use of Twins to Combat Known Sources of Variation

Monozygotic twins have an identical genotype, they develop in the same uterus contemporaneously, they are born in the same year and they share a common post-natal environment. Monozygotic twins in sheep are rare; however, the frequently occurring dizygotic twin lambs are full-sibs, and they share a common pre-natal and post-natal environment contemporaneously. Hence some known sources of variation established in the first section of this literature review are not present in the error variance when dizygotic twin lambs are used for experimental purposes. This reduces the error and increases the efficiency of the experiment.

Robertson (1950) stated that twins of a monozygous pair resemble each other for the following reasons: (1) they have the same genotype;

(2) they have had the same prenatal environment; (3) they are contemporaries; and (4) they have similar local environment. Some of these reasons may be trivial, but they produce, in total, a similarity between monozygotic twins which cannot be ascribed solely to heredity.

Chapman and Lush (1932) found that the total variance of lamb birth weights for 174 twin males was 2.57, and the variance found within the litter for birth weights was 1.33. Therefore, from the calculation

$$\frac{2.57 - 1.33}{2.57} = .48$$

it was determined that the variance was 48 percent less when the study was restricted to lambs born in the same litter than it was when all twin males were included. Corresponding reductions were $(2.67 - 1.44) \div 2.67 = 46$ percent for 180 twin females and $(3.15 - 1.77) \div 3.15 = 44$ percent for 368 twins of unlike sex. They concluded that part of the variation in birth weight is caused by genetic differences, part by definite environmental influences and part by accidents in development such as one embryo being located in a more favorable position. In a random bred population, and for characteristics without dominance, the genetic variance between lambs from a single pair of parents should be one-half the genetic variance between all lambs. Further, lambs in the same litter (1) develop in the same uterus contemporaneously and therefore are subjected to influence by the same general variations in nutrition or other physiological conditions of the dam during fetal development; and (2) they are born in the same year. From an average of the previous analysis the authors estimated that approximately 45 percent of the total variation in birth weight was due to lambs developing from different dams. Some of this variance is genetic and some maternal. Hence

55 percent of the total variation arises from genetic differences and uncontrollable environment. From this assumption they estimated that 25 to 30 percent was due to tangible environment, that is the portion to disappear if all lambs could develop in the same uterus contemporaneously, and 40 to 45 percent of the variance was due to accidents in development.

Donald (1953) collected dairy heifer pairs of one-egg and two-egg twins and half-sibs. He stated that within-pairs of one-egg twins the only known source of variation should be pre-natal and post-natal accidents of environment. In two-egg twins the sources should be supplemented with genetic variation which in a fair sample of pairs should approximate to one half the genetic variance characteristics of the populations from which their parents came. Half sib-pairs should show the greatest variation since they should contain three-quarters of the genetic variance plus maternal effects because they have different dams instead of one as with twins. King and Donald (1955) compared the variance arising within the uniformly treated one-egg, two-egg and half-sib pairs. Analysis of variance of the coefficients within pairs yielded a mean square for dizygotic twins 6.8 times larger than the mean square for monozygous twins. The half-sibs mean square for within pairs was 10 times larger than for monozygous twins.

King (1953) compared 15 sets of one-egg twins with an equal number of two-egg twins and with sets of two half-sibs. All groups were treated uniformly. Variability in the growth rate for the heifers was measured by the mean square within set. The advantage of one-egg twins increased over two-egg twins and half-sibs progressively from weaning to

18 months of age. Two-egg twins appeared to be an improvement on half-sibs and could well be used for husbandry experiments involving simple comparisons of two treatments because they are more readily available.

Brothers (1959) investigated average daily gain of lambs from 50 to 90 pounds and found that the variation within pairs of like-sexed dizygotic twins was less than the variation within groups of randomly selected lambs of the same sex. He also summarized the variants which may contribute to the variance within dizygotic twin pairs of lambs and to the variance within groups of randomly selected lambs. He concluded that breed and age of lamb differences would be absent within twin pairs but present within groups of randomly selected lambs. Also genetic and birth weight differences and differences due to maternal influence are present within groups of random lambs but are reduced to some degree within twin pairs.

This section of the literature review indicates that monozygotic twins are very useful to increase experimental efficiency in some types of animal experiments. Monozygotic twins in sheep are rare, but dizygotic twins occur frequently and have been shown to increase experimental efficiency in growth studies. This occurs because many of the known sources of variation affecting lamb rate of gain are not present within these twin pairs.

Methods Used to Calculate Twin Efficiency Values

Hancock (1950) defined twin efficiency value as the number of animals chosen at random which each member of a twin set will replace without loss of statistical efficiency. The first attempt to estimate twin efficiency values was made by Bonnier _et al._ (1946). However, his method was later proven unsatisfactory and additional methods have developed. Dick and Whittle (1951) contributed a formula to estimate twin efficiency based on a uniformity trial with twins only. The analysis of variance for this method is

Source	Degrees of freedom	Mean square	Expected mean square
Total	$n - 1$		
Between pairs	$\frac{n}{2} - 1$	M_B	$\sigma_W^2 + 2\sigma_B^2$
Within pairs	$\frac{n}{2}$	M_W	σ_W^2

and the twin efficiency value $= \dfrac{\sigma_B{}^2}{\sigma_W{}^2} = \dfrac{1}{2}\left(\dfrac{M_B}{M_W} - 1\right)$.

This method has been the one used most in the establishment of twin efficiency values for various traits.

Carter (1951) finally suggested that twin efficiency should be estimated as

$$E = \frac{1}{2}\left(\frac{M_B}{M_W} + 1\right)$$

because the use of the formula suggested by Dick and Whittle (1951) can possibly yield efficiency values less than one for twins. Stormont (1954) also stated that the efficiency value of twins should be computed as the ratio

$$\frac{1}{2}\left(\frac{\text{between-pair-variance}}{\text{within-pair-variance}} + 1\right)$$

which is simply the variance within pairs of unrelated animals divided by the variance within pairs of twins. This formula increases efficiency values by one over the method of Dick and Whittle (1951).

White (1951) stated that the comparison of between-twin-pair variance with within-pair variance is likely to give an inflated estimate of the twin efficiency value unless all the animals are reasonably alike. He suggested comparing within-pair variance of twins to within-pair variance of pairs of unrelated but similar animals to obtain twin efficiency estimates. This method was also suggested by Dick and Whittle (1951) and has been used by King (1953) and King and Donald (1955) and by Brothers (1959) after slight modification.

Hancock (1951) stated that the basis for calculations of twin efficiency has been the ratio of variances (or variance components) within and between sets of twins which may vary quite widely with sample, environment and character. Hence such estimates of efficiency must not be taken too literally; however, there is no doubt as to their usefulness in experimental work.

Three methods to estimate twin efficiency values have been used or proposed. Two of these methods estimate twin efficiency from a uniformity trial using twins only. However, the third method employs a control group of unrelated individuals similar to the twin pairs and should yield more reliable estimates of twin efficiency values.

MATERIALS AND METHODS

This study was divided into two parts. Part I is a demonstration phase, the purpose of which is to indicate the reduction in experimental error one may expect to obtain if certain known sources of variation are held constant when measuring average daily gain of lambs from approximately 50 to 90 pounds. Part II is concerned with the actual application of the results from Part I to a sample of independent lamb data not previously examined. All major mathematical and statistical calculations were done on the International Business Machines' type 650 data processing machine.

General

The lambs used in this study were obtained from the experimental sheep flock (project S-908) located at the Fort Reno Agricultural Experiment Station. The lambs were born during the late falls of 1956, 1957, 1958 and 1959.

The flock was managed according to the usual practice of commercial sheep breeders in Oklahoma. Breeding began about May 20th in 1956, 1958 and 1959. The breeding period lasted 48 days in 1956 and 40 days in 1958 and 1959. However, breeding began about June 1st and continued for approximately 32 days in 1957. The flock was divided into two groups after lambing. One group was composed of ewes rearing lambs and the other group was composed of ewes rearing no lambs. The ewes with lambs were moved to wheat pasture when the lambs were about 10 days old. Lambs had access to a creep feed consisting of two parts cracked milo grain and one part chopped alfalfa hay of good quality. Ewes rearing twins were separated from ewes rearing singles in the wheat pasture area by a partition fence and were fed grain about one month longer. However, all other management of the two groups was similar.

Birth date, birth weight, sex and birth type were recorded each year at lambing within a few hours after the lamb was born. Each lamb was identified by a number which was the same as that of its dam. In the case of twins, both received their dam's number. However, one of the pair received the number preceded by a bar (-). All the lambs were docked during the first week after birth, and the ram lambs were castrated between one and four weeks of age.

The lambs were weighed again in late November or early December. This weight occurred when the older lambs were 40 to 45 days old. After this the lambs were weighed at regular two-week intervals until marketed in the spring. All lambs were marketed when they reached a minimum weight of about 90 pounds.

Part I: Statistical Control of Variables

The lambs used in this part of the study were from the second, third, fourth and fifth lamb crops of grade Rambouillet (R) and grade Rambouillet X Panama-Rambouillet (RPR) ewes purchased near Del Rio, Texas, in April and May, 1955. All were yearlings when obtained. The lambs were sired by purebred Dorset rams purchased from breeders in Oklahoma.

As previously stated, this part of the study intends to demonstrate the reduction in experimental error that may occur when certain sources of variation are held constant in growth studies with lambs from approximately 50 to 90 pounds. Twin pairs of lambs were used as a standard for comparison because they are probably the most efficient experimental material available for lamb growth studies during this particular growth period (Brothers, 1959).

The twin pairs used were of the same sex and were selected on one of the regular weighing days when they weighed nearest 50 pounds. Twin pairs with more than a six pound difference in their weights were not used. All other lambs in the flock that were of the same sex and weighed within the same weight range that a twin pair did on the particular weigh day the twins were selected were selected also. Hence, for each twin pair selected there was a group of random lambs selected that was of the same sex and approximately the same weight. Table 1 demonstrates how each twin pair and its corresponding group of random lambs was selected simultaneously. There were 33 wether twin pairs and their corresponding groups and 28 ewe lamb twin pairs and their corresponding groups selected from the four years data available. Some lambs appeared in more than one random group. However, this should only reduce the between group variance but not greatly affect the within group variance which is the primary interest here.

The selection date and weight of all lambs were used to begin an average daily gain uniformity trial to market weight of approximately 90 pounds. Analyses of variance were computed to determine the within-twin-pairs variance for the twin lamb data and the lambs-within-groups variance for the random lamb data. These two variances were used to estimate twin efficiency values for the twin pairs by the method suggested by White (1951) and Dick and Whittle (1951). The data were analyzed both on a within year basis and with all four years together. This resulted in a hierarchical or nested classification which was analyzed by the method of Pulley (1959).

TABLE 1. A PORTION OF THE PART I DATA DEMONSTRATING HOW EACH TWIN PAIR AND ITS CORRESPONDING GROUP OF RANDOM LAMBS WERE SELECTED WITHIN THE SAME WEIGHT RANGE SIMULTANEOUSLY

12-20-56		1-4-57		2-13-57	
Lamb number	Selection weight	Lamb number	Selection weight	Lamb number	Selection weight
Twin		Twin		Twin	
197	48	150	53	175	56
-197	47	-150	48	-175	52
Random		Random		Random	
87	47	7	48	17	55
95	47	-15	52	59	52
117	47	18	51	60	56
122	47	25	49	130	54
134	47	38	53	144	56
		106	53	162	54
		148	49		
		-149	52		
		155	53		

There was slightly more than six pounds difference between pairs and groups in some cases. However, this was not thought to affect the twin efficiency values calculated since the methods of Dick and Whittle (1951) and Carter (1951) and Stormont (1954) were not used to compute twin efficiency values.

Twin efficiency values were also calculated when there were no more than four and no more than two pounds difference between members of a twin pair and members of their corresponding random groups. This was done by selecting out all twin pairs and their corresponding groups with more than four pounds spread and more than two pounds spread in weight range and running the same analyses as previously described. Table 2 shows the numbers of lambs used in this part of the study by year. The numbers are assembled according to group (twin or random), sex and selection weight range.

TABLE 2. NUMBERS OF LAMBS USED IN PART I OF THIS STUDY ASSEMBLED ACCORDING TO GROUP, SEX AND SELECTION WEIGHT RANGE

Group	Sex	Selection weight range	Number of lambs 1956	1957	1958	1959	Total
Twin	Wether	6 pounds	14	12	12	28	66
		4 pounds	12	12	8	24	56
		2 pounds	4	12	2	18	36
	Ewe lamb	6 pounds	8	10	28	10	56
		4 pounds	6	8	20	8	42
		2 pounds	6	6	10	4	26
Random	Wether	6 pounds	69	32	86	143	330
		4 pounds	56	32	51	109	248
		2 pounds	8	32	5	67	112
	Ewe lamb	6 pounds	39	36	220	47	342
		4 pounds	21	25	125	28	199
		2 pounds	21	13	42	6	82

The sources of variation known to exist in the growth rate data from these lambs are birth weight, breed of dam, birth and rearing type, sex, sire and year (Harrington et al., 1959, 1960a, 1960b and Brothers and Whiteman, 1960). Hence a computed average daily gain may be assumed to be represented by the model:

$$Y_{ijklm} = M + WX + B_i + T_j + S_k + H_l + YR_m + e_{ijklm}$$

where

Y_{ijklm} = average daily gain from approximately 50 to 90 pounds.

M = a constant for all lambs, the mean.

W = a constant for the effect of the lamb's birth weight X, a covariable.

B_i = a constant for the i^{th} ewe breed (R or RPR).

T_j = a constant for the j^{th} birth and rearing type (SS, TS or TT).

S_k = a constant for the k^{th} sex.

H_l = a constant for the l^{th} sire.

YR_m = a constant for the m^{th} year.

e_{ijklm} = error or failure of the above constants to estimate the average daily gain of a lamb from approximately 50 to 90 pounds.

Twin lambs of the same sex generally have more of these sources of variation in common than any random group of lambs. However, random lambs may be selected within various classifications of these variables and perhaps perform almost as much alike when treated alike as do twin pairs.

The random groups of lambs were corrected for the seven possible combinations of birth weight, breed of dam, and birth and rearing type. Corrections for sex and year were not made because the data were analyzed within sex and year, and year was removed as a source of variation when all four years' data were analyzed together. A correction for sire was not made because each sire's influence is unique and not applicable to unrelated data. The correction factors used were obtained by least squares analyses of all of each year's data by the method of Anderson and Bancroft (1952). The partial regression coefficients (constants) obtained were used as correction factors to apply back to lambs selected from that year only. Hence correction factors obtained from all of each year's data were applied back to a selected portion of lambs from that year.

Partial regression coefficients are known to change when various variables are included in the model if there is a correlation between these variables. Therefore, partial regression coefficients were obtained for the seven different combinations of the three variables used. These combinations were: (1) birth weight only; (2) breed of dam only; (3) birth and rearing type only; (4) birth weight and breed of dam; (5) birth weight and birth and rearing type; (6) breed of dam and birth and rearing type; and (7) birth weight, breed of dam and birth and rearing type. The effect of sex was also removed in each analysis. The results of these seven least squares analyses are shown in Appendix A.

The correction factors obtained when less than all the known sources of variation were included in the least squares model may have over corrected for particular variables if these variables are correlated with the variables not included. Nevertheless, this over correction should be more representative of what one actually does when he physically selects lambs from within particular classifications of one variable but ignores classifications of a correlated variable.

Both additive and multiplicative correction factors were used. The additive corrections were made by adding or subtracting the mean difference between one classification of a particular variable and its classification selected as a standard to correct to. This method has been used by Hazel and Terrill (1945a), Gregory et al. (1950), Koch and Clark (1955), Botkin and Whatley (1953) and Rollins and Guilbert (1954). The multiplicative corrections used are further explained in Appendix B.

Analyses of variance for these corrected average daily gains were computed by the same methods used for the uncorrected data. These analyses should demonstrate the increase in experimental efficiency to be obtained when one holds these variables constant by selecting lambs that have these known sources of variation in common.

Part II: Physical Control of Variables

The lambs used in this part of the study were born in the falls of 1958 and 1959 only. The 1958 data were from the second lamb crop of one-half Dorset, Panama and fine wool (principally Rambouillet) breeds of ewes. The one-half Dorset ewes were raised as replacements from the ewes (R and RPR) described in Part I of this study, and the Panama and fine wool ewes were purchased in New Mexico. The 1959 data were from the third lamb crop of these ewes, the second lamb crop of another group of one-half Dorset ewes saved as replacements and Rambouillet and whitefaced (principally Rambouillet) breeds of ewes purchased in Texas and New Mexico. All lambs were sired by Suffolk sires in 1958 and by Suffolk, Hampshire and Dorset sires in 1959. These sires were obtained from purebred breeders in Oklahoma.

Like-sexed twin pairs from these data were not used to compare the random groups to because few were available. Only four twin pairs weighed within six pounds of each other at about 50 pounds in 1958 and only five pairs in 1959. This occurred because large numbers to select from were not available in 1958, and twin pairs or one member of several twin pairs were transferred to another project when they weighed about 50 pounds in 1959. Consequently, the 1958 and 1959 twin lamb data from Part I of this experiment had to be used for comparison to these random groups of lambs.

Selection of the groups of like-sexed lambs was modified from Part I because the weight range of a twin pair could not be used as the range to select all random lambs within. Therefore, two six pound weight ranges for each sex were established to select within on each regular weighing day. These two weight ranges were 44 to 50 pounds and 51 to 57 pounds. The difference in initial weight was not thought to greatly influence average daily gain to market weight. Table 3 demonstrates how the groups of lambs were selected on each weighing day.

It can be noticed that some lambs were selected more than once and appear in more than one group. This usually occurred when lambs weighed within the 44 to 50 pound range one weigh day and the 51 to 57 pound range the next weigh day. However, numbers of lambs for this part of the study were not too large and this procedure of two selection weight ranges enabled the use of some lambs that were too light for a single six pound range one weigh day but too heavy the next. The occurrence of some lambs in more than one group should tend to reduce the between group variance but should not affect the within group

TABLE 3. A PORTION OF THE PART II DATA DEMONSTRATING HOW TWO GROUPS OF LAMBS WERE SELECTED WITHIN TWO WEIGHT RANGES ON EACH REGULAR WEIGHING DAY

12-29-58		1-13-59		1-26-59	
Lamb number	Selection weight	Lamb number	Selection weight	Lamb number	Selection weight
44-50 pounds		44-50 pounds		44-50 pounds	
212	47	228	48	211	47
213	47	246	45	224	48
225	49	251	47	-232	46
269	48	266	47	246	48
288	47			259	49
51-57 pounds		51-57 pounds		51-57 pounds	
-212	56	212	53	215	51
217	53	220	56	-220	51
256	53	-248	52	234	54
285	56	-253	51	251	56
		288	55	279	56

variance as previously stated in Part I. Table 4 shows the numbers of lambs used in this part of the study.

TABLE 4. NUMBERS OF LAMBS USED IN PART II OF THIS STUDY ASSEMBLED ACCORDING TO YEAR AND SEX

Year	Sex	
	Wether	Ewe Lamb
1958	45	59
1959	95	154

This part of the study intended to physically control the known variables that were statistically controlled in Part I. However, this intention had to be modified some. Physical control was applied to four of the seven original variable combinations. These were: (1) birth weight only; (2) breed of dam only; (3) birth and rearing type only; and (4) breed of dam and birth and rearing type. The effect due to birth weight was then removed as a covariable in the combinations: (5) birth weight and breed of dam; (6) birth weight and birth and rearing type; and (7) birth weight, breed of dam and birth and rearing type. This was necessary because there were six to eight birth weight classes when this classification was based on each one pound difference in birth weight. There were also three breed of dam classifications in 1958 and five in 1959 and three birth and rearing type classifications in both years. Consequently, since large numbers were not available, it can be seen that many cells in the cross-classification would have been empty or only contained one or two observations had birth weight been completely physically controlled.

Analyses of variance within each of the four combinations plus the three combinations with birth weight removed as a covariable were made. The degrees of freedom and sums of squares were then pooled to get an estimate of the variance of lambs when they are selected within common classifications of these variable combinations. Variation due to group was the only source removed from the 1958 data, but additional sources had to be removed from the 1959 data. These were age of dam (two and three-year-old) and breed of sire (Suffolk, Hampshire and Dorset).

Only the six pound weight range was used in this part of the study because selecting within four and within two pound weight ranges caused a considerable reduction in lamb numbers. Difference due to initial weight was accounted for by later considering it as a covariable.

RESULTS AND DISCUSSION

Part I: Statistical Control of Variables

The results of the analyses of variance computed for the uncorrected and corrected average daily gains of the random lambs selected within a six pound range are presented in tables 5 - 8. The results of the analyses computed for these data when lambs were selected within four and two pound ranges are presented in tables 17 - 24, Appendix C.

In general, the additive correction more accurately adjusted the data for birth weight and birth and rearing type differences. This method was more accurate because the percent reduction in the total variance obtained by correcting for these two differences more nearly equaled the percent of the total variance due to these two variables in the original data when the additive rather than multiplicative method was used. Over the four year period corrections made by the additive method were rather accurate to adjust for differences due to birth weight and fairly accurate to adjust for differences due to birth and rearing type. Both were considerably more accurate than the multiplicative method. However, this was not true in all years. The multiplicative method was slightly more accurate to adjust both sexes for birth weight differences in 1956 and the ewe lambs only in 1958. This method was also slightly more accurate to adjust the ewe lambs in 1956 and the wethers in 1959 for differences due to birth and rearing

TABLE 5. ANALYSES OF VARIANCE FOR THE UNCORRECTED AND ADDITIVELY CORRECTED AVERAGE DAILY GAINS OF RANDOM WETHER LAMBS SELECTED WITHIN A SIX POUND RANGE

Source in year	Degrees of freedom	Mean squares for uncorrected and corrected average daily gains: Uncorrected	Birth weight	Breed of dam	Birth & rearing type	Birth wt. & breed of dam	Birth wt. & B. & R. type	Breed & B. & R. type	Birth wt., breed & B. & R.
1956									
Total	68	0.0036	0.0027	0.0036	0.0036	0.0027	0.0027	0.0036	0.0027
Between groups	6	0.0033	0.0024	0.0033	0.0030	0.0023	0.0024	0.0030	0.0024
Lambs in groups	62	0.0036	0.0027	0.0036	0.0036	0.0027	0.0027	0.0036	0.0027
1957									
Total	31	0.0087	0.0071	0.0087	0.0084	0.0071	0.0068	0.0084	0.0068
Between groups	5	0.0016	0.0019	0.0017	0.0010	0.0019	0.0016	0.0010	0.0016
Lambs in groups	26	0.0100	0.0082	0.0100	0.0098	0.0082	0.0077	0.0098	0.0078
1958									
Total	85	0.0149	0.0142	0.0146	0.0131	0.0141	0.0128	0.0131	0.0128
Between groups	5	0.0085	0.0096	0.0091	0.0102	0.0109	0.0099	0.0098	0.0103
Lambs in groups	80	0.0153	0.0145	0.0150	0.0132	0.0143	0.0130	0.0133	0.0130
1959									
Total	142	0.0104	0.0089	0.0104	0.0106	0.0087	0.0089	0.0106	0.0088
Between groups	13	0.0231	0.0122	0.0230	0.0171	0.0120	0.0120	0.0170	0.0118
Lambs in groups	129	0.0092	0.0085	0.0092	0.0099	0.0084	0.0086	0.0099	0.0085
1956-59									
Total	329	0.0100	0.0088	0.0100	0.0096	0.0088	0.0085	0.0096	0.0084
Year	3	0.0074	0.0116	0.0166	0.0110	0.0213	0.0155	0.0187	0.0153
Groups in years	29	0.0128	0.0079	0.0128	0.0102	0.0081	0.0078	0.0101	0.0078
Lambs in groups in years	297	0.0097	0.0089	0.0096	0.0095	0.0088	0.0085	0.0095	0.0084

TABLE 6. ANALYSES OF VARIANCE FOR THE UNCORRECTED AND MULTIPLICATIVELY CORRECTED AVERAGE DAILY GAINS OF RANDOM WETHER LAMBS SELECTED WITHIN A SIX POUND RANGE

Source in year	Degrees of freedom	Mean squares for uncorrected and corrected average daily gains							
		Uncorrected	Birth weight	Breed of dam	Birth & rearing type	Birth wt. & breed of dam	Birth wt. & B. & R. type	Breed & B. & R. type	Birth wt., breed & B. & R.
1956									
Total	68	0.0036	0.0028	0.0036	0.0035	0.0028	0.0028	0.0035	0.0029
Between groups	6	0.0033	0.0026	0.0033	0.0030	0.0026	0.0026	0.0030	0.0026
Lambs in groups	62	0.0036	0.0028	0.0036	0.0036	0.0028	0.0029	0.0036	0.0029
1957									
Total	31	0.0087	0.0074	0.0085	0.0081	0.0073	0.0074	0.0078	0.0075
Between groups	5	0.0016	0.0033	0.0017	0.0010	0.0033	0.0023	0.0010	0.0024
Lambs in groups	26	0.0100	0.0082	0.0098	0.0095	0.0081	0.0084	0.0091	0.0085
1958									
Total	85	0.0149	0.0145	0.0152	0.0116	0.0155	0.0115	0.0114	0.0119
Between groups	5	0.0085	0.0097	0.0094	0.0087	0.0124	0.0094	0.0082	0.0103
Lambs in groups	80	0.0153	0.0148	0.0155	0.0118	0.0157	0.0116	0.0116	0.0120
1959									
Total	142	0.0104	0.0103	0.0105	0.0096	0.0101	0.0106	0.0097	0.0105
Between groups	13	0.0231	0.0120	0.0233	0.0168	0.0119	0.0125	0.0170	0.0126
Lambs in groups	129	0.0092	0.0101	0.0092	0.0089	0.0099	0.0104	0.0089	0.0103
1956-59									
Total	329	0.0100	0.0096	0.0102	0.0088	0.0099	0.0090	0.0088	0.0091
Year	3	0.0074	0.0144	0.0159	0.0105	0.0334	0.0233	0.0187	0.0238
Groups in years	29	0.0128	0.0081	0.0130	0.0098	0.0086	0.0082	0.0098	0.0084
Lambs in groups in years	297	0.0097	0.0097	0.0098	0.0086	0.0098	0.0089	0.0085	0.0090

TABLE 7. ANALYSES OF VARIANCE FOR THE UNCORRECTED AND ADDITIVELY CORRECTED AVERAGE DAILY GAINS OF RANDOM EWE LAMBS SELECTED WITHIN A SIX POUND RANGE

Source in year	Degrees of freedom	Mean squares for uncorrected and corrected average daily gains							
		Uncorrected	Birth weight	Breed of dam	Birth & rearing type	Birth wt. & breed of dam	Birth wt. & B. & R. type	Breed & B. & R. type	Birth wt., breed & B. & R.
1956									
Total	38	0.0034	0.0023	0.0034	0.0035	0.0023	0.0021	0.0035	0.0022
Between groups	3	0.0027	0.0032	0.0026	0.0027	0.0034	0.0032	0.0026	0.0035
Lambs in groups	35	0.0035	0.0022	0.0035	0.0036	0.0022	0.0020	0.0036	0.0021
1957									
Total	35	0.0052	0.0037	0.0051	0.0051	0.0037	0.0039	0.0049	0.0039
Between groups	4	0.0042	0.0009	0.0043	0.0040	0.0009	0.0008	0.0042	0.0008
Lambs in groups	31	0.0054	0.0041	0.0052	0.0052	0.0041	0.0043	0.0050	0.0043
1958									
Total	219	0.0072	0.0052	0.0074	0.0064	0.0054	0.0053	0.0064	0.0053
Between groups	13	0.0121	0.0037	0.0113	0.0041	0.0033	0.0020	0.0041	0.0019
Lambs in groups	206	0.0069	0.0053	0.0071	0.0066	0.0055	0.0055	0.0065	0.0055
1959									
Total	46	0.0061	0.0060	0.0060	0.0060	0.0061	0.0060	0.0060	0.0060
Between groups	4	0.0071	0.0035	0.0068	0.0036	0.0036	0.0039	0.0035	0.0041
Lambs in groups	42	0.0060	0.0062	0.0059	0.0062	0.0063	0.0062	0.0062	0.0062
1956-59									
Total	341	0.0066	0.0049	0.0066	0.0065	0.0050	0.0053	0.0064	0.0053
Year	3	0.0277	0.0169	0.0167	0.0686	0.0112	0.0592	0.0688	0.0541
Groups in years	24	0.0088	0.0031	0.0083	0.0038	0.0030	0.0022	0.0038	0.0023
Lambs in groups in years	314	0.0062	0.0049	0.0064	0.0061	0.0051	0.0051	0.0060	0.0051

TABLE 8. ANALYSES OF VARIANCE FOR THE UNCORRECTED AND MULTIPLICATIVELY CORRECTED AVERAGE DAILY GAINS OF RANDOM EWE LAMBS SELECTED WITHIN A SIX POUND RANGE

		Mean squares for uncorrected and corrected average daily gains							
Source in year	Degrees of freedom	Uncorrected	Birth weight	Breed of dam	Birth & rearing type	Birth wt. & breed of dam	Birth wt. & R. & R. type	Breed & B. & R. type	Birth wt., breed & B. & R.
1956									
Total	38	0.0034	0.0024	0.0034	0.0034	0.0025	0.0022	0.0034	0.0024
Between groups	3	0.0027	0.0035	0.0026	0.0027	0.0038	0.0038	0.0026	0.0042
Lambs in groups	35	0.0035	0.0023	0.0035	0.0035	0.0023	0.0020	0.0035	0.0022
1957									
Total	35	0.0052	0.0050	0.0050	0.0050	0.0050	0.0063	0.0047	0.0063
Between groups	4	0.0042	0.0003	0.0043	0.0040	0.0003	0.0005	0.0040	0.0005
Lambs in groups	31	0.0054	0.0056	0.0051	0.0052	0.0056	0.0071	0.0048	0.0070
1958									
Total	219	0.0072	0.0058	0.0077	0.0056	0.0067	0.0050	0.0054	0.0053
Between groups	13	0.0121	0.0042	0.0119	0.0042	0.0043	0.0018	0.0041	0.0020
Lambs in groups	206	0.0069	0.0060	0.0075	0.0057	0.0069	0.0052	0.0055	0.0055
1959									
Total	46	0.0061	0.0092	0.0061	0.0054	0.0096	0.0098	0.0054	0.0105
Between groups	4	0.0071	0.0051	0.0068	0.0036	0.0064	0.0068	0.0036	0.0080
Lambs in groups	42	0.0060	0.0096	0.0060	0.0056	0.0099	0.0101	0.0056	0.0107
1956-59									
Total	341	0.0066	0.0059	0.0068	0.0058	0.0065	0.0062	0.0056	0.0064
Year	3	0.0277	0.0125	0.0170	0.0636	0.0080	0.0871	0.0633	0.0826
Groups in years	24	0.0088	0.0036	0.0086	0.0039	0.0039	0.0027	0.0038	0.0030
Lambs in groups in years	314	0.0062	0.0060	0.0066	0.0054	0.0066	0.0057	0.0052	0.0060

type. Consequently, there is no definite conclusion concerning which of these methods should be used when adjustments for birth weight and birth and rearing type are to be made.

The multiplicative correction for birth and rearing type usually reduced the variance more than the additive correction. However, it was found that this reduction was too great, and the additive correction more nearly reduced the variance the expected amount.

Corrections for breed of dam differences caused little change in the variances regardless of method used. Little difference has been found between these two breeds (R and RPR) in previous studies (Harrington _et al._, 1958, 1960a, 1960b and Brothers and Whiteman, 1960). Consequently, there apparently was not enough difference between the two breeds to adequately test which method should be used when a correction for differences due to breed of dam is to be made.

Multiplicative corrections for sex differences have been indicated by Botkin (1952) and used by Marlowe and Gaines (1958), Koch _et al._ (1959) and Minyard and Dinkel (1960). The assumption that this method may be more accurate is based on the fact that sex differences increase as age and weight increase. Hence a female's record may be more accurately corrected to what it would have been had she been a male by use of a percentage correction factor. Minyard and Dinkel (1960) also applied the multiplicative method to correct for age of calf and Marlowe and Gaines (1958) used it to correct for season of birth and age of dam. Birth weight and birth and rearing type differences usually have a more important effect on early gain than on later gain in lambs. Phillips *et.al.* (1940) reported that birth weight and birth and rearing type were important factors affecting weight of farm raised lambs at three months of age but were of little importance at one year. However, birth and rearing type differences were important at one year of age in lambs raised under range conditions. The lambs used in this study were raised under farm conditions, and further examination of the original data indicated birth weight and birth and rearing type had more influence on early lamb gain than on subsequent gain. Therefore, differences due to these two factors tend to decrease as age and weight of the lamb increase. Apparently this decrease is more rapid under management conditions that force an early maturity. Differences due to breed of dam could be greater early in a lamb's life because more milk is produced by certain breeds or the greater difference could occur later because some breeds mature later than others.

The research reports concerning multiplicative corrections are as inconclusive as are the results of this study. The additive correction for birth weight and birth and rearing type differences more nearly reduced the variances the expected amount. Hence variances of random lamb average daily gains corrected by the additive method were used to estimate twin efficiency values. Twin efficiency values using variances of random lamb average daily gains corrected for differences due to breed of dam were not computed because this particular correction had almost no effect on the variance.

The analyses of variance for average daily gain of the twin lambs used in this experiment are contained in tables 9 and 10. The within-pairs variance for twin wethers did not decrease as the selection weight

TABLE 9. ANALYSES OF VARIANCE OF AVERAGE DAILY GAIN FOR THE WETHER TWIN PAIRS SELECTED WITHIN SIX, FOUR AND TWO POUND RANGES

Source in year	6 Pounds		4 Pounds		2 Pounds	
	Degrees of freedom	Mean square	Degrees of freedom	Mean square	Degrees of freedom	Mean square
1956						
Total	13	0.0040	11	0.0038	3	0.0029
Between pairs	6	0.0065	5	0.0062	1	0.0021
Within pairs	7	0.0018	6	0.0017	2	0.0033
1957						
Total	11	0.0104	11	0.0104	11	0.0104
Between pairs	5	0.0205	5	0.0205	5	0.0205
Within pairs	6	0.0019	6	0.0019	6	0.0019
1958						
Total	11	0.0181	7	0.0187	1	0.0006
Between pairs	5	0.0343	3	0.0387	0	-
Within pairs	6	0.0047	4	0.0038	1	0.0006
1959						
Total	27	0.0060	23	0.0066	17	0.0072
Between pairs	13	0.0098	11	0.0106	8	0.0117
Within pairs	14	0.0025	12	0.0029	9	0.0032
1956-59						
Total	65	0.0085	55	0.0086	35	0.0078
Between years	3	0.0076	3	0.0119	3	0.0093
Pairs in years	29	0.0152	24	0.0153	14	0.0142
Within pairs in years	33	0.0026	28	0.0026	18	0.0027

TABLE 10. ANALYSES OF VARIANCE OF AVERAGE DAILY GAIN FOR THE EWE LAMB TWIN PAIRS SELECTED WITHIN SIX, FOUR AND TWO POUND RANGES

Source in year	6 Pounds		4 Pounds		2 Pounds	
	Degrees of freedom	Mean square	Degrees of freedom	Mean square	Degrees of freedom	Mean square
1956						
Total	7	0.0025	5	0.0033	5	0.0033
Between pairs	3	0.0039	2	0.0054	2	0.0054
Within pairs	4	0.0015	3	0.0019	3	0.0019
1957						
Total	9	0.0095	7	0.0061	5	0.0072
Between pairs	4	0.0132	3	0.0093	2	0.0134
Within pairs	5	0.0065	4	0.0038	3	0.0030
1958						
Total	27	0.0060	19	0.0076	9	0.0032
Between pairs	13	0.0070	9	0.0092	4	0.0048
Within pairs	14	0.0052	10	0.0062	5	0.0019
1959						
Total	9	0.0043	7	0.0044	3	0.0050
Between pairs	4	0.0063	3	0.0065	1	0.0144
Within pairs	5	0.0028	4	0.0029	2	0.0003
1956-59						
Total	55	0.0069	41	0.0067	25	0.0050
Between years	3	0.0240	3	0.0131	3	0.0097
Pairs in years	24	0.0075	17	0.0083	9	0.0079
Within pairs in years	28	0.0044	21	0.0045	13	0.0019

range was reduced from six to two pounds when all four years' data were considered. However, there tends to be a trend for the ewe lamb twin pairs selected within a two pound range to have a smaller within-pairs variance than pairs with a greater selection weight range. There is some within year deviation from the patterns reflected when all four years' data were analyzed together.

Investigation of tables 5 and 7 and tables 17, 19, 21 and 23, Appendix C, also reveals that within-groups variance of random lambs did not decrease as the selection weight range was reduced from six to two pounds. Hence, initial weight with no more range than six pounds had little effect on lamb rate of gain from about 50 to 90 pounds in this study. The between-groups variances in these tables indicate that there was little variation due to group. This may partially have been caused by the presence of some lambs in more than one group. The variance due to year when all four years' data were analyzed together changed when the various corrections were applied. This occurred because the correction factors used were not the same each year.

The twin efficiency values calculated are contained in table 11. Those calculated using the uncorrected within-groups variances indicate the increase in experimental efficiency one may expect to obtain if like-sexed twin pairs are selected within six, four or two pound ranges for growth studies from 50 to 90 pounds rather than like-sexed groups of lambs within the same selection weight ranges. The efficiency values calculated using within-groups variances of average daily gain corrected for the various variables considered indicate the increase in experimental efficiency expected when one selects twins in preference to lambs that have these

TABLE 11. TWIN EFFICIENCY VALUES FOR AVERAGE DAILY GAIN OF LAMBS SELECTED WITHIN SIX, FOUR AND TWO POUND RANGES (PART I)

Sex and range	Year	Number of twin pairs	Uncorrected	Corrected for: Birth weight	Corrected for: Birth & rearing type	Corrected for: Birth wt. & B. & R. type
Wether						
	1956	7	2.0	1.5	2.0	1.5
	1957	6	5.3	4.3	5.2	4.1
6 lb.	1958	6	3.3	3.1	2.8	2.8
	1959	14	3.7	3.4	4.0	3.4
	1956-59	33	3.7	3.4	3.7	3.3
	1956	6	2.2	1.4	2.1	1.4
	1957	6	5.3	4.3	5.2	4.1
4 lb.	1958	4	4.7	4.9	4.1	4.4
	1959	12	3.2	3.2	3.8	3.2
	1956-59	28	3.8	3.7	3.9	3.5
	1956	2	1.7	1.4	1.7	1.3
	1957	6	5.3	4.3	5.2	4.1
2 lb.	1958	1	5.8	8.3	5.8	8.2
	1959	9	2.8	2.5	3.1	2.5
	1956-59	18	3.2	2.9	3.5	2.8
Ewe lamb						
	1956	4	2.3	1.5	2.4	1.3
	1957	5	0.8	0.6	0.8	0.7
6 lb.	1958	14	1.3	1.0	1.3	1.1
	1959	5	2.1	2.2	2.2	2.2
	1956-59	28	1.4	1.1	1.4	1.2
	1956	3	1.8	1.1	1.8	1.0
	1957	4	1.8	1.4	1.7	1.5
4 lb.	1958	10	1.1	0.8	1.0	0.8
	1959	4	2.9	2.9	3.0	2.9
	1956-59	21	1.5	1.2	1.4	1.1
	1956	3	1.8	1.1	1.8	1.0
	1957	3	2.6	2.0	2.6	2.0
2 lb.	1958	5	4.8	3.2	4.2	3.5
	1959	2	16.0	9.0	16.0	7.3
	1956-59	13	3.7	2.5	3.6	2.6

certain variables in common. The differences in twin efficiency when the average daily gain of random lambs is uncorrected and corrected indicates the increase in experimental efficiency one may obtain by selecting random lambs within common classifications of these variables rather than ignoring them.

Twin efficiency values calculated from all four years' data using the uncorrected within-groups variances for comparison indicate little change for wethers as the selection weight range decreased. However, ewe lamb values increased when the two pound selection weight range was used. This was due to the within-twin-pairs variance decreasing more than 50 percent and the within-groups variance increasing slightly. Ewe lamb twin efficiency values less than 1.0 and as high as 16.0 also occurred. These were due to fluctuations of the variances calculated. The best estimate of twin efficiency is probably the estimate calculated from all four years' data combined. Hancock (1951) stated that variances used to calculate twin efficiency values may vary quite widely with sample and environment. Hence individual year estimates in this study that vary widely are probably less accurate than those nearer the overall estimate. However, any overall estimate may not be too accurate itself when extremes are combined to yield it.

The twin efficiency values calculated indicate that wether twin pairs are about 3.2 - 3.8 times more efficient than random groups of wether lambs in growth studies from about 50 to 90 pounds when there is no more than six pounds difference in initial weight. Ewe lamb twin pairs tend to have lower twin efficiency values (about 1.4) when selected with as much as six and as much as four pounds difference in initial weight; however, they appear to be as efficient as wether twin pairs when selected within a two pound initial weight range.

Brothers (1959) used data included in the first two years of this study and found that wethers had higher twin efficiency values than ewe lambs. A further examination of the variances calculated in this study showed that random lamb within-groups variances were usually greater for wethers than ewe lambs. However, within-twin-pairs variances were usually smaller for wether twins than for ewe lamb twins. These differences in variances caused the different twin efficiency values for the two sexes.

Larger variances for wethers are expected if the coefficient of variation for the two sexes is equal. Wethers are known to gain faster than ewe lambs, consequently they should have a larger variance. The coefficients of variation (C = standard deviation ÷ mean x 100) for all four years' data selected within the six pound range were 18% for the random wether lambs, 17% for the random ewe lambs, 10% for the wether twin pairs and 14% for the ewe lamb twin pairs. Very similar estimates for the random lambs were found when the selection weight range was restricted to four and two pounds and for the twins when the four pound range was employed. However, the estimates were 10% for wether twin pairs and 9% for ewe lamb twin pairs when the two pound range was used. This accounts for the similar twin efficiency values for the two sexes when the range was restricted to two pounds. These similar estimates for random lambs are expected. There is no explanation why the ewe lamb twin pairs had a larger coefficient of variation than the wether twin pairs in some cases. This may have occurred because the ewe lamb twin pairs had a greater variance or the wether twin pairs had a smaller variance than the populations which were sampled. If so, this difference can be contributed to sampling error.

The twin efficiency values calculated after the data were corrected for the effects of the variables considered (table 11) indicate that selection of experimental units from within birth weight classes is more important than selection from within birth and rearing type classes. Twin efficiency values were not greatly reduced due to the corrections made. In some years corrections had no effect or else increased twin efficiency values.

For the four year period, correction for the effect of birth weight reduced twin efficiency from 0.1 to 0.3 for all selection weight ranges in wethers. Corresponding reductions for ewe lambs were 0.3 to 1.2. Correction for birth and rearing type differences had very little effect on twin efficiency values for either sex. When the data were corrected for both birth weight and birth and rearing type differences the twin efficiency values decreased from 0.3 to 0.4 for all weight ranges in wethers and from 0.2 to 1.1 in ewe lambs. Correction of the wether lamb data for both variables reduced twin efficiency values slightly more than any single correction, but this did not hold true for ewe lambs.

The results of this part of the study indicate that like-sexed twin pairs are the most efficient experimental units that can be used in lamb growth studies from about 50 to 90 pounds. However, if twins are not suitable for the experimental design planned, random groups of lambs should be selected within common birth weight classes in order to increase the efficiency of the experiment. Further restriction of selection to within birth and rearing type classes may or may nor result in slightly more experimental efficiency.

Part II: Physical Control of Variables

The within-groups mean squares calculated for this part of the study are presented in table 12. The mean squares calculated when no variable control was used are the within-groups variances of all random lambs used in this part of the study. The mean squares calculated when the lambs were physically selected from within classes of the three variables considered were calculated by the same procedure for each class. The within-groups sums of squares and the corresponding degrees of freedom for each class were then pooled to estimate within-groups variance when the lambs were selected from a single class of the variables considered. Birth weight was controlled statistically (covariance analysis) when it as well as another variable were considered. The degrees of freedom are not the same for each mean square because some groups only contained one unit when physical control was applied. Consequently there was no within-group variance. Also the removal of the variance due to birth weight caused a further reduction in within-groups degrees of freedom.

The variance of 1958 lambs was greater than 1959 lambs, and the 1958 wethers had the largest variance of either sex. This also occurred in the part I random lamb data. The 1959 ewe lambs had a greater variance than the wethers, but this did not occur in the 1959 part I data. Between-groups variance was not significant in any year which may be due to some lambs appearing in more than one group and because initial weight had little effect on rate of gain from 50 to 90 pounds. The between-groups variance was less than the within-groups variance for the 1958 wethers only. This may be one reason why the 1958 wethers had the largest within-groups variance calculated in this part of the study.

TABLE 12. LAMBS IN GROUPS MEAN SQUARES WITH NO VARIABLE CONTROL, AND LAMBS IN GROUPS MEAN SQUARES WHEN THE ESTIMATES WITHIN PHYSICAL AND STATISTICAL CONTROL CLASSES WERE POOLED[a]

			Physical control				Statistical control of birth weight		
Sex	Year	No control	Birth weight	Breed of dam	Birth & rearing type	Breed & B. & R. type	Birth wt. & breed of dam	Birth wt. & B. & R. type	Birth wt. breed & B. & R.
	1958	0.0129 (39)	0.0115 (16)	0.0132 (28)	0.0145 (34)	0.0135 (24)	0.0108 (25)	0.0111 (32)	0.0099 (19)
Wether	1959	0.0035 (81)	0.0028 (45)	0.0037 (52)	0.0038 (59)	0.0050 (29)	0.0025 (47)	0.0038 (56)	0.0030 (24)
	1958-59	0.0066 (120)	0.0051 (61)	0.0070 (80)	0.0077 (93)	0.0088 (53)	0.0054 (72)	0.0064 (88)	0.0060 (43)
	1958	0.0066 (50)	0.0084 (19)	0.0056 (37)	0.0065 (41)	0.0058 (28)	0.0054 (34)	0.0066 (39)	0.0056 (24)
Ewe lamb	1959	0.0040 (137)	0.0048 (79)	0.0038 (93)	0.0036 (114)	0.0034 (63)	0.0034 (88)	0.0034 (111)	0.0024 (54)
	1958-59	0.0047 (187)	0.0055 (98)	0.0043 (130)	0.0044 (155)	0.0042 (91)	0.0040 (122)	0.0042 (150)	0.0034 (78)

[a] Corresponding degrees of freedom in parenthesis.

The 1958 and 1959 data contained different sources of variation. However, the different sources, which were breed of sire and age of dam in 1959 only, were removed in the analyses of variance computed. Pooling both years' data may have pooled variances which do not completely estimate the same thing. However, this estimate of within-groups variance may be the most reliable because it was made from larger numbers than the intra-year estimates.

Physical control of birth weight reduced within-groups variance for wethers but increased it for ewe lambs. Physical control of breed of dam, birth and rearing type and the two combined reduced within-groups variance for ewe lambs but increased it for wethers. This pattern occurred each year. Certainly no definite conclusions can be made concerning which of these variables should be physically controlled. Present knowledge offers no evidence why these sex x variable interactions should occur.

Statistical control of birth weight used with physical control of breed of dam, birth and rearing type or both generally caused a reduction in within-groups variance. No reduction occurred in the 1958 ewe lamb variance when birth weight and birth and rearing type were controlled, and a slight increase occurred in the 1959 wether variance when these two variables were controlled. When the two years' data were pooled the combinations of physical and statistical control reduced within-groups variance in all combinations.

The twin efficiency values computed for this part of the study are presented in table 13. The values for wether twins, when compared to the uncontrolled random lambs, are lower than they were in 1958 and 1959, part I. The values for ewe lambs are the same as the 1958 estimate but

TABLE 13. TWIN EFFICIENCY VALUES FOR AVERAGE DAILY GAIN (PART II)

				Physical control				Statistical control of birth weight		
Sex	Year	Number of twin pairs	No control	Birth weight	Breed of dam	Birth & rearing type	Breed & B. & R. type	Birth wt. & breed of dam	Birth wt. & B. & R. type	Birth wt. breed & B. & R.
	1958	6	2.7	2.4	2.8	3.1	2.9	2.3	2.4	2.1
Wether	1959	14	1.4	1.1	1.5	1.5	2.0	1.0	1.5	1.2
	1958-59	20	2.1	1.6	2.2	2.4	2.8	1.7	2.0	1.9
	1958	14	1.3	1.6	1.1	1.3	1.1	1.0	1.3	1.1
Ewe lamb	1959	5	1.4	1.7	1.4	1.3	1.2	1.2	1.2	0.9
	1958-59	19	1.0	1.2	1.0	1.0	0.9	0.9	0.9	0.8

lower than the 1959 estimate, part I. For the two years pooled, the efficiency values were less for both sexes than in part I. This occurred because the within-groups variances as well as the coefficients of variation were less.

Twin efficiency values between sexes showed no consistency when only the physical control combinations were applied. This was expected due to the inconsistency of within-groups variances between sexes discussed previously. However, when birth weight effect was removed by covariance analysis, the efficiency values were usually less than when no variable control was practiced. Some twin efficiency values in table 13 are less than 1.0 for the ewe lambs. This is an unreasonable estimate, but, as previously pointed out, such estimates may occur due to fluctuations in the sample variances computed.

The preceding physical and statistical control of variables has restricted groups of random lambs to common classes of these variables. Like-sexed twin lambs with similar weights at 50 pounds have common classifications of these variables. However, they also have a common birth date, and consequently have had similar rates of gain up to the date of selection. Lambing occurred for about 40 days. Few random lambs selected for use in this study were born near the beginning or end of the lambing seasons, but there definitely was more difference in random lamb rate of gain prior to selection than within twin pairs.

The regression and partial regression of average daily gain from 50 to 90 pounds on average daily gain from birth to 50 pounds were calculated for all the original data from which the part I lambs were selected. The partial regression was computed when birth weight, breed of dam, birth and rearing type and sex differences were held constant. These regressions are presented in table 14.

TABLE 14. REGRESSION AND PARTIAL REGRESSION OF AVERAGE DAILY GAIN FROM 50 TO 90 POUNDS ON AVERAGE DAILY GAIN FROM BIRTH TO 50 POUNDS

Coefficient	Year 1956	1957	1958	1959
Regression	0.27	0.15	0.50	0.51
Partial regression[a]	0.24	0.02	0.29	0.44

[a] Birth weight, breed of dam, birth and rearing type and sex differences held constant.

These coefficients indicate that rate of gain prior to selection has an influence on subsequent rate of gain, and that this influence may be less important when all the sources of variation considered in this study are held constant. Therefore, average daily gain prior to selection was considered a source of variation, and the part II data was further analyzed removing the variance due to this source by the analysis of covariance.

Another source of variation considered and removed by this method was weight at selection. There was little indication in part I of this study that initial weight has an influence on subsequent gain from 50 to 90 pounds, but since numbers available did not permit restriction of the selection weight range to four and two pounds it was investigated as a source of variation.

The inclusion of both these covariables as well as birth weight causes the analysis of covariance to become very laborious unless the analysis is done on a data processing machine. Hence a single covariable, weight for day of age at selection, was also included. This covariable is influenced by both birth weight and average daily gain. Therefore, it may cause a reduction in the experimental error equivalent to both birth weight and average daily gain prior to selection combined.

Table 15 shows the pooled within-groups mean squares resulting when the variance due to average daily gain from birth to 50 pounds, initial weight at selection, the two combined and weight for day of age at selection were removed in addition to the physical and statistical control previously applied. A comparison of this table to the last column in table 12 shows that the removal of the variance due to average daily gain prior to selection reduced the within-groups variance in the 1958 lamb data, had no effect on the variance of 1959 wethers and increased the 1959 ewe lamb variance. For the two years pooled, within-groups variance was reduced for the wethers but unchanged for the ewe lambs. No advantage can be seen in favor of removing the variance due to initial weight in the wether lamb data, and this practice increased the within-groups variance for ewe lambs. Removal of the variances

TABLE 15. LAMBS IN GROUPS MEAN SQUARES WHEN THE ESTIMATES WITHIN PHYSICAL AND STATISTICAL CONTROL CLASSES WERE POOLED[a]

Sex	Year	ADG, birth wt., breed of dam & B. & R. type	Initial wt., birth wt., breed of dam & B. & R.	ADG, initial wt., birth wt., breed of dam & B. & R.	Wt. for day of age, breed of dam, & B. & R.
	1958	0.0084 (15)	0.0096 (15)	0.0064 (12)	0.0079 (19)
Wether	1959	0.0030 (19)	0.0031 (19)	0.0027 (15)	0.0029 (24)
	1958-59	0.0054 (34)	0.0059 (34)	0.0043 (27)	0.0051 (43)
	1958	0.0049 (20)	0.0064 (20)	0.0051 (16)	0.0061 (24)
Ewe lamb	1959	0.0028 (50)	0.0028 (50)	0.0027 (46)	0.0031 (54)
	1958-59	0.0034 (70)	0.0038 (70)	0.0033 (62)	0.0040 (78)

[a] Corresponding degrees of freedom in parenthesis.

due to both average daily gain prior to selection and initial weight caused the greatest reduction in within-groups variances for the wethers but had little effect on the variances of ewe lambs. Removal of the variance due to weight for day of age at selection reduced the within-groups variances for wethers but increased them for ewe lambs. A comparison of within-groups variances computed by this method to those computed when both birth weight and average daily gain prior to selection were considered reveals that removal of the variance due to weight for day of age reduced the variances for wethers but increased the variances for ewe lambs. Consideration of the results for both sexes indicated that this method may be nearly as efficient as the use of both birth weight and average daily gain prior to selection.

The results of this part of the study indicate that wether twin pairs are about twice as efficient as random groups of wether lambs in growth studies from about 50 to 90 pounds. Ewe lamb twin pairs may be less efficient than wether twin pairs, although the results reported here may be due to fluctuations in sample variances. Physical control of birth weight, birth and rearing type and breed of dam differences may have little effect on error variance, but some reduction in experimental error may be accomplished if either or both of these latter two variables are physically controlled and birth weight is statistically controlled. Consideration of average daily gain prior to selection as an additional covariable may further reduce the error variance. However, this second covariable causes the analysis of covariance to become a laborious process. Removal of the variance due to a single covariable, weight for day of age at selection, may reduce the experimental error nearly as much as removal of the variances due to birth weight and average daily gain prior to selection combined. Removal of the variance due to weight at selection appears to be an ineffective method to reduce the experimental error unless it as well as the variance due to average daily gain prior to selection are removed by covariance analysis.

Conclusions

The twin efficiency values computed in both parts of this study indicate that like-sexed twin pairs should yield the greatest experimental efficiency in lamb growth studies from about 50 to 90 pounds when there is no more than six pounds difference in their initial weights. Twin pairs should be especially suited when only two treatments are applied and the pairing design is employed. Twin pairs may also be used in experiments involving more than two treatments; however, this necessitates the use of some form of the incomplete block design, and difficulty in acquiring enough twin pairs to yield an adequate test may result.

Twin efficiency value is no more than the ratio of the experimental error for any control group used for comparison to the experimental error for twins. Twin efficiency value has been defined as the number of animals chosen at random which each member of a twin set will replace without loss of statistical efficiency (Hancock, 1950). This definition is true if pairs of twins rather than pairs of random lambs are selected for experimentation. However, if pairs of twins are selected rather than groups of lambs this definition is no longer accurate because the error degrees of freedom for the control group will be larger which increases the sensitivity of the experiment to detect true differences that exist.

Cochran and Cox (1957) define the ratio of error variances for two experimental designs as relative efficiency because the number of degrees of freedom for error are relevant to the comparison of the two designs. They further state that a decrease in the error degrees of freedom as well as the error variance may not necessarily be advantageous. Fisher (1947) presented a table which makes possible the comparison of experimental errors and degrees of freedom to determine which design may yield the greatest relative efficiency. A comparison of the values in this table with the error variances and corresponding degrees of freedom computed in this study indicate that the relative efficiency of twin pairs is only slightly less than the twin efficiency values calculated.

The results of the statistical and physical control of variables investigated in this study restrict definite conclusions. The review of literature indicates that birth weight, breed of dam and birth and rearing type influence lamb growth rate. These variables may have less effect on growth rate from 50 to 90 pounds than on previous gain. Results of this study concerning these variables were not consistent, but one should surely consider selecting lambs from within common classes of these as well as other known variables when growth studies are to be made. Removal of the variance due to birth weight by covariance analysis appears to be more practical than physically controlling it. Physical control can at best be restricted to a one-pound range per class, whereas covariance analysis may cause a greater reduction in the error term if birth weights are recorded to the nearest one-tenth of a pound as they were in the data used in this study.

The results from part I indicate that birth weight differences should be controlled in attempts to reduce the error variance of 50 to 90 pound average daily gain in lambs. Part II also yielded similar evidence that the error variance should be reduced if the variance due to birth weight is removed by covariance analysis when lambs are selected from common breed of dam and birth and rearing type classes. The removal of the variance due to average daily gain from birth to selection should further reduce the error variance. However, a single covariable, weight for day of age at selection, may reduce the error variance nearly as much as both birth weight and average daily gain prior to selection combined when breed of dam and birth and rearing type are physically controlled. The use of this single covariable will simplify the statistical analysis and is probably the most practical method to use if the analysis is not done on a data processing machine. Therefore, the results of this study indicate that breed of dam and birth and rearing type differences should be physically controlled, and either birth weight and average daily gain prior to selection or weight for day of age at selection should be statistically controlled in attempts to increase experimental efficiency when twin pairs are unsuitable for the design planned.

Many research workers may have the opportunity to select lambs for growth studies from large experimental flocks which have complete records available. Utilization of the information contained in these records should be practiced when selection is made and the units are allotted for treatments. The lamb data used in part II of this study were not too plentiful, but the data used in part I were adequate enough that actual application of the results obtained from this study could have been readily applied.

SUMMARY

This study was divided into two parts. The lambs used in part I were born in the falls of 1956, 1957, 1958 and 1959. The lambs used in part II were born in 1958 and 1959 only. All lambs were raised under uniform conditions at the Fort Reno Agricultural Experiment Station.

In part I, variances within 61 like-sexed twin pairs were compared to variances within groups of 672 randomly selected lambs to estimate the increase in experimental efficiency obtainable by use of twins in growth studies from about 50 to 90 pounds. This same comparison of variances was made when the average daily gains of the random lambs were corrected by both additive and multiplicative correction factors for differences due to the seven possible combinations of birth weight, breed of dam and birth and rearing type. These latter comparisons indicated which variables should be controlled in order to obtain the most efficient experimental units available when twin lambs are not suitable for the experimental design planned.

In part II, lambs were physically selected from within common classes of birth weight, breed of dam, birth and rearing type and the latter two combined. Birth weight was then statistically controlled when in combination with another variable. Average daily gain from birth to selection, initial weight at selection and weight for day of age at selection as additional covariables were investigated. Variances within groups of the 353 lambs available were then computed to determine the increase in experimental efficiency obtainable by use of twins and by physically and statistically

controlling variables in random groups of lambs.

The additive correction more nearly reduced the variance the expected amount when differences due to birth weight and birth and rearing type were adjusted. There apparently was not enough difference between the two dam breeds used (Rambouillet and Rambouillet x Panama-Rambouillet) to adequately test which method of correction should be used.

The results of both parts of this study indicate that like-sexed twin pairs should yield the greatest experimental efficiency in lamb growth studies from about 50 to 90 pounds. Correction for birth weight differences in part I caused the greatest reduction in experimental error, but correction for differences due to birth and rearing type and breed of dam had little influence on the error variance. Results from part II were not conclusive concerning the effect of physical control of birth weight, breed of dam, birth and rearing type or the latter two combined on the error variance. However, the error variance was reduced when birth weight was statistically controlled by covariance analysis and either or both of the other two variables were physically controlled. Average daily gain from birth to selection as an additional covariable may further reduce the experimental error. However, a single covariable, weight for day of age at selection, may be almost as effective to reduce the error variance as birth weight and average daily gain prior to selection combined. Removal of the variance due to weight at selection had little effect.

Many research workers may have the opportunity to select lambs for growth studies from large experimental flocks which have complete records available. Utilization of the information contained in these records should be practiced when selection is made for treatment allocation as a means to reduce the experimental error and consequently increase the efficiency of an experiment.

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APPENDIX

APPENDIX A

TABLE 16. RESULTS OF THE LEAST SQUARES ANALYSES WHEN SEVEN DIFFERENT COMBINATIONS OF BIRTH WEIGHT, BREED OF DAM AND BIRTH AND REARING TYPE WERE INCLUDED IN THE MODEL

Combination	Variable	Constants 1956	1957	1958	1959
Birth weight only	Mean[a]	0.396	0.310	0.297	0.241
	Birth weight	+0.0140	+0.0220	+0.0248	+0.0270
	Wether - ewe	+0.0390	+0.0359	+0.0533	+0.0629
Breed of dam only	Mean[b]	0.489	0.491	0.513	0.476
	R - RPR	+0.0009	+0.0071	-0.0171	-0.0053
	Wether - ewe	+0.0467	+0.0526	+0.0726	+0.0803
Birth and rearing type only	Mean[c]	0.486	0.486	0.462	0.441
	SS - TT	+0.0061	+0.0132	+0.0872	+0.0643
	TS - TT	-0.0047	+0.0180	+0.0673	+0.0109
	Wether - ewe	+0.0471	+0.0534	+0.0641	+0.0894
Birth weight and breed of dam	Mean[d]	0.397	0.310	0.305	0.244
	Birth weight	+0.0141	+0.0220	+0.0252	+0.0271
	R - RPR	-0.0032	+0.0012	-0.0216	-0.0093
	Wether - ewe	+0.0391	+0.0357	+0.0555	+0.0629
Birth weight and birth and rearing type	Mean[e]	0.394	0.295	0.327	0.229
	Birth weight	+0.0153	+0.0249	+0.0181	+0.0283
	SS - TT	-0.0121	-0.0171	+0.0531	-0.0033
	TS - TT	-0.0032	+0.0378	+0.0736	+0.0173
	Wether - ewe	+0.0379	+0.0338	+0.0533	+0.0604
Breed of dam and birth and rearing type	Mean[f]	0.485	0.480	0.458	0.443
	R - RPR	+0.0011	+0.0110	+0.0075	-0.0041
	SS - TT	+0.0062	+0.0160	+0.0893	+0.0642
	TS - TT	-0.0044	+0.0202	+0.0684	+0.0104
	Wether - ewe	+0.0471	+0.0515	+0.0631	+0.0894
Birth weight, breed of dam and birth and rearing type	Mean[g]	0.396	0.295	0.327	0.232
	Birth weight	+0.0154	+0.0251	+0.0186	+0.0286
	R - RPR	-0.0046	-0.0038	-0.0067	-0.0090
	SS - TT	-0.0127	-0.0184	+0.0502	-0.0043
	TS - TT	-0.0045	+0.0372	+0.0728	+0.0164
	Wether - ewe	+0.0380	+0.0342	+0.0539	+0.0601

[a]Mean = ewe lambs, zero birth weight.
[b]Mean = ewe lambs, RPR breed.
[c]Mean = ewe lambs, TT birth and rearing type.
[d]Mean = ewe lambs, zero birth weight, RPR breed.
[e]Mean = ewe lambs, zero birth weight, TT birth and rearing type.
[f]Mean = ewe lambs, RPR breed, TT birth and rearing type.
[g]Mean = ewe lambs, zero birth weight, RPR breed, TT birth and rearing type.

APPENDIX B

METHODS USED TO MAKE MULTIPLICATIVE CORRECTIONS FOR THE EFFECTS OF BIRTH WEIGHT, BREED OF DAM AND BIRTH AND REARING TYPE

The classifications chosen to correct all lambs to were the average birth weight of all lambs, the RPR breed of dam and the TT birth and rearing type.

The formula used to correct any birth weight to the average birth weight of all lambs was

$$\hat{Y} = Y - \left[(A - \bar{X})\ C \times Y\right]$$

where $\hat{Y}$ = corrected average daily gain from 50 to 90 pounds.

Y = actual average daily gain from 50 to 90 pounds.

A = actual birth weight of the lamb.

$\bar{X}$ = average birth weight of all lambs.

C = the percent faster or slower a lamb gained for each one pound heavier or lighter he was at birth than the average of all lambs.

The formula used to correct the R breed of dam to the RPR breed of dam was

$$\hat{Y} = Y \pm B \times Y$$

where B = the percent faster (-) or slower (+) a lamb gained because he had a R dam rather than a RPR dam.

The formula used to correct the SS and TS birth and rearing types to the TT type was

$$\hat{Y} = Y \pm BR \times Y \qquad \text{for SS}$$

and

$$\hat{Y} = Y \pm BRT \times Y \qquad \text{for TS}$$

where BR = the percent faster (-) or slower (+) a lamb gained because his birth and rearing type was SS rather than TT

and BRT = the percent faster (-) or slower (+) a lamb gained because his birth and rearing type was TS rather than TT.

The general formula used to correct for more than one of these classifications was

$$\hat{Y} = Y + \Sigma \text{ (corrections for each variable).}$$

Correction factors (C, B, BR and BRT) are not the same for wethers and ewe lambs because the rate of gain for the two sexes is different. Consequently, differences in rate of gain expressed as percent change.

TABLE 17. ANALYSES OF VARIANCE FOR THE UNCORRECTED AND ADDITIVELY CORRECTED AVERAGE DAILY GAINS OF RANDOM WETHER LAMBS SELECTED WITHIN A FOUR POUND RANGE

Source in year	Degrees of freedom	Mean squares for uncorrected and corrected average daily gains							
		Uncorrected	Birth weight	Breed of dam	Birth & rearing type	Birth wt. & breed of dam	Birth wt. & B. & R. type	Breed & B. & R. type	Birth wt., breed & B. & R.
1956									
Total	55	0.0037	0.0024	0.0037	0.0036	0.0024	0.0024	0.0036	0.0024
Between groups	5	0.0036	0.0024	0.0036	0.0033	0.0024	0.0025	0.0033	0.0024
Lambs in groups	50	0.0037	0.0024	0.0037	0.0036	0.0024	0.0024	0.0036	0.0024
1957									
Total	31	0.0087	0.0071	0.0087	0.0084	0.0071	0.0068	0.0084	0.0068
Between groups	5	0.0016	0.0019	0.0017	0.0010	0.0019	0.0016	0.0010	0.0016
Lambs in groups	26	0.0100	0.0082	0.0100	0.0098	0.0082	0.0077	0.0098	0.0078
1958									
Total	50	0.0174	0.0182	0.0173	0.0156	0.0182	0.0163	0.0156	0.0164
Between groups	3	0.0141	0.0133	0.0147	0.0138	0.0140	0.0122	0.0135	0.0124
Lambs in groups	47	0.0177	0.0186	0.0175	0.0157	0.0185	0.0166	0.0157	0.0166
1959									
Total	108	0.0101	0.0092	0.0101	0.0110	0.0090	0.0091	0.0110	0.0090
Between groups	11	0.0162	0.0081	0.0161	0.0118	0.0079	0.0081	0.0117	0.0080
Lambs in groups	97	0.0094	0.0093	0.0094	0.0109	0.0092	0.0093	0.0109	0.0091
1956-59									
Total	247	0.0101	0.0094	0.0101	0.0101	0.0094	0.0090	0.0102	0.0090
Year	3	0.0178	0.0184	0.0246	0.0192	0.0233	0.0280	0.0293	0.0290
Groups in years	24	0.0102	0.0063	0.0103	0.0080	0.0063	0.0061	0.0080	0.0061
Lambs in groups in years	220	0.0099	0.0096	0.0099	0.0102	0.0095	0.0091	0.0102	0.0090

TABLE 18. ANALYSES OF VARIANCE FOR THE UNCORRECTED AND MULTIPLICATIVELY CORRECTED AVERAGE DAILY GAINS OF RANDOM WETHER LAMBS SELECTED WITHIN A FOUR POUND RANGE

Source in year	Degrees of freedom	Mean squares for uncorrected and corrected average daily gains: Uncorrected	Birth weight	Breed of dam	Birth & rearing type	Birth wt. & breed of dam	Birth wt. & B. & R. type	Breed & B. & R. type	Birth wt., breed & B. & R.
1956									
Total	55	0.0037	0.0025	0.0037	0.0036	0.0025	0.0026	0.0036	0.0026
Between groups	5	0.0036	0.0026	0.0036	0.0033	0.0026	0.0026	0.0033	0.0026
Lambs in groups	50	0.0037	0.0024	0.0037	0.0036	0.0025	0.0026	0.0036	0.0026
1957									
Total	31	0.0087	0.0074	0.0085	0.0081	0.0073	0.0074	0.0078	0.0075
Between groups	5	0.0016	0.0033	0.0017	0.0010	0.0033	0.0023	0.0010	0.0024
Lambs in groups	26	0.0100	0.0082	0.0098	0.0095	0.0081	0.0084	0.0091	0.0085
1958									
Total	50	0.0174	0.0185	0.0179	0.0138	0.0199	0.0146	0.0135	0.0152
Between groups	3	0.0141	0.0128	0.0152	0.0120	0.0150	0.0102	0.0114	0.0109
Lambs in groups	47	0.0177	0.0189	0.0181	0.0139	0.0202	0.0148	0.0136	0.0155
1959									
Total	108	0.0101	0.0112	0.0102	0.0100	0.0109	0.0114	0.0100	0.0113
Between groups	11	0.0162	0.0100	0.0163	0.0113	0.0097	0.0113	0.0114	0.0114
Lambs in groups	97	0.0094	0.0113	0.0095	0.0098	0.0111	0.0115	0.0099	0.0113
1956-59									
Total	247	0.0101	0.0103	0.0103	0.0092	0.0106	0.0098	0.0092	0.0100
Year	3	0.0178	0.0169	0.0243	0.0185	0.0276	0.0311	0.0293	0.0346
Groups in years	24	0.0102	0.0074	0.0105	0.0075	0.0076	0.0075	0.0075	0.0076
Lambs in groups in years	220	0.0099	0.0106	0.0101	0.0092	0.0107	0.0098	0.0091	0.0099

TABLE 19. ANALYSES OF VARIANCE FOR THE UNCORRECTED AND ADDITIVELY CORRECTED AVERAGE DAILY GAINS OF RANDOM EWE LAMBS SELECTED WITHIN A FOUR POUND RANGE

Source in year	Degrees of freedom	Mean squares for uncorrected and corrected average daily gains							
		Uncorrected	Birth weight	Breed of dam	Birth & rearing type	Birth wt. & breed of dam	Birth wt. & B. & R. type	Breed & B. & R. type	Birth wt., breed & B. & R.
1956									
Total	20	0.0035	0.0024	0.0034	0.0035	0.0024	0.0022	0.0035	0.0022
Between groups	2	0.0041	0.0046	0.0040	0.0040	0.0049	0.0046	0.0039	0.0051
Lambs in groups	18	0.0034	0.0021	0.0034	0.0035	0.0021	0.0019	0.0035	0.0019
1957									
Total	24	0.0064	0.0049	0.0063	0.0063	0.0049	0.0051	0.0061	0.0050
Between groups	3	0.0037	0.0010	0.0039	0.0038	0.0010	0.0008	0.0042	0.0008
Lambs in groups	21	0.0068	0.0055	0.0066	0.0066	0.0055	0.0057	0.0064	0.0057
1958									
Total	124	0.0073	0.0049	0.0075	0.0059	0.0052	0.0046	0.0058	0.0047
Between groups	9	0.0130	0.0038	0.0122	0.0048	0.0036	0.0023	0.0048	0.0023
Lambs in groups	115	0.0068	0.0050	0.0071	0.0060	0.0053	0.0048	0.0059	0.0049
1959									
Total	27	0.0085	0.0080	0.0084	0.0083	0.0080	0.0080	0.0082	0.0080
Between groups	3	0.0091	0.0041	0.0087	0.0047	0.0045	0.0046	0.0046	0.0050
Lambs in groups	24	0.0084	0.0085	0.0083	0.0087	0.0084	0.0085	0.0087	0.0084
1956-59									
Total	198	0.0070	0.0051	0.0070	0.0065	0.0052	0.0053	0.0064	0.0053
Year	3	0.0139	0.0081	0.0070	0.0374	0.0051	0.0336	0.0380	0.0302
Groups in years	17	0.0096	0.0034	0.0092	0.0045	0.0035	0.0027	0.0046	0.0028
Lambs in groups in years	178	0.0067	0.0052	0.0068	0.0062	0.0054	0.0051	0.0061	0.0051

TABLE 20. ANALYSES OF VARIANCE FOR THE UNCORRECTED AND MULTIPLICATIVELY CORRECTED AVERAGE DAILY GAINS OF RANDOM EWE LAMBS SELECTED WITHIN A FOUR POUND RANGE

Source in year	Degrees of freedom	Mean squares for uncorrected and corrected average daily gains: Uncorrected	Birth weight	Breed of dam	Birth & rearing type	Birth wt. & breed of dam	Birth wt. & B. & R. type	Breed & B. & R. type	Birth wt., breed & B. & R.
1956									
Total	20	0.0035	0.0025	0.0034	0.0035	0.0025	0.0023	0.0035	0.0024
Between groups	2	0.0041	0.0051	0.0039	0.0040	0.0055	0.0054	0.0039	0.0060
Lambs in groups	18	0.0034	0.0022	0.0034	0.0034	0.0022	0.0020	0.0034	0.0020
1957									
Total	24	0.0064	0.0063	0.0062	0.0062	0.0063	0.0076	0.0059	0.0075
Between groups	3	0.0037	0.0003	0.0039	0.0038	0.0003	0.0007	0.0041	0.0006
Lambs in groups	21	0.0068	0.0071	0.0065	0.0065	0.0071	0.0086	0.0061	0.0084
1958									
Total	124	0.0073	0.0054	0.0078	0.0052	0.0065	0.0043	0.0049	0.0046
Between groups	9	0.0130	0.0028	0.0128	0.0048	0.0039	0.0017	0.0047	0.0018
Lambs in groups	115	0.0068	0.0055	0.0074	0.0052	0.0067	0.0045	0.0050	0.0048
1959									
Total	27	0.0085	0.0115	0.0085	0.0075	0.0116	0.0123	0.0075	0.0127
Between groups	3	0.0090	0.0063	0.0088	0.0048	0.0082	0.0083	0.0047	0.0102
Lambs in groups	24	0.0084	0.0122	0.0084	0.0078	0.0121	0.0127	0.0078	0.0130
1956-59									
Total	198	0.0070	0.0060	0.0073	0.0059	0.0068	0.0063	0.0057	0.0065
Years	3	0.0139	0.0065	0.0073	0.0353	0.0050	0.0530	0.0357	0.0489
Groups in years	17	0.0096	0.0032	0.0095	0.0045	0.0042	0.0031	0.0045	0.0036
Lambs in groups in years	178	0.0067	0.0063	0.0070	0.0055	0.0070	0.0058	0.0053	0.0060

TABLE 21. ANALYSES OF VARIANCE FOR THE UNCORRECTED AND ADDITIVELY CORRECTED AVERAGE DAILY GAINS OF RANDOM WETHER LAMBS SELECTED WITHIN A TWO POUND RANGE

		Mean squares for uncorrected and corrected average daily gains							
Source in year	Degrees of freedom	Uncorrected	Birth weight	Breed of dam	Birth & rearing type	Birth wt. & breed of dam	Birth wt. & B. & R. type	Breed & B. & R. type	Birth wt., breed & B. & R.
1956									
Total	7	0.0048	0.0049	0.0048	0.0050	0.0049	0.0045	0.0050	0.0045
Between groups	1	0.0007	0.0060	0.0007	0.0008	0.0061	0.0059	0.0008	0.0059
Lambs in groups	6	0.0055	0.0047	0.0055	0.0057	0.0047	0.0042	0.0057	0.0043
1957									
Total	31	0.0087	0.0071	0.0087	0.0084	0.0071	0.0068	0.0084	0.0068
Between groups	5	0.0016	0.0019	0.0017	0.0010	0.0019	0.0016	0.0010	0.0016
Lambs in groups	26	0.0100	0.0082	0.0100	0.0098	0.0082	0.0077	0.0098	0.0078
1958									
Total	4	0.0035	0.0050	0.0031	0.0035	0.0046	0.0049	0.0036	0.0048
Between groups	0	-	-	-	-	-	-	-	-
Lambs in groups	4	0.0035	0.0050	0.0031	0.0035	0.0046	0.0049	0.0036	0.0048
1959									
Total	66	0.0097	0.0078	0.0097	0.0101	0.0076	0.0077	0.0101	0.0076
Between groups	8	0.0159	0.0063	0.0159	0.0111	0.0062	0.0060	0.0111	0.0060
Lambs in groups	58	0.0088	0.0080	0.0088	0.0100	0.0078	0.0079	0.0100	0.0078
1956-59									
Total	111	0.0089	0.0073	0.0091	0.0090	0.0073	0.0071	0.0091	0.0071
Year	3	0.0120	0.0090	0.0166	0.0073	0.0121	0.0074	0.0117	0.0081
Groups in years	14	0.0097	0.0047	0.0097	0.0067	0.0047	0.0044	0.0068	0.0045
Lambs in groups in years	94	0.0087	0.0077	0.0087	0.0094	0.0076	0.0075	0.0094	0.0074

TABLE 22. ANALYSES OF VARIANCE FOR THE UNCORRECTED AND MULTIPLICATIVELY CORRECTED AVERAGE DAILY GAINS OF RANDOM WETHER LAMBS SELECTED WITHIN A TWO POUND RANGE

Source in year	Degrees of freedom	Mean squares for uncorrected and corrected average daily gains: Uncorrected	Birth weight	Breed of dam	Birth & rearing type	Birth wt. & breed of dam	Birth wt. & B. & R. type	Breed & B. & R. type	Birth wt., breed & B. & R.
1956									
Total	7	0.0048	0.0053	0.0048	0.0049	0.0054	0.0049	0.0049	0.0050
Between groups	1	0.0007	0.0082	0.0007	0.0008	0.0082	0.0078	0.0008	0.0078
Lambs in groups	6	0.0055	0.0048	0.0055	0.0056	0.0049	0.0044	0.0056	0.0045
1957									
Total	31	0.0087	0.0074	0.0085	0.0081	0.0073	0.0074	0.0078	0.0075
Between groups	5	0.0016	0.0033	0.0017	0.0010	0.0033	0.0023	0.0010	0.0024
Lambs in groups	26	0.0100	0.0082	0.0098	0.0095	0.0081	0.0084	0.0091	0.0085
1958									
Total	4	0.0035	0.0067	0.0033	0.0033	0.0063	0.0065	0.0033	0.0068
Between groups	0	-	-	-	-	-	-	-	-
Lambs in groups	4	0.0035	0.0067	0.0033	0.0033	0.0063	0.0065	0.0033	0.0068
1959									
Total	66	0.0097	0.0088	0.0098	0.0090	0.0084	0.0088	0.0091	0.0086
Between groups	8	0.0159	0.0037	0.0161	0.0103	0.0036	0.0038	0.0106	0.0038
Lambs in groups	58	0.0088	0.0095	0.0089	0.0088	0.0091	0.0095	0.0089	0.0092
1956-59									
Total	111	0.0089	0.0080	0.0091	0.0083	0.0079	0.0080	0.0083	0.0079
Year	3	0.0120	0.0062	0.0163	0.0073	0.0110	0.0054	0.0119	0.0059
Groups in years	14	0.0097	0.0039	0.0099	0.0063	0.0038	0.0036	0.0065	0.0036
Lambs in groups in years	94	0.0087	0.0087	0.0087	0.0086	0.0084	0.0087	0.0085	0.0086

TABLE 23. ANALYSES OF VARIANCE FOR THE UNCORRECTED AND ADDITIVELY CORRECTED AVERAGE DAILY GAINS OF RANDOM EWE LAMBS SELECTED WITHIN A TWO POUND RANGE

Source in year	Degrees of freedom	Mean squares for uncorrected and corrected average daily gains: Uncorrected	Birth weight	Breed of dam	Birth & rearing type	Birth wt. & breed of dam	Birth wt. & B. & R. type	Breed & B. & R. type	Birth wt., breed & B. & R.
1956									
Total	20	0.0035	0.0024	0.0034	0.0035	0.0024	0.0022	0.0035	0.0022
Between groups	2	0.0041	0.0046	0.0040	0.0040	0.0049	0.0046	0.0039	0.0051
Lambs in groups	18	0.0034	0.0021	0.0034	0.0035	0.0021	0.0019	0.0035	0.0019
1957									
Total	12	0.0070	0.0052	0.0068	0.0069	0.0051	0.0051	0.0066	0.0052
Between groups	2	0.0031	0.0009	0.0034	0.0033	0.0009	0.0008	0.0038	0.0007
Lambs in groups	10	0.0078	0.0060	0.0074	0.0077	0.0060	0.0060	0.0071	0.0061
1958									
Total	41	0.0097	0.0059	0.0101	0.0083	0.0063	0.0062	0.0081	0.0063
Between groups	4	0.0156	0.0055	0.0151	0.0055	0.0057	0.0027	0.0054	0.0028
Lambs in groups	37	0.0091	0.0060	0.0095	0.0086	0.0064	0.0066	0.0084	0.0066
1959									
Total	5	0.0056	0.0042	0.0055	0.0056	0.0040	0.0038	0.0055	0.0037
Between groups	1	0.0091	0.0100	0.0095	0.0091	0.0108	0.0100	0.0094	0.0108
Lambs in groups	4	0.0048	0.0027	0.0045	0.0048	0.0023	0.0022	0.0045	0.0019
1956-59									
Total	81	0.0074	0.0047	0.0075	0.0069	0.0049	0.0051	0.0068	0.0051
Year	3	0.0057	0.0033	0.0053	0.0123	0.0035	0.0125	0.0125	0.0111
Groups in years	9	0.0095	0.0048	0.0094	0.0051	0.0050	0.0035	0.0052	0.0037
Lambs in groups in years	69	0.0071	0.0048	0.0073	0.0069	0.0050	0.0050	0.0067	0.0050

TABLE 24. ANALYSES OF VARIANCE FOR THE UNCORRECTED AND MULTIPLICATIVELY CORRECTED AVERAGE DAILY GAINS OF RANDOM EWE LAMBS SELECTED WITHIN A TWO POUND RANGE

		Mean squares for uncorrected and corrected average daily gains							
Source in year	Degrees of freedom	Uncorrected	Birth weight	Breed of dam	Birth & rearing type	Birth wt. & breed of dam	Birth wt. & B. & R. type	Breed & B. & R. type	Birth wt., breed & B. & R.
1956									
Total	20	0.0035	0.0025	0.0034	0.0035	0.0025	0.0023	0.0035	0.0024
Between groups	2	0.0041	0.0051	0.0039	0.0040	0.0055	0.0054	0.0039	0.0060
Lambs in groups	18	0.0034	0.0022	0.0034	0.0034	0.0022	0.0020	0.0034	0.0020
1957									
Total	12	0.0070	0.0070	0.0067	0.0069	0.0070	0.0081	0.0064	0.0082
Between groups	2	0.0031	0.0003	0.0033	0.0033	0.0003	0.0009	0.0038	0.0008
Lambs in groups	10	0.0078	0.0084	0.0074	0.0076	0.0084	0.0096	0.0069	0.0097
1958									
Total	41	0.0097	0.0059	0.0105	0.0073	0.0073	0.0054	0.0070	0.0057
Between groups	4	0.0156	0.0043	0.0157	0.0057	0.0062	0.0013	0.0055	0.0017
Lambs in groups	37	0.0091	0.0060	0.0100	0.0075	0.0074	0.0058	0.0072	0.0061
1959									
Total	5	0.0056	0.0050	0.0055	0.0056	0.0050	0.0044	0.0055	0.0043
Between groups	1	0.0091	0.0115	0.0095	0.0092	0.0131	0.0133	0.0096	0.0138
Lambs in groups	4	0.0048	0.0034	0.0045	0.0047	0.0030	0.0021	0.0045	0.0019
1956-59									
Total	81	0.0074	0.0050	0.0077	0.0064	0.0058	0.0055	0.0061	0.0056
Year	3	0.0057	0.0026	0.0053	0.0116	0.0037	0.0204	0.0119	0.0186
Groups in years	9	0.0095	0.0044	0.0096	0.0052	0.0055	0.0035	0.0052	0.0038
Lambs in groups in years	69	0.0071	0.0052	0.0075	0.0063	0.0059	0.0051	0.0060	0.0053

VITA

Don G. Brothers

Candidate for the Degree of

Doctor of Philosophy

Thesis: SELECTION OF LAMBS THAT YIELD THE GREATEST EXPERIMENTAL EFFICIENCY IN GROWTH STUDIES FROM APPROXIMATELY FIFTY TO NINETY POUNDS

Major Field: Animal Breeding

Biographical:

Personal Data: Born in Paducah, Texas, December 25, 1935, the son of Arlie L. and Doris M. Brothers. Married Gayle Porterfield, December, 16, 1960.

Education: Received the Bachelor of Science degree from Texas Technological College, with a major in Animal Husbandry in June, 1957; received the Master of Science degree from Oklahoma State University of Agriculture and Applied Science in May, 1959.

Member: The American Society of Animal Production, Alpha Zeta, Phi Kappa Phi and Associate Member of The Society of the Sigma Xi.

Experiences: Self employed as a farmer in 1955 and 1956. Graduate assistant at Oklahoma State University of Agriculture and Applied Sciences, 1957-61.

Date of Final Examination: May, 1961.