VARIATION IN GROWTH RATE BETWEEN SELECTED LIKE-SEXED TWINS AS COMPARED TO RANDOMLY SELECTED LIKE-SEXED LAMBS

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INTRODUCTION

Probably the most profound problem confronting the statistical analysis of an experiment is the size of the experimental error. The efficiency of an experiment is directly affected by the size of the experimental error, because the larger the error the more the experimental efficiency is reduced.

Improvement of experimental efficiency can only come from a consideration of the factors which contribute to the error. In experiments in which animals are used errors arise from variation due to age, weight, sex, previous treatments, genetic effects and any other variants which may be present. Also errors in the determination of the characteristic being measured contribute to the experimental error.

An attempt is usually made to reduce the effects of the inherent variation by one or more of the following methods: (1) the selection of homogeneous animals to reduce the variation between units; (2) the stratification of units into sub-populations of similar individuals; (3) the use of covariance analysis; and (4) by increasing the numbers used. The increase in numbers does not reduce the experimental error, but will increase the efficiency of an experiment due to an increase in the degrees of freedom. Also larger numbers will reduce the standard error of the mean. However, large numbers are often impossible in large animal research due to their expense and the lack of available facilities.

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. Hence some known sources of variation are not present in the error variance when monozygotic twins are used for experimental purposes. This reduces the error and increases the efficiency of the experiment. For this reason considerable interest has developed in the use of monozygotic cattle twins for experimental purposes during the past few years.

Monozygotic twins in sheep are rare; however, the frequently occurring dizygotic twin lambs are full-sibs, and they share a common pre- and post-natal environment contemporaneously. Therefore, like-sexed twin lambs, when selected within a limited weight range at a particular weight, should react more alike than randomly selected like-sexed lambs of the same weight when both groups are selected simultaneously and treated similarly. It is the purpose of this study to estimate the twin efficiency values of lambs for some characteristics, and therefore establish the worth of twin lambs as experimental units. The efficiency values of the selected like-sexed twin lambs estimated in this study were for average daily gain, carcass grade and carcass yield.

REVIEW OF LITERATURE

Lillie (1916, 1917) and Keller and Tandler (1916) aroused interest in twins by their well known studies with free-martins. Both believed in the occurrence of identical twins in cattle but found them very rare. Lillie (1916) described a homosexual twin case in which only one ovary was present when the uterus was received from the slaughter floor, and it contained no corpus luteum. Lillie (1923) found one corpus luteum for two embryos once in 126 twin cases. He concluded that both of these cases were probably monozygotic twins.

Gowen (1922) made an inquiry into the sex ratios of twin pairs and concluded that identical twins are rarely or never produced in cattle. However, Lush (1924) observed a pair of yearling Brahman X Hereford bull twins which he termed apparently identical. Also Lush (1929) described a pair of Jersey twins apparently identical; both even dropped their first calf on the same day.

Much work has been done since in an attempt to devise a satisfactory method to diagnose monozygotic twin pairs. Bonnier and Hansson (1946) claimed that muzzle prints were one of the most useful criteria in the diagnosis of monozygous twins. However, Hancock (1949) pointed out that many dizygotic sets showed no greater differences than the most similar monozygotic sets. Hancock (1954) concluded that in a population of mainly Jersey breeding, in which other more suitable methods of diagnosis are available, muzzle prints are of little additional value.

Hancock (1949) stated that whorls in the hair pattern were valuable in the diagnosis only when they showed features which were unusual in the general population.

Bonnier and Hansson (1946), Donald *et al.* (1951) and Johansson and Venge (1951) worked with spotted breeds and concluded that white spotting was useful in diagnosis of monozygous twins. However, Hancock (1949) worked with twins of Jersey breeding and considered this character of little use. Also he noted that pigmentation patterns on the bare or slightly hairy areas of the skin were especially useful in the diagnosis.

Stormont *et al.* (1945) and Stormont (1950) described thirty-eight definite antigens in the erythrocytes of cattle. These antigenic factors can determine if a twin pair is not monozygous and is presently the final step in the analysis of a twin pair for zygosity. Yet Stormont (1954) stated that no known test or group of tests will differentiate with absolute certainty all monozygous and dizygous twin sets from each other.

Frequency of Twinning in Domestic Animals

Many workers have reported on the twinning conditions in cattle and sheep. In general, dairy cattle twin more frequently than beef cattle, and farm breeds of sheep twin more frequently than range breeds. Swine give birth to litters and, therefore, are classified as a multiparous animal. Consequently, few investigations on the twinning condition in swine have been reported.

Lamb (1935) calculated the multiple birth ratio for the five principal dairy breeds and found an average of one multiple birth per 32.41 single births in a study of 940 calvings. His ratio for breeds were:

Holstein, 1 :23.3; Jersey, 1 : 58.33; Guernsey, 1 : 82.5; Ayrshire, 1 : 22.67; and Brown Swiss, no multiple births.

Lush (1925) observed twenty-two twin births in a total of 509 births. From this data he calculated a twinning rate of 4.32 percent ± 0.61 percent of all births. The Holstein breed was highest of all breeds with sixteen twin births in 181 total births for an 8.84 percent twinning rate.

Gowen (1918) found twenty-one twin births in 2,573 calvings which is one twin birth in 125 calvings for an occurrence of 0.82 percent. King (1953) stated that the twinning rate in cattle is only one to two percent of all births, and probably only about one in twenty of these twins are one-egg twins.

Pfau <u>et al</u>. (1948) collected data from a Holstein herd over a fifteen year period. A total of 937 parturitions and abortions were observed. An average of one twin birth in every 25.3 births and one triplet birth in 468.5 births was found. This is an average of one multiple birth in every twenty-four parturitions. Numbers of twin births reported for individual dairy breeds ranged from less than 0.5 percent to 4.5 percent.

Bonnier and Skarman (1938) estimated only about ten percent of like-sexed cattle twins to be monozygotic. Johansson and Venge (1951) computed and tabulated the monozygotic twinning frequencies for several European, Australian and African dairy breeds. A great variation was found between breeds and within breeds according to location. It was concluded that in all breeds of dairy cattle approximately ten percent of all like-sexed twins might be expected to be monozygotic.

Jones and Rouse (1920) studied 747,100 calvings in beef cattle and found twinning frequency to increase with the age of the cow. Among twelve and thirteen year old cows they found about one twin birth in 144. This is about one identical pair in 2,215 births in cows this age. Winchester (1951) estimated that identical twins in beef cattle are born once in 2,270 calvings.

Clark (1931) studied the sex ratio of 523 pairs of sheep twins and found no statistically significant departure from a 1 : 2 : 1 sex ratio which is expected in twin pairs if no monozygotic twins are expected. Hence it was concluded that the modal class of sheep twins are of dizygotic origin.

Johansson (1932) found a statistically significant deviation from the 1 : 2 : 1 ratio with a chi-square test which favored the opposite-sexed twin class. This test on the sex combination frequencies of 5,088 pairs of lambs again indicated monozygotic twins to be very rare in sheep.

Chapman and Lush (1932) reported no evidence of monozygotic twins in a flock chiefly of Hampshire breeding. In this flock thirty-six percent of lambings were singles, sixty percent twins and less than five percent were triplets.

Kammlade and Kammlade (1955) list a considerable variation in the percent lamb crop between breeds. The average percentage lamb crops for breeds were: Rambouillet, 122; Shropshire, 149; Hampshire, 144; Oxford, 152; Southdown, 151; Dorset, 158; Lincoln, 157; Cotswold, 144; and Tunis, 141. The average lamb crop of the nine breeds combined was 146 percent.

Monozygous twinning is generally not considered to occur in sheep. However, Cole and Craft (1945) described a lamb monster which they assumed to be an incomplete development of monovular twins.

Henning (1937) reports the discovery of a double sheep pregnancy with a single corpus luteum among 675 sheep fetuses. Both were males and were very similarly marked. One fetus was slightly heavier. The two chorions were continuous. It was concluded that the two fetuses were of monozygotic origin.

Streeter (1924) described a blastocyst in swine which contained two embryonic areas. Hughes (1931) states that Streeter's work demonstrated conclusively the occurrence of single-ovum twinning in the pig. Hughes further described three cases which he concluded to be monozygotic.

Efficiency of Monozygotic Cattle Twins as Experimental Units

A considerable amount of work has been done toward establishing efficiency values for a number of characteristics in monozygous twin cattle. Most work has been done with dairy cattle and the efficiency values have considerable range, depending upon the characteristic which is studied.

Hutt (1930) stated that bovine monozygotic twins would be particularly valuable for investigations in nutrition, physiology and husbandry because of their being genotypically identical.

The first real attempt to collect cattle twins for research purposes was by Kronacher (1930). Bonnier and Hansson (1948) stated that further work was done at Kronacher's Berlin school in Germany, but World War II prevented advanced study. Since the war the leading research work with monozygotic cattle twins has been done in New Zealand, Sweden, Denmark, Finland and England. Winchester (1951) reports that the first experiments of this kind in this country were those at the University of Minnesota in

1947. A number of other agricultural experiment stations have recently begun twin studies; however, little data has been published concerning this research in the United States.

Bonnier and Hansson (1948) stated that in the case where experimental units are unrelated, their number is equal to a certain number of twins if the two tests give the same amount of information, i.e. if their significance is equal. 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 <u>et al</u>. (1946). A uniformity trial for growth rates from 80 to 180 days of age was run on eight pairs of twins. The analysis of variance of the trial was

Source	Degrees of Freedom	Sum of Squares	Mean Square
Total	15	4334	
Between pairs	7	4239	605.6
Within pairs	8	95	11.9

From this information a method to estimate the relative efficiency of monozygotic twins was set forth as

$$E = \frac{M_B}{M_W}$$

Where E = the number of ordinary animals in each of two groups that one set of monozygotic twins can replace without loss of statistical precision

M_B = the mean square between sets of twins

M_W = the mean square within sets of twins

This formula yielded an efficiency value for growth of 50.9. Also Bonnier and coworkers ran a group of unrelated animals on the same scheme so that the number of animals and the procedure used were the same as with the twin experiment. The efficiency ratio of between cows mean square/within twin pairs mean square came to 24.1. This comparison led to the conclusion that a group experiment required twenty-four times as many animals as a twin experiment. However, since the comparison was made between animals of a different nature (twins vs. unrelated) the previous comparison of 50.9 was thought to be more accurate. It was concluded that to be safe under all circumstances at least twenty times as many animals would be required as in the case of a twin experiment if the experiment were to be conducted in two equal groups.

Bonnier and Hansson (1948) again stated that efficiency values of twins could be estimated by comparing the mean squares between twin pair means with the mean squares within pairs. In the case where all animals are treated similarly, the ratio of these two mean squares measures the relative efficiency of the two kinds of experiments.

The second formula for twin efficiency values and the one used most was contributed by Dick and Whittle (1951). They stated that since the purpose of the experiment is primarily to differentiate treatments, the efficiency should be defined on the basis of the number of animals required to do this to a given degree of precision. The development of the formula of Dick and Whittle follows.

Suppose design one used N_1 animals and that the difference of two treatment constants has variance V_1. Similarly, for design two, number of animals is N_2, and the variance V_2. Suppose further that the level of precision is such that the variance of treatment differences must be V. Hence if the first design is used, the number of animals required is V_1N_1/V and if the second is used the number required is V_2N_2/V. The efficiency of the first design relative to the second is defined as

$$\frac{V_2N_2}{V} \Big/ \frac{V_1N_1}{V} = \frac{N_2V_2}{N_1V_1}$$

Now for any design in which the only factors are blocks and treatments, the variance of two treatment constants can be expressed as

$$V(t_i - t_j) = 2\sigma_T^{\ 2} + K\sigma_{BT}^{\ 2}$$

where $\sigma_T^{\ 2}$ = the component of variance due to treatments

and $\sigma_{BT}^{\ 2}$ = the component of variance due to blocks and treatments.

K is a constant of the design, under the null hypothesis $\sigma_T^{\ 2} = 0$, so the relative efficiency of experiments one and two can be expressed as

$$\frac{N_2V_2}{N_1V_1} = \frac{N_2K_2}{N_1K_1} \; \frac{(\sigma_{BT})_2^2}{(\sigma_{BT})_1^2}$$

The essential part of this expression is the ratio

$$\frac{(\sigma_{BT})_2^2}{(\sigma_{BT})_1^2} = F$$

which represents the relative inherent variability of the two sets of animals used. So, if the one subscript refers to twins and the two subscript to the comparatively unrelated animals, which would be used otherwise, F is a measure of the twin efficiency. It could be estimated by running a number of pairs of twins together with a number of cows such as would be used in an ordinary group trial under uniform conditions. The ratio of between cow and within twin variance would then be an estimate of F. More economically the ratio can be estimated from the twin uniformity data if it is assumed that the variation between twin pairs is the same as that expected between ordinary cows. Under these assumptions the efficiency is simply the ratio of σ^2_B to σ^2_W where σ^2_B and σ^2_W are simply the components of variance for between and within twin pairs, respectively, in the analysis of a twin uniformity trial. If M_B and M_W are the mean squares for between and within twin pairs, then

$$M_B = \sigma^2_W + 2\sigma^2_B$$

$$M_W = \sigma^2_W$$

$$\therefore \frac{\sigma^2_B}{\sigma^2_W} = \frac{1}{2}\left(\frac{M_B}{M_W} - 1\right)$$

Dick and Whittle (1951) stated that Bonnier et al. (1946) attempted to deduce the efficiency from the twin trial alone, but in doing so overlooked the difference between the between pair mean square and the between pair components of variance. From the data of Bonnier and coworkers Dick and Whittle calculated $\sigma_B^2 = 296.9$ and $\sigma_W^2 = 11.9$. This gives an efficiency estimate of 25.0 from the twins. This value is almost an identical estimate of efficiency as that of 24.1 that Bonnier and coworkers calculated by comparing between cow to within cow mean squares from the unrelated animals and twin pairs, respectively.

Carter (1951) finally suggested that 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 can possibly yield efficiency values of less than one for monozygous twins. This formula increases efficiency values by one over the preceding formula.

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 monozygous twins.

Dick and Whittle (1951) also devised a method to determine the efficiency value of monozygotic twins in experiments involving more than two treatments. The formula $NE/2(N-1)$, where N is the number of treatments and E is the efficiency value of twins when used in a two treatment trial, estimates the efficiency of twins when more than two treatments are applied. This formula takes into account both direct and indirect comparisons allowed from the incomplete block which is the most suitable design when more than two treatments are applied.

Hancock (1951) calculated growth rates by the method of Dick and Whittle (1951) on an unselected sample of ten sets of heifer twins born on various farms and collected when seven-ten days old. Absolute growth rates were calculated for seven periods all beginning at four weeks of age but varying in length from twelve to eighty-four weeks. The twin efficiency value for absolute growth rate was thirteen. When the seven periods were computed separately the values were: 4-16 weeks, 16; 4-28 weeks, 5; 4-40 weeks, 4; 4-52 weeks, 21; 4-64 weeks, 19; 4-76 weeks, 13; 4-88 weeks, 8. When the length of periods was extended beyond thirty-six weeks the within-set variations became very low which, with steady between set variations, caused high twin-efficiency values. This series illustrated how even small fluctuations in the variances can alter the calculated twin-efficiency values.

Hancock (1951) also reported that the pounds deviation from the mean in a growth trial of a monozygous twin pair increased from 4-88 weeks of age. However the deviations on a percentage basis decreased up to seventy-six weeks of age, then increased, partly due to the differences which existed within the sets in regard to stage of pregnancy.

Bailey et al. (1958) reported from a series of twenty-four short-term experiments on the protein and energy requirements of growing dairy heifers with live weights ranging from 250 to 600 pounds. Friesian and Dairy Shorthorn herd replacements and monozygous twins of various dairy breeding were used. Covariance analysis of rate of gain with initial live weight was carried out in thirteen experiments. The results were very variable but no advantage could be shown by the use of covariance analysis or by the use of monozygous twins. This indicated that genetic effects contributed relatively little to the error in experiments lasting three to six weeks.

Hancock (1954) and Stormont (1954) list several twin efficiency values which have been calculated for dairy production, general habits, growth, physiological characteristics, and semen characteristics. These values range from one to seventy-two, depending upon the characteristic studied. In many cases a considerable advantage is gained in efficiency by the use of monozygous twins.

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 monozygous 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.

Dizygotic Twin Comparisons

Dizygotic twins are those twins which have developed from two different ova and sperms and are thus as genetically unlike as full sibs. Therefore, their genotype is unlike and variation due to hereditary differences will be present in the experimental error.

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 environments. 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 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 forty-eight 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 - 1.44/2.67 = 46 percent for 180 twin females and 3.15 - 1.77/3.15 = 44 percent for 368 twins of unlike sex. It was 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 analyses it was estimated that approximately forty-five percent of the total variance in birth weight was due to lambs developing from different dams. Some of this variance is genetic and some maternal. Hence fifty-five percent of the total variance arises from genetic differences and uncontrollable environment. From this assumption it was estimated that twenty-five to thirty percent of the variance in birth weight was genetic; thirty to thirty-five percent was due to tangible environment, that is the portion to disappear if all lambs could develop in the same uterus contemporaneously, and forty to forty-five 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. The pairs were not too markedly different in weight and were uniformly treated. Within-pairs of one-egg twins the only known source of variation should be pre- and post-natal accidents of environment (e^2). In two-egg twins the source should be supplemented with genetic variation which in a fair sample of pairs should approximate to one-half the genetic variance (g^2) characteristics of the populations from which their parents came. Half-sib pairs should show the greatest variance since they should contain three-quarters of the genetic variance and maternal effects (m^2) due to their having two different dams instead of one as with twins as well as error variance presumably the same as that shown by twins.

King and Donald (1955) compared the variances 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 ten times larger than for monozygous twins. The total variation expected between unrelated animals is

$$e^2 + g^2 + m^2$$

However, these partitions (e^2, g^2, m^2) may be over simplified. The variation within pairs of the three groups was (neglecting non-additive effects) represented by the following scheme

mean square within monozygotic pairs $= \sigma_{MZ}^2 = e^2$

mean square within dizygotic pairs $= \sigma_{DZ}^2 = e^2 + 1/2g^2$

mean square within half-sibs pairs $= \sigma_{HS}^2 = e^2 + 3/4g^2 + m^2$

King (1953) compared fifteen 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 sets. Relative mean squares within sets were as follows:

Character	One-egg twins	Two-egg twins	Half-sibs
weight at weaning	1	2.6	3.5
weight at six months	1	3.9	3.9
weight at twelve months	1	3.8	6.3
weight at eighteen months	1	5.6	9.9

The advantage of one-egg twins increased over two-egg twins and half-sibs progressively from weaning to eighteen 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.

Bonnier (1947) determined the protein and lactose levels of milk with fixed fat levels. The studies were based on 2,245 samples taken from twenty-nine pairs of twins of which nineteen were identical, seven were fraternal and three were uncertain. It was found that the distribution of the ratios had the smallest variation for the intra-identical twin comparisons, somewhat larger for the intra-fraternal twin comparisons and very much larger for the comparisons of twin pair means (i.e. for the comparisons between unrelated animals). The type of variation in the intra-identical twin comparisons must be due only to external and random causes. Due to the variation in unrelated animals it was concluded that several pair of genes are in action and the case here is of polygenic effect.

White (1951) found that identical twin calves had no advantage over fraternal twins in experiments involving the blood constituents of plasma chlorides, erythrocyte fragility and erythrocyte counts; therefore, it was concluded that identical twins may offer no particular advantage over fraternal twins for research on blood constituents. He stated that it would be interesting to extend these comparisons to nutritional studies to see if the more readily obtainable fraternal twins are of comparable experimental value with the rarer identical animals. A logical extension of this work would be to compare the within-pair variance of fraternal twins with the within-pair variance of pairs of unrelated but similar animals with respect to breed, sex, age and environment. The comparisons of between-twin-pair variation with within-pair variation are likely to give an inflated estimate of the twin efficiency value unless all the animals are reasonably alike.

Summary of the Review of Literature

Twinning in cattle has been found to range from less than one percent to as high as eight percent. In dairy cattle monozygotic twins occur approximately once in one to two thousand calvings. In beef cattle an identical twin pair may be expected in approximately 2300 calvings. Hence the monozygotic twinning rate in cattle is very low.

There is little evidence of monozygotic twins in sheep. However, dizygotic twin lambs occur frequently, for lamb crops in excess of 100 percent are common in farm flocks. In some cases multiple births occur as often as 60 percent of all births. Breed and environment are known to influence the multiple birth frequency in sheep.

Interest began in the use of monozygotic cattle twins for experimental purposes about 1930, but no attempt was made to estimate their worth as experimental units until 1946. Since then three methods to estimate twin efficiency values for experimental purposes have been set forth. Two of these methods attempt to estimate the efficiency by use of a twin trial only. One method compares the variation within a twin pair to the variation within randomly selected pairs of animals, which serve as a control group, to estimate twin efficiency.

The similarities between members of a monozygotic twin pair are not all contributed to an identical genotype. Twins also share the same pre- and post-natal environment contemporaneously. Some work has shown that dizygotic cattle twins are less variable than half-sib pairs and unrelated animals.

MATERIALS AND METHODS

The lambs used in this study were obtained from the experimental sheep flock (Project S-908) located at the Fort Reno Experiment Station. The lambs were born during the late falls of 1955, 1956 and 1957.

The dams of these lambs were grade Rambouillet and grade Rambouillet X Panama-Rambouillet ewes purchased near Del Rio, Texas, during April and May, 1955. All were yearlings when obtained. The lambs were sired by purebred Dorset rams, all of which were purchased from breeders in Oklahoma. Breeding began on or after May 20th., and continued for a forty-eight day period in 1955 and 1956. In 1957 breeding began June 1st. and continued for thirty-two days.

The flock was managed according to the usual practice of commercial sheep breeders in Oklahoma. During the winter months the ewes were grazed on wheat pasture and were supplementally fed alfalfa when adverse weather prevailed. After lambing, the flock was divided into two groups, one group was composed of ewes rearing lambs and the other group was composed of ewes rearing no lambs. During the 1956-57 and 1957-58 seasons the ewes rearing twins were separated from those rearing singles, all of the lambs had access to a creep feed consisting of two parts cracked kafir grain and one part chopped good quality alfalfa hay. The lambs were separated from their dams only during the time of weighing.

Birth weights of the lambs were recorded to the nearest one-half pound in 1955 and to the nearest one-tenth pound in 1956 and 1957. This weight, as well as date of birth and sex of the lamb, were recorded as soon as possible after the lamb was dry. All the lambs were docked during the first week after birth, and the ram lambs were castrated between one and four weeks of age. In December when the older lambs were approximately 40 to 45 days of age the lambs were weighed again. After that the lambs were weighed at two week intervals until they reached a market weight of 90 to 92 pounds. Each year a few lambs which were born late were marketed at slightly less than 90 pounds.

Each lamb was identified by a number which was usually the same as that of its dam. The number was stamped on a metal ear tag and was also paint branded on the lamb's back to facilitate identification. In the case of twins during the 1955-56 season, one twin was usually assigned its dam's number and the other twin was assigned another number. During the 1956-57 and 1957-58 season both twins received their dam's number, one of the pair receiving the number preceded by a bar (-). This latter method was found to be more useful because it facilitated identification of a twin pair without having to check the record book numbers.

The lambs were shipped to Oklahoma City and slaughtered by Wilson and Company within two days after their final weighing. The carcass weights and grades were recorded before the carcasses were processed.

There were eighty-three pairs of twins normally raised as twins during the three year period. Forty-eight of these eighty-three pairs were like-sexed twins. These like-sexed twins were selected to begin an average daily gain uniformity trial when both members of a pair weighed within one of three different weight ranges of fifty pounds. The three weight ranges were 47-53 pounds, 48-52 pounds and 49-51 pounds. Hence, these selection weight ranges contained like-sexed twin pairs with not more than six, four and two pounds difference in weight between them. There were thirty-two, twenty-four and fifteen pairs of like-sexed twins within the six, four and two pound weight ranges, respectively.

Since the two week weigh periods did not always record the lamb weights when they were within these weight ranges it was necessary to adjust the weights to a particular day when they came nearest the fifty pound weight. Average daily gain for the pairs was then calculated from the weigh period following selection to the date when each individual lamb reached market weight. Analyses of variances to determine the variances between and within pairs of twins were then computed on these daily gain data.

The fifty pound selection weight was arbitrary. However, some definite selection weight was necessary so that all twin pairs might have a fairly uniform gain period on which to base their average daily gain. Also there should be no more difference between pairs than within pairs at the time of selection if accurate twin efficiency values are to be computed for twin performance by the methods of Dick and Whittle (1951) and Carter (1951) and Stormont (1954).

Theoretically, if a twin pair had not been selected for the uniformity trial then two random lambs of the same sex within the same weight range would have been selected from the flock. However, the performance of a randomly selected pair would possibly not be indicative of similar random lambs in the flock due to random variation encountered with small numbers. Therefore, on the particular day that a twin pair was selected all other lambs in the flock that were of the same sex and within that particular weight range were selected too and their average daily gain to market was calculated. Analyses of variances were also computed on these daily gain data. This was done so that a comparison could be made between the variance within a twin pair's performance and the variance among individual lambs in the flock. This provided a third method to estimate the twin efficiency values as suggested by Dick and Whittle (1951) and White (1951).

Carcass yields and grades were also recorded for the twin pairs and corresponding random groups within each weight range. Analyses of variances were computed for these data also and twin efficiency estimates were made for yield and grade by the three methods previously stated. The carcasses were graded to the nearest one-third of a grade by a United States Department of Agriculture grader. This resulted in fifteen possible grades from the five grades of lamb: prime, choice, good, utility and cull. To facilitate carcass grade computations the numbers one through fifteen were assigned each of the fifteen grades from low cull through high prime. This made possible the analyses of variances of these data and the mean carcass grade calculations. The numerical conversion of carcass grades is shown in Appendix A.

Table I shows the number of lambs used in each of the three phases of this study. The numbers are assembled within the three phases of the study according to group (twin or random), sex and selection weight range. It is noted that fewer numbers were used in carcass yield and carcass grade studies than in the average daily gain studies. Carcass grades were lost in the 1955-56 season and a number of carcass data were lost in the 1956-57 season. Also no carcass data were available on females saved as replacements.

TABLE I NUMBER OF LAMBS USED FOR THE AVERAGE DAILY GAIN, CARCASS YIELD AND CARCASS GRADE STUDIES ASSEMBLED ACCORDING TO GROUP, SEX AND SELECTION WEIGHT RANGE

Group	Sex	Selection Weight Range	Average Daily Gain	Carcass Yield	Carcass Grade
Twin	Male	6 Pounds	38	32	24
		4 Pounds	26	22	18
		2 Pounds	16	16	14
	Female	6 Pounds	26	12	8
		4 Pounds	22	12	8
		2 Pounds	14	10	8
Random	Male	6 Pounds	259	193	169
		4 Pounds	125	96	89
		2 Pounds	48	48	46
	Female	6 Pounds	151	44	26
		4 Pounds	85	30	19
		2 Pounds	35	18	15

The analyses of variances for average daily gains, carcass yields and carcass grades within the three different weight ranges for twin pairs and corresponding random groups were computed according to the equal and unequal subclass number methods of Snedecor (1956) pages 237 and 268. The procedure used to set up these data for analyses is explained in more detail in Appendix B. The analyses of variance methods are presented in detail in Appendix C.

RESULTS AND DISCUSSION

The results of the several analyses of variances which were made are presented in Tables XI, XII and XIII for the selected like-sexed twin pairs and in Tables XIV, XV and XVI for the randomly selected like-sexed lambs. These tables are contained in Appendix D. These tabulated data were obtained from the analyses of variances, examples of which are presented in Appendix C.

Efficiency Values Calculated

The twin efficiency values for average daily gain, carcass yield and carcass grade studies were computed by three methods. The methods used were: (A) the comparison of variance components between-twin-pairs/within-pairs of twins, from Dick and Whittle (1951); (B) the method of Carter (1951) and Stormont (1954) which theoretically compares the variance within-pairs of unrelated animals to the variance within-twin-pairs by use of a twin trial only; and (C) the comparison of the variance among-random-lambs/variance within-twin-pairs as suggested by Dick and Whittle (1951) and White (1951). The efficiency values obtained by method B are exactly one larger than those obtained by method A. These three methods will be referred to by letter in the following discussion.

The tabulated data in Tables XI - XVI, Appendix D, were used to make these calculations. The twin efficiency values obtained from these three methods are presented in Table II. The twin efficiency values were

TABLE II TWIN EFFICIENCY VALUES FOR AVERAGE DAILY GAINS, CARCASS YIELDS AND CARCASS GRADES COMPUTED BY THREE METHODS FOR THREE SELECTION WEIGHT RANGES WITHIN BOTH SEXES

Characteristic	Selection Weight Range (Pounds)	Method A $\frac{1}{2}\left(\frac{M_B}{M_W} - 1\right)$	Method B $\frac{1}{2}\left(\frac{M_B}{M_W} + 1\right)$	Method C $\frac{\text{M.S. Among Random Lambs}}{\text{M.S. Within Twin Pairs}}$	Number of Twin Pairs Used
Daily Gain					
Males	6	1.32	2.32	1.50	19
	4	3.05	4.05	3.40	13
	2	4.82	5.82	5.00	8
Females	6	2.04	3.04	2.00	13
	4	1.84	2.84	1.62	11
	2	3.32	4.32	2.14	7
Carcass Yield					
Males	6	.08	1.08	1.17	16
	4	.25	1.25	1.00	11
	2	.40	1.40	1.60	8
Females	6	-.11	.89	.56	6
	4	-.11	.89	.44	6
	2	.00	1.00	.44	5
Carcass Grade					
Males	6	2.71	3.71	1.80	12
	4	1.96	2.96	1.68	9
	2	2.56	3.56	1.58	7
Females	6	2.84	3.84	6.12	4
	4	2.84	3.84	7.48	4
	2	2.84	3.84	9.44	4

calculated by the three different methods so that a comparison could be made between the values obtained.

There were from seven to nineteen pairs of twins used in the daily gain efficiency value studies. Hancock (1951) used ten sets of heifer twins and Theole and Hervey (1952) used twenty-one sets of heifer twins in monozygotic twin cattle growth studies. Hence the number of twin pairs used in this study may be sufficient to give a reasonable indication of twin lamb efficiency values for growth studies.

Twin efficiency estimates obtained by method C showed the efficiency values for male twins to progress steadily upward, as expected, from 1.50 to 5.00 as the selection weight range was restricted from six to two pounds. These estimates were nearer the values obtained by method A than to the values obtained by method B. The efficiency value estimates for females obtained by method C indicated a slight upward trend (but not consistent) as the selection weight range was restricted. Method A produced efficiency estimates for the female twin lambs which were nearer those obtained by method C than by method B.

From five to sixteen pairs of twins were used in the carcass yield studies. Estimates of less than one for both males and females resulted when method A was used. However, larger values were obtained by method B and did correspond fairly uniformly to the values calculated by method C for the male twin pairs but less so for the female twin pairs. When the selection weight range was reduced the efficiency values calculated by method C failed to indicate a consistent upward trend, but when method B was used the efficiency values increased fairly consistently. The efficiency values of less than one calculated by method C for females are probably the result of a random variation due to small numbers used because both members of each female twin set used and all lambs in their corresponding randomly selected groups reached market on the same day. Therefore, there should be little discrepancy due to time allowed for shrink before slaughter. However both members of each male twin set and the lambs in their corresponding randomly selected groups did not always reach market on the same day. Hence some discrepancy may be present in the yield data collected from males since the periods allowed for shrink varied from one to two days.

Four to twelve pairs of twins were used in the carcass grade studies. However, the four pairs of female twins used were all within the two pound selection weight range, hence the restriction of the selection weight range from six to two pounds did not reduce the variance within female twin pairs. The twin efficiency estimates obtained by method C were very different between males and females. The estimates for males were rather low, but the estimates for females were quite high. Methods A and B gave more reasonable estimates of the female twin efficiency values. The efficiency values obtained by each of these two methods did not change with selection weight range since the number of female twin pairs was constant. Method A yielded efficiency estimates for males nearer those obtained by method C than did method B. Only a few random individuals were available for the female carcass grade studies, and the mean squares among these random lambs were rather high (Table XVI, Appendix D). This could have been due to a random error resulting from a small number, and consequently may have contributed to the high efficiency estimates for females since both members of a twin set and all lambs in their corresponding randomly selected groups were marketed on the same day also. Therefore, little discrepancy should be present due to an inconsistency in grading. This discrepancy due to an inconsistency in grading may be present in the carcass grade data obtained from males since both members of each male twin set and the lambs in their corresponding randomly selected groups did not always reach market on the same day.

The formulas presented by Dick and Whittle (1951), method A, and by Carter (1951) and Stormont (1954), method B, were developed due to the necessity for a method to estimate twin efficiency values without having randomly selected pairs of animals on a uniformity trial simultaneously. Hancock (1954) stated that method A had been used in all his twin efficiency value calculations. However, method B may yield a more accurate estimate because method A theoretically fails to subject different pairs of twins to the same environment as twins within a pair are subjected to.

It is difficult to conceive that twin pairs could be less efficient in reducing the animal variation than randomly selected individuals. Values of less than one computed by methods A and B occur when the variation is greater within pairs of twins than between twin pairs. This may result from there being more variation within pairs than between pairs at the time of selection; however, this is not likely. There should be no more variation at the time of selection between pairs of twins or among random individuals than within twin pairs if accurate twin efficiency values are to be computed. This should be true in the data worked with in this study due to the restrictions placed on the selection weights. Yet random variation may have caused some difference.

The most accurate twin efficiency estimate could be made by comparing within-random-pairs variance/within-twin-pairs variance obtained from a uniformity trial in which a control group of randomly selected pairs were selected to correspond to each twin pair used, and the variation between random and twin pairs was equal at the trial's beginning. A rather large number of pairs would be required in this type of trial because there would be considerable chance for a random error in sampling to occur if only a few pairs of randomly selected individuals were used for the comparison. Therefore, in this study the random lamb groups were used rather than a randomly selected pair from each group since there were not a great number of twin sets available. It seems that the mean square comparisons of among-random-lambs/within-twin-pairs (method C) should provide the most accurate estimate of twin efficiency values in this study. This method gives a working estimate, for a researcher may either select like-sexed twin lambs at some arbitrary weight or else a random group of lambs with similar weights. However, twin efficiency estimates do not account for a difference in the degrees of freedom available for the error variance. Hence one may use fewer twin pairs than randomly selected pairs and obtain an error variance with less degrees of freedom similar to that obtained when random pairs are used, or he may use a like number of twin pairs as the random pairs he would otherwise use and obtain a smaller error variance with equal degrees of freedom.

Confidence in the results of the carcass studies is limited. The lambs were weighed off at Ft. Reno and slaughtered by Wilson and Co., Oklahoma City, within one or two days. This difference of one or two days allowed for shrink should affect the yield data for the males since both members of a twin set and their corresponding random groups were not always marketed on the same day. However, this was not so for the females, as previously mentioned. The carcasses were graded by different U.S.D.A. graders and there was a noticeable difference in grades obtained from week to week. This difference may have been manifest in the data obtained from the males but should not be in the females. The numbers of twin pairs available for the carcass studies is relatively small. This also limits the confidence which can be placed in the results of the carcass studies. The daily gain data was personally collected, and the numbers of twin pairs available are somewhat larger. Hence there is reasonable confidence in the efficiency estimates computed for the daily gain studies.

The efficiency values computed in this study indicate that twin lambs may reduce the experimental error, as expected, due to animal variation by approximately one-half in growth studies.

Hancock (1951) found a twin efficiency value of eleven for growth of monozygotic twin heifers on an eighty-four week trial. Theole and Hervey (1952) found efficiency values of six to twenty-four for growth of monozygotic heifer twins. King (1953) found an efficiency value of ten for growth to eighteen months when one-egg cattle twins were compared to contemporary half-sibs in a uniformity trial. The dizygotic twin lambs used in this trial have much lower efficiency values for growth but are much more available than cattle twins. They may prove useful in experiments requiring precise measurements, for King and Donald (1955) concluded that the more precise the problem and technique, the greater the cumulative merit of one-egg twins. This may also be the case for dizygotic twin lambs.

In some experiments a small difference may not be statistically significant even though it is real. In such cases a large number of experimental animals must be used if the results are to be significant. Since large numbers are often not possible the increase in efficiency of the experiment, which may be obtained by use of these dizygotic twin lambs, should aid the experimenter in drawing his conclusions.

The cost of animal research is proportional to the number of experimental animals required. The use of these twin lambs should reduce the number of animals required by approximately one-half. This will amount to a considerable saving in animal unit cost over a period of years.

Not only may these twin lambs be useful in lamb growth studies but also in studies involving ruminants.

Variants Possibly Contained Within the Variances Computed

In this study the variants removed or minimized were sex, initial weight and previous treatment. The effects of the other variants which may be present in the different sources of variation computed are presented in Table III.

Harrington (1957) reported on the rate of gain data obtained from the lambs in this flock in 1955-56 and 1956-57 and found little difference in the rate of gain due to breed. Yet any breed difference that may be present is absent within the twin pairs.

The variation in lambs due to genetic differences, birth weight and maternal influences are present in both the randomly selected lambs and the twin pairs. The genetic variation is less within twin pairs than among random lambs because the twins are full-sibs.

TABLE III A SUMMARY OF THE VARIANTS WHICH MAY BE PRESENT IN THE DIFFERENT SOURCES OF VARIATION COMPUTED IN THIS STUDY

VARIANTS	SOURCES OF VARIATION: Between Groups of Randomly Selected Lambs	Among Randomly Selected Lambs	Between Pairs of Twins	Within Twin Pairs
Breed of dam	Present	Present	Present	Absent
Genetic differences between lambs	Present	Present	Present	Reduced
Birth weight of lambs	Present	Present	Present	Reduced
Maternal influences on lambs	Present	Present	Present	Reduced
Year of trial	Present	Absent	Present	Absent
Age of dam	Present	Absent	Present	Absent
Age of lamb	Present	Present	Present	Absent
Time of trial within year	Present	Absent	Present	Absent

Birth weight of lambs is known to influence the rate of growth (deBaca et al. 1956). However, Chapman and Lush (1932) have shown that there is less variation in birth weight between lambs born in the same litter than between lambs born in different litters.

Maternal influences apparently have some effect on the rate of growth as indicated by Chapman and Lush (1932), Robertson (1950) and King and Donald (1955). These maternal influences are manifest in the random lambs because they have different dams but are reduced within a twin pair since they develop with a common dam simultaneously.

Variation due to year of trial and age of dam are present between groups of randomly selected lambs and between pairs of twins. However, these variants have been removed from the among randomly selected lambs and within twin pairs sources of variation.

Twin pairs and random lamb groups from the three separate years were grouped for analyses. Sidwell and Grandstaff (1949) and Blackwell and Henderson (1955) found that body weights of lambs were influenced by the year in which the lambs were raised. Also that lambs from three year old ewes were heavier at weaning than lambs from two year old ewes. Harrington (1957) found a rather apparent difference in the rate of gain of the lambs reared in the two different seasons. He also found that two year old ewes reared heavier lambs than they had the previous year. This effect on growth rate due to year and age of dam should increase the variance between pairs of twins and a larger efficiency value would probably result when the between twin pairs mean square is used in twin efficiency value calculations. This is the case when methods A and B are used. However, further statistical tests indicated that the mean square between pairs of twins was affected relatively little due to yearly effect. Twin efficiency values calculated by the comparison of mean square among-random-lambs/mean square within-twin-pairs (method C) should not be influenced because the variance due to year and increasing age of dam have been removed from these two sources of variation by the removal of the variance between groups of random lambs and the variance between twin pairs from the total variance in each corresponding analysis of variance.

Variation due to the age of lamb at selection and time of trial within year are absent within twin pairs because both members of a twin set were the same age when they began the trial simultaneously. The time of trial within year is absent among randomly selected lambs because all lambs within a group began the trial simultaneously.

The results reported by Harrington (1957) indicated that lamb growth rate in 1956-57 was relatively linear to 160 days. Wallace (1948) and deBaca et al. (1956) have also reported that lamb growth rate up to approximately 135 days was essentially linear. Hence the age of the lambs at time of selection should have had little effect on the variation in rate of gain among randomly selected lambs. The lambs were all relatively the same age. Yet since twin pairs do not gain as fast as singles (Harrington, 1957) the corresponding groups to the twin pairs probably consisted of younger lambs or lambs that had not gained as fast as the twins prior to selection. A comparison of Tables XI and XIV, Appendix D, gives no indication that the mean gains within selection weight ranges of twin and randomly selected lambs are from different populations except the females selected within six pounds of each other.

However, application of the t-test also gave no indication that these random and twin female groups are from different populations.

The time of trial within year was quite variable, for the twin pairs reached the selection weight ranges at varied times within a six week interval. Therefore, some variation due to time of trial within year was probably included in the variance between pairs of twins.

The effects due to age of lamb and time of trial within year were impossible to remove because the lambs were selected within a weight range on a particular date regardless of age of lamb and period within season. In cases where a twin pair did not reach the selection weight range until late in the season there were few random lambs to use for a comparison.

It is not known what the combined effects of the previous variables discussed had on the carcass yield and grade studies. However, it was found that yearly effect on yield did not influence between pairs mean square for female twins but contributed some to the between pair mean square for male twins. Yearly effect greatly influenced the between pairs of twins mean square for both males and females in the carcass grade studies. This would influence the estimates calculated by methods A and B.

A comparison of means from Tables XII and XV and Tables XIII and XVI, Appendix D, gives no indication that the female twin and randomly selected lambs are from different populations of both carcass yields and carcass grades. However, application of the t-test indicated that the twin and random male lambs may be from two different populations for both carcass yield and grade.

As previously mentioned, the carcass data collected from male lambs in this study are questionable due to some discrepancies which were noted. It is not definitely known what effect these discrepancies had on the variances estimated in the carcass studies on males. These discrepancies did not appear to be present in the data collected from females since both members of each twin pair and their corresponding randomly selected groups were marketed on the same day.

A more accurate estimate of the variances computed may have been obtained from the randomly selected lambs than from the selected twin pairs due to a larger number of random lambs available. The number of twin and random lambs available for the female carcass studies were rather small. Hence the variances computed for the female carcass studies may be less accurate than the variances computed in other phases of the studies made. However, the numbers of lambs available, both twin and random, for the average daily gain studies should be sufficient to give a reasonable indication of the increased efficiency of the experiment obtainable by the use of twin lambs in studies involving daily gain.

SUMMARY

Variances between and within selected like-sexed twin pairs and among randomly selected like-sexed lambs were computed to estimate the experimental efficiency obtainable by the use of twins in growth studies. The lambs were all of similar breeding and were raised under similar conditions at the Fort Reno Experiment Station over a three year period. Nineteen pairs of male and thirteen pairs of female twins were selected within six, four and two pounds of each other when they weighed approximately fifty pounds. Like-sexed random lambs were also selected within the same weight ranges simultaneously. Average daily gains to marketing, carcass yields and carcass grades were obtained. Twin efficiency values were calculated for these characteristics by: (A) a formula which compared the variance components between-twin-pairs/within-twin-pairs; (B) a formula which compared the variance within-pairs of unrelated animals/variance within-twin-pairs by the use of a twin trial only; and (C) the comparison of variance among-random-lambs/variance within-twin-pairs.

The efficiency values calculated by Method C for average daily gains were 1.50, 3.40 and 5.00 for males and 2.00, 1.62 and 2.14 for females when pairs were selected within six, four and two pounds of each other, respectively. Methods A and B yielded similar values for the males but less similar values for the females.

For carcass yield the males had values of 1.17, 1.00 and 1.60 for the six, four and two pound selection weight ranges, but the values for females were all less than one when the C method of calculation was used. Method B yielded similar values for the males and slightly higher values for the females. Method A yielded values dissimilar to the values obtained by the other two methods of calculation.

Carcass grade studies yielded twin efficiency estimates of 1.80, 1.68 and 1.58 for males and 6.12, 7.48 and 9.44 for females for the six, four and two pound selection weight ranges, respectively, when method C was used. The values for females were higher than the values for the males and did not correspond to the two other values obtained by the use of methods A and B. The values for the males were higher when computed by methods A and B.

Confidence is limited in the efficiency estimates for carcass yield and grade due to some discrepancies which were known to be present along with a smaller number of twin sets available for the carcass studies. However, there is reasonable confidence in the daily gain efficiency estimates because these data were personally collected and the number of twin sets is greater.

These twin efficiency estimates, although quite variable, indicate that selected like-sexed twin lambs may be useful in reducing the experimental error of random sampling in studies involving growth.

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APPENDIX

APPENDIX A

CONVERSION OF CARCASS GRADES TO A NUMERICAL SCORE

The method used to convert the carcass grades to a numerical score is listed below. It was necessary to make this conversion so that analyses of variances could be made on the carcass grade data.

Carcass Grade	Numerical Score
Low Cull	1
Average Cull	2
High Cull	3
Low Utility	4
Average Utility	5
High Utility	6
Low Good	7
Average Good	8
High Good	9
Low Choice	10
Average Choice	11
High Choice	12
Low Prime	13
Average Prime	14
High Prime	15

APPENDIX B

PREPARATION OF THE DATA FOR ANALYSES

Before the data could be analyzed it was necessary to record the required information for each lamb used. Appendix Table IV shows the data recorded for one pair of male twins and their corresponding random group which were selected simultaneously. These data were recorded for each of the thirty-two like-sexed twin pairs and their corresponding random groups used in this study.

TABLE IV A PORTION OF THE DATA AS IT WAS PREPARED FOR THE STUDIES ON AVERAGE DAILY GAINS, CARCASS YIELDS AND CARCASS GRADES

Lamb No.	Sex	Weight at Selection (lbs.) 2-17-58	Weight at Beginning of Trial 3-3-58	Final Weight (lbs.)	Date of Final Weight	Average Daily Gain (lbs.)	Carcass Weight (lbs.)	Carcass Yield	Carcass Grade Score
(Twins)									
141	W	50	62	95	5-12-58	.47	49	.52	9
-141	W	49	57	90	5-12-58	.47	43	.48	9
(Randoms)									
51	W	51	58	83	5-12-58	.36	51	.61	11
109	W	51	59	95	4-28-58	.64	49	.52	10
112	W	50	59	88	5-12-58	.41	43	.49	9
-119	W	47	57	92	4-28-58	.63	43	.47	9
193	W	51	62	93	4-28-58	.55	47	.51	9

APPENDIX C

ANALYSES OF VARIANCE METHODS

Appendix Tables V, VI and VII show a portion of the analyses of variances which were made for daily gain, carcass yield and carcass grade studies on both sexes of the like-sexed twin lambs selected within six, four and two pounds of each other. There were eighteen such tables constructed for the twin pairs. Likewise, there were eighteen analyses of variances tables constructed for the randomly selected like-sexed lambs. Appendix Tables VIII, IX and X show a portion of these analyses of variances and correspond to the analysis of the particular study, sex and weight range shown in Appendix Tables X, XI and XII, respectively.

TABLE V ANALYSIS OF VARIANCE OF DAILY GAINS FOR MALE TWINS SELECTED WITHIN SIX POUNDS OF EACH OTHER

Source	Degrees of Freedom	Sum of Squares	Mean Square
Total	37	.2877	
Between pairs of twins	18	.2225	.0124
Within twin pairs	19	.0652	.0034

TABLE VI ANALYSIS OF VARIANCE OF CARCASS YIELDS FOR MALE TWINS SELECTED WITHIN SIX POUNDS OF EACH OTHER

Source	Degrees of Freedom	Sum of Squares	Mean Square
Total	31	.0228	
Between pairs of twins	15	.0134	.0007
Within twin pairs	16	.0094	.0006

TABLE VII ANALYSIS OF VARIANCE OF CARCASS GRADES FOR MALE TWINS SELECTED WITHIN SIX POUNDS OF EACH OTHER

Source	Degrees of Freedom	Sum of Squares	Mean Square
Total	23	41.33	
Between pairs of twins	11	35.33	3.21
Within twin pairs	12	6.00	.50

TABLE VIII ANALYSIS OF VARIANCE OF DAILY GAINS FOR MALE LAMBS RANDOMLY SELECTED WITHIN SIX POUNDS OF EACH OTHER

Source	Degrees of Freedom	Sum of Squares	Mean Square
Total	258	1.3412	
Between groups of lambs	18	.1148	.0064
Among lambs	240	1.2264	.0051

TABLE IX ANALYSIS OF VARIANCE OF CARCASS YIELDS FOR MALE LAMBS RANDOMLY SELECTED WITHIN SIX POUNDS OF EACH OTHER

Source	Degrees of Freedom	Sum of Squares	Mean Square
Total	192	.1945	
Between groups of lambs	15	.0674	.0045
Among lambs	177	.1271	.0007

TABLE X ANALYSIS OF VARIANCE OF CARCASS GRADES FOR MALE LAMBS RANDOMLY SELECTED WITHIN SIX POUNDS OF EACH OTHER

Source	Degrees of Freedom	Sum of Squares	Mean Square
Total	168	346.00	
Between groups of lambs	11	205.00	18.64
Among lambs	157	141.00	.90

APPENDIX D

RESULTS OF THE ANALYSES OF VARIANCES COMPUTED

Appendix Tables XI, XII and XIII contain the results of the analyses of variances which were computed for daily gain, carcass yield and carcass grade studies on the selected like-sexed twin lambs selected within six, four and two pounds of each other. Appendix Tables XIV, XV and XVI contain the results of these studies on the randomly selected like-sexed lambs selected within the same weight ranges.

These results were obtained by the analyses of variance methods presented in Appendix C.

TABLE XI MEAN SQUARES AND CONFIDENCE LIMITS* BETWEEN PAIRS AND WITHIN PAIRS OF TWINS, MEAN GAINS AND STANDARD ERRORS** AND NUMBERS OF LAMBS USED FOR DAILY GAIN STUDIES OF TWIN LAMBS SELECTED WITHIN SIX, FOUR AND TWO POUNDS OF EACH OTHER

Selection Weight Range	Sex	Mean Square and C.L. Between Pairs	Mean Square and C.L. Within Pairs	Mean Gain and S.E.	Number of Animals Used
Six Pounds	Male	$.0071 \leq .0124 \leq .0270$	$.0020 \leq .0034 \leq .0073$	$.5184 \pm .0143$	38
	Female	$.0060 \leq .0117 \leq .0319$	$.0012 \leq .0023 \leq .0059$	$.5023 \pm .0162$	26
Four Pounds	Male	$.0073 \leq .0142 \leq .0388$	$.0010 \leq .0020 \leq .0051$	$.5062 \pm .0174$	26
	Female	$.0059 \leq .0122 \leq .0374$	$.0013 \leq .0026 \leq .0076$	$.4923 \pm .0181$	22
Two Pounds	Male	$.0088 \leq .0202 \leq .0836$	$.0009 \leq .0019 \leq .0071$	$.5081 \pm .0206$	16
	Female	$.0044 \leq .0107 \leq .0516$	$.0006 \leq .0014 \leq .0057$	$.4564 \pm .0201$	14

$$^{*}\text{C.L.} = \frac{\Sigma_x^2}{\chi^2_{0.025}} \leq \sigma^2 \leq \frac{\Sigma_x^2}{\chi^2_{0.975}}$$

$$^{**}\text{S.E.} = \frac{\text{standard deviation}}{\sqrt{N}}$$

TABLE XII MEAN SQUARES AND CONFIDENCE LIMITS* BETWEEN PAIRS AND WITHIN PAIRS OF TWINS, MEAN YIELDS AND STANDARD ERRORS** AND NUMBERS OF LAMBS USED FOR CARCASS YIELD STUDIES OF TWIN LAMBS SELECTED WITHIN SIX, FOUR AND TWO POUNDS OF EACH OTHER

Selection Weight Range	Sex	Mean Square and C.L. Between Pairs	Mean Square and C.L. Within Pairs	Mean Yield and S.E.	Number of Animals Used
Six Pounds	Male	$.0005 \leq .0007 \leq .0021$	$.0003 \leq .0006 \leq .0014$	$.5075 \pm .0011$	32
	Female	$.0003 \leq .0007 \leq .0041$	$.0004 \leq .0009 \leq .0044$	$.5158 \pm .0082$	12
Four Pounds	Male	$.0006 \leq .0012 \leq .0038$	$.0004 \leq .0008 \leq .0022$	$.5064 \pm .0067$	22
	Female	$.0003 \leq .0007 \leq .0041$	$.0004 \leq .0009 \leq .0044$	$.5158 \pm .0082$	12
Two Pounds	Male	$.0004 \leq .0009 \leq .0036$	$.0002 \leq .0005 \leq .0020$	$.5000 \pm .0066$	16
	Female	$.0003 \leq .0009 \leq .0071$	$.0003 \leq .0009 \leq .0052$	$.5160 \pm .0029$	10

$$^{*}\text{C.L.} = \frac{\Sigma_x^2}{X^2_{0.025}} \leq \sigma^2 \leq \frac{\Sigma_x^2}{X^2_{0.975}}$$

$$^{**}\text{S.E.} = \frac{\text{standard deviation}}{\sqrt{N}}$$

TABLE XIII MEAN SQUARES AND CONFIDENCE LIMITS* BETWEEN PAIRS AND WITHIN PAIRS OF TWINS, MEAN GRADES AND STANDARD ERRORS** AND NUMBERS OF LAMBS USED FOR CARCASS GRADE STUDIES OF TWIN LAMBS SELECTED WITHIN SIX, FOUR AND TWO POUNDS OF EACH OTHER

Selection Weight Range	Sex	Mean Square and C.L. Between Pairs	Mean Square and C.L. Within Pairs	*** Mean Grade and S.E.	Number of Animals Used
Six Pounds	Male	$1.16 \leq 3.21 \leq 9.25$	$.26 \leq .50 \leq 1.36$	$10.33 \pm .27$	24
	Female	$.53 \leq 1.67 \leq 22.73$	$.09 \leq .25 \leq 2.08$	$10.50 \pm .33$	8
Four Pounds	Male	$1.26 \leq 2.76 \leq 10.14$	$.26 \leq .56 \leq 1.85$	$10.22 \pm .30$	18
	Female	$.53 \leq 1.67 \leq 22.73$	$.09 \leq .25 \leq 2.08$	$10.50 \pm .33$	8
Two Pounds	Male	$1.44 \leq 3.48 \leq 16.82$	$.25 \leq .57 \leq 2.37$	$10.29 \pm .37$	14
	Female	$.53 \leq 1.67 \leq 22.73$	$.09 \leq .25 \leq 2.08$	$10.50 \pm .33$	8

*C.L. = $\dfrac{\Sigma_x^2}{X^2_{0.025}} \leq \sigma^2 \leq \dfrac{\Sigma_x^2}{X^2_{0.975}}$

**S.E. = $\dfrac{\text{standard deviation}}{\sqrt{N}}$

***See Appendix A.

TABLE XIV MEAN SQUARES AND CONFIDENCE LIMITS* BETWEEN GROUPS AND AMONG INDIVIDUAL LAMBS, MEAN GAINS AND STANDARD ERRORS** AND NUMBERS OF LAMBS USED FOR DAILY GAIN STUDIES OF RANDOM LAMBS SELECTED WITHIN SIX, FOUR AND TWO POUNDS OF EACH OTHER

Selection Weight Range	Sex	Mean Square and C.L. Between Groups	Mean Square and C.L. Among Lambs	Mean Gain and S.E.	Number of Animals Used
Six Pounds	Male	$.0036 \leq .0064 \leq .0139$	$.0043 \leq .0051 \leq .0062$	$.5303 \pm .0045$	259
	Female	$.0029 \leq .0057 \leq .0155$	$.0037 \leq .0046 \leq .0059$	$.4828 \pm .0018$	151
Four Pounds	Male	$.0037 \leq .0071 \leq .0194$	$.0054 \leq .0068 \leq .0091$	$.5254 \pm .0074$	125
	Female	$.0042 \leq .0087 \leq .0267$	$.0032 \leq .0042 \leq .0059$	$.4816 \pm .0020$	85
Two Pounds	Male	$.0038 \leq .0086 \leq .0356$	$.0064 \leq .0095 \leq .0156$	$.5375 \pm .0140$	48
	Female	$.0013 \leq .0030 \leq .0147$	$.0019 \leq .0030 \leq .0055$	$.4740 \pm .0093$	35

$$^{*}\text{C.L.} = \frac{\Sigma_x^2}{X^2_{0.025}} \leq \sigma^2 \leq \frac{\Sigma_x^2}{X^2_{0.975}}$$

$$^{**}\text{S.E.} = \frac{\text{standard deviation}}{\sqrt{N}}$$

TABLE XV MEAN SQUARES AND CONFIDENCE LIMITS* BETWEEN GROUPS AND AMONG INDIVIDUAL LAMBS, MEAN YIELDS AND STANDARD ERRORS** AND NUMBERS OF LAMBS USED FOR CARCASS YIELD STUDIES OF RANDOM LAMBS SELECTED WITHIN SIX, FOUR AND TWO POUNDS OF EACH OTHER

Selection Weight Range	Sex	Mean Square and C.L. Between Groups	Mean Square and C.L. Among Lambs	Mean Yield and S.E.	Number of Animals Used
Six Pounds	Male	$.0025 \leq .0045 \leq .0107$	$.0006 \leq .0007 \leq .0009$	$.5222 \pm .0023$	193
	Female	$.0004 \leq .0009 \leq .0054$	$.0003 \leq .0005 \leq .0009$	$.5136 \pm .0036$	44
Four Pounds	Male	$.0018 \leq .0038 \leq .0116$	$.0006 \leq .0008 \leq .0012$	$.5241 \pm .0035$	96
	Female	$.0002 \leq .0006 \leq .0037$	$.0003 \leq .0004 \leq .0008$	$.5137 \pm .0039$	30
Two Pounds	Male	$.0014 \leq .0032 \leq .0133$	$.0005 \leq .0008 \leq .0013$	$.5281 \pm .0049$	48
	Female	$.0002 \leq .0006 \leq .0048$	$.0002 \leq .0004 \leq .0010$	$.5111 \pm .0049$	18

$$*\text{C.L.} = \frac{\Sigma_x^2}{X^2_{0.025}} \leq \sigma^2 \leq \frac{\Sigma_x^2}{X^2_{0.975}}$$

$$**\text{S.E.} = \frac{\text{standard deviation}}{\sqrt{N}}$$

TABLE XVI MEAN SQUARES AND CONFIDENCE LIMITS* BETWEEN GROUPS AND AMONG INDIVIDUAL LAMBS, MEAN GRADES AND STANDARD ERRORS** AND NUMBERS OF LAMBS USED FOR CARCASS GRADE STUDIES OF RANDOM LAMBS SELECTED WITHIN SIX, FOUR AND TWO POUNDS OF EACH OTHER

Selection Weight Range	Sex	Mean Square and C.L. Between Groups	Mean Square and C.L. Among Lambs	*** Mean Grade and S.E.	Number of Animals Used
Six Pounds	Male	$9.35 \leq 18.64 \leq 53.66$	$.73 \leq .90 \leq 1.14$	$11.00 \pm .11$	169
	Female	$2.59 \leq 8.08 \leq 110.18$	$.92 \leq 1.53 \leq 3.07$	$11.00 \pm .30$	26
Four Pounds	Male	$6.05 \leq 13.25 \leq 48.62$	$.70 \leq .94 \leq 1.31$	$11.01 \pm .15$	89
	Female	$2.03 \leq 6.32 \leq 86.14$	$1.02 \leq 1.87 \leq 4.47$	$11.05 \pm .37$	19
Two Pounds	Male	$.48 \leq 1.15 \leq 5.56$	$.59 \leq .90 \leq 1.46$	$11.07 \pm .14$	46
	Female	$1.24 \leq 3.87 \leq 52.73$	$1.19 \leq 2.36 \leq 6.81$	$11.40 \pm .42$	15

$$^{*}\text{C.L.} = \frac{\Sigma_x^2}{X^2_{0.025}} \leq \sigma^2 \leq \frac{\Sigma_x^2}{X^2_{0.975}}$$

$$^{**}\text{S.E.} = \frac{\text{standard deviation}}{\sqrt{N}}$$

***See Appendix A.

VITA

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