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GENETIC PARAMETERS AMONG PRODUCTION, CARCASS COMPOSITION
AND CARCASS QUALITY TRAITS OF BEEF CATTLE

BY

DARRELL A. BUSCH

A thesis submitted
in partial fulfillment of the requirements for the
degree Master of Science, Major in
Animal Science, South Dakota State
University

1968

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GENETIC PARAMETERS AMONG PRODUCTION, CARCASS COMPOSITION
AND CARCASS QUALITY TRAITS OF BEEF CATTLE

This thesis is approved as a creditable, independent investigation by a candidate for the degree, Master of Science, and is acceptable as meeting the thesis requirements for this degree, but without implying that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Thesis Adviser

Date

Head of the ~~the~~ Major Department

Date

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DAB

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INTRODUCTION

There were 1,642,000 beef cows in South Dakota on January 1, 1967, which was 14 percent higher than the 1961-65 average (South Dakota Crop and Livestock Reporting Service, 1967). These cows were valued at \$307,054,000, a 27 percent increase over the 1961-65 average. There were 390,000 head of cattle and calves on feed on January 1, 1967, a 33 percent increase over 1961 and a 22 percent increase over the 1961-65 average. The sale of cattle and calves has accounted for 44 percent of the cash farm income in South Dakota for the period 1958-65 and is the largest farm enterprise even allowing for the fact that a good share of the crops produced are marketed through beef cattle. The per capita consumption of beef in the United States for the period 1961-66 was 95 pounds, more than all other red meat combined.

These statistics indicate the importance of the beef cattle industry to the state of South Dakota. Any improvement in beef cattle performance or in the quantity and quality of the meat produced would benefit the entire industry from rancher to consumer. Increasing costs of producing beef and the real possibility of competition from meat substitute products should make all segments of the beef cattle industry concerned about ways they can improve their product.

One of the ways to improve beef cattle traits is through selection. The progress that can be made through selection for a certain trait is equal to the heritability of the trait times the selection differential. The selection differential is defined as the difference between the average of the selected animals and the average of the

population from which they came. This is largely dependent on the proportion of animals needed for replacements. Heritability refers to that portion of the observed phenotypic variation due to heredity and in a narrow sense includes only the average effects of the individual genes.

The relationship between two traits observed directly is the phenotypic correlation. The environmental correlation is a measure of the effects common to both traits that originate from environmental effects or non linear gene effects. A genetic correlation defines the relationship between two traits which is due to common genic action of one or more genes. The genetic correlation between two traits is used to determine correlated response. Correlated response is the change in one trait resulting from selection applied to another trait. Correlated response can be either desirable or undesirable depending on the traits involved and the sign of the genetic correlation. Another way to improve beef cattle traits then is to take advantage of desirable correlated response.

The major objectives of this study were to estimate the heritability of beef cattle traits and the genetic, phenotypic and environmental correlations among them.

REVIEW OF LITERATURE

Influence of Age and Weight on Beef Cattle Traits

Differences in age between calves at weaning and marketing result because calving takes place over a two to three month period on most farms and ranches. Feeding cattle on a time constant basis results in differences in weight at marketing. Removing variation due to known sources is important in studying genetic parameters, therefore effects of these environmental sources of variation must be estimated.

Studies with swine at weaning (Whatley and Quaife, 1937) and near market weight (Bywaters and Willham, 1935) have shown that age has a significant influence on weight and that adjusting for age differences by regression is more accurate in removing this influence than adjustment based on individual growth rate. The growth curve of beef cattle has been found to be linear from birth to 155 days of age and from 155 days of age to weaning (Johnson and Dinkel, 1951). Linear adjustment factors developed for each of these growth periods were used by Minyard and Dinkel (1965a) and resulted in a substantial reduction in the regression of weaning weight on age.

Age has been shown to have a significant effect on tenderness of beef by Hiner and Hankins (1949) and Tuma et al. (1962). The cattle in their studies ranged in age from veal calves to 5½ year old cows and from 12 to 90 months of age, respectively.

Swiger et al. (1966) reported that both age and carcass weight had a significant influence on weight of the retail product and fat trim and that carcass weight had a significant influence on these traits

expressed as a percent of carcass weight. Rib-eye area, fat thickness and dressing percent were influenced by both age and weight. Dinkel et al. (1965) reported that calculating ratios and percents involving weight as the denominator does little more than change the sign of the relationship between weight and the trait involved. Therefore the use of a ratio or percent is not a satisfactory weight adjustment procedure.

In general, previous work indicates that age and weight affect certain beef cattle traits and that adjusting for these differences by regression is the most accurate adjustment procedure.

The primary purpose of calculating the regression of the traits studied on age and weight was to use these regression coefficients to adjust traits that were significantly influenced by either factor.

Heritability of Beef Cattle Traits

Many workers have studied the heritability of production traits in beef cattle. These estimates come from a wide variety of environments and experimental populations resulting in a rather wide range of values. Examination of some of the more thorough studies however should give an accurate estimate of the heritability of production traits of beef cattle. Carcass composition traits have not been studied from the standpoint of genetic variation to the same extent. Traits such as dressing percent, rib-eye area and fat thickness have been studied by several workers while cutability and other measures of overall carcass merit have been studied by only a few workers. The heritability of carcass quality traits of beef cattle have been studied by only a few workers except for carcass grade. Estimates reported for these traits

are based on a small number of animals in most cases.

The first heritability estimates known for beef cattle traits were reported by Knapp and Nordskog (1946a). They reported a heritability estimate of 23 percent for weaning weight and extremely high estimates for gain during a post-weaning test period and final feedlot weight (99 and 81 percent, respectively). Since 1946 numerous heritability estimates of growth traits have been reported. Estimates obtained for these traits have varied somewhat but in general, estimates for weaning weight have been about 30 percent and for daily gain and final feedlot weight, slightly higher (45 and 60 percent, respectively). In the past, conformation scores at various ages and other subjective evaluations have received the most emphasis in selection programs. Heritability estimates for conformation scores have been about 35 to 40 percent. Objectives of this study in regard to heritability of beef cattle production traits were to compare estimates for growth and conformation traits to previous estimates and to estimate heritability of some subjective live animal traits not previously studied.

Knapp and Nordskog (1946b) also reported the first heritability estimates for carcass composition traits. They reported a high heritability estimate for rib-eye area (69 percent) and a low estimate for dressing percent (1 percent). More recent estimates have been about 50 percent for dressing percent and 65 and 40 percent for rib-eye area and fat thickness, respectively. Heritability estimates of overall carcass composition traits have not been reported until recently when an estimate of 40 percent for cutability was reported by Cundiff et al.

(1964) and estimates of 65 and 24 percent for retail product and percent retail product, respectively, were reported by Swiger et al. (1965).

Swiger et al. (1966) indicated that carcass weight had a significant influence on all carcass traits. Data used to obtain previous heritability estimates for carcass composition traits have not been adjusted for this influence. Objectives of this study were to obtain heritability estimates for the carcass composition traits after adjustment for carcass weight and to include fat trim and percent fat trim as no previous heritability estimates for these traits have been reported.

Carcass quality traits have received the least attention of all beef cattle traits as far as heritability is concerned. Heritability estimates for carcass grade have been about 50 percent. Estimates for tenderness have averaged about 50 percent, ranging from near zero to 92 percent but have been obtained from relatively small bodies of data. Lean color, lean firmness and marbling have not been studied from the standpoint of heritability except for an estimate of 31 percent for lean color by Shelby et al. (1963) and an estimate of 5 percent for marbling by Harwin et al. (1961).

Heritability of these traits would have to be relatively high in order to warrant selection for them because they would be difficult traits to evaluate on a live animal. Objectives of obtaining heritability estimates for the carcass quality traits were to obtain estimates from a larger body of data than has previously been available and to study lean color, lean firmness and marbling.

Genetic, Phenotypic and Environmental Correlations among Beef Cattle Traits

The first estimates of genetic, phenotypic and environmental relationships among beef cattle production traits were presented by Koch and Clark (1955). Data from 4553 animals were used to obtain the following genetic, phenotypic and environmental correlations: between weaning weight and final weight of 0.54, 0.47 and 0.46; between weaning weight and gain of -.03, -.33 and -.47; between weaning weight and yearling score of 0.23, 0.26 and 0.27; between yearling weight and gain of 0.83, 0.67 and 0.56; between yearling weight and yearling score of 0.49, 0.56 and 0.61; and between gain and yearling score of 0.44, 0.35 and 0.38. Recent studies have also shown that the genetic, phenotypic and environmental correlations between weaning weight and final weight and between daily gain and final weight are relatively high. Most workers have reported positive genetic correlations between weaning weight and daily gain in contrast to the value near zero reported by Koch and Clark (1955). Recent studies of genetic correlations between conformation scores and growth traits have indicated low genetic relationships, some of which have been negative.

One objective of this study in regard to the genetic, phenotypic and environmental correlations among production traits was to compare the values found with previous estimates. These estimates should be more accurate because of the wider source of germ plasm in the data and an opportunity to adjust the data for some interactions that may be important in estimating these relationships. Another objective was to

study the relationships among some subjective scores not previously studied and between these scores and the growth traits.

Several workers have studied phenotypic relationships among carcass traits. These studies were primarily meats oriented and conducted with carcasses of cattle of unknown parentage and in many cases age and management prior to slaughter were also unknown. Several were conducted for the purpose of predicting different measures of carcass merit. In general, these studies have shown that relationships between measures of muscle growth (edible portion, cutability and rib-eye area) and measures of fat (fat thickness, percent kidney fat and fat trim) are high and negative and that edible portion or cutability can be predicted accurately using traits such as carcass weight, fat thickness, rib-eye area and percent kidney fat in multiple regression equations.

High positive genetic correlations have been reported between dressing percent and both fat thickness and rib-eye area. Genetic correlations between overall carcass composition and other carcass composition traits have not been studied until recently. Cundiff et al. (1964) reported that cutability had genetic correlations of 0.28 with rib-eye area and $-.95$ with fat thickness. Swiger et al. (1965) reported genetic correlations of $-.77$ between percent retail product and fat thickness, $-.14$ between weight of the retail product and fat thickness and $-.15$ between weight of the retail product and percent retail product.

Another objective was to study the relationships among carcass traits. In particular to study the relationships between carcass muscle and other carcass traits and to include fat trim for which no previous genetic relationships had been reported. In addition, in view of the significant effect of weight on carcass composition traits, these relationships need to be studied after weight adjustments have been made.

A recent study has indicated that the genetic correlations between growth traits and carcass muscle are high and positive (Swiger et al. 1965) and that selection for growth would bring about the desired increase in carcass muscle. Reports of genetic correlations between subjective live animal evaluation and carcass composition traits are lacking and another objective was to determine whether or not these traits are accurate indicators of carcass meatiness. These scores should not be considered as endpoints in themselves and are useful only if they are accurate indicators of other traits of major economic importance.

Another objective was to study genetic correlations among carcass quality traits and between these traits and other beef cattle traits. Genetic correlations have been reported for carcass grade and indicate high positive relationships with dressing percent and fat thickness and low relationships with measures of growth. Genetic correlations involving other carcass quality traits have not been reported. Phenotypic correlations involving quality traits have been reported by only a few workers and have indicated low relationships with most traits.

SOURCE OF THE DATA

Data for this study were obtained from 679 grade Hereford steers raised to weaning on 18 private ranches in the state of South Dakota over an 8 year period from 1958 to 1965. Figure 1 gives the location and number of calves from each ranch that were included in this study. The 18 ranches represent almost every area of the state and as a result, wide variations exist in the climate and management procedures under which the calves were raised. The ranches were essentially rangeland operations with the exception of ranches 5 and 9.

The steers were the progeny of 70 sires, 30 of which were raised by the South Dakota Agricultural Experiment Station and leased to the cooperating ranches. These 30 bulls sired 345 of the steers, while the remaining 40 bulls that were raised by purebred breeders and purchased by the cooperators, sired 334 of the steers. Both Experiment Station and privately owned bulls were used the same year with the cows being assigned randomly to breeding groups.

Twenty-one of the 30 sires produced by the Experiment Station were inbred with the highest inbreeding coefficient being 32 percent. The average inbreeding coefficient of the 21 sires was 11.2 percent and the average of all 70 sires was 3.4 percent.

The steers were purchased at weaning and were selected only to minimize variation in weaning age between and within sire groups from the same ranch. The calves were trucked to Brookings and placed in a commercial type feedlot.

Ranch number	Name	Address	Number of calves
5	Ray Barnett	Brookings	28
6	Moncur's Inc.	Miller	156
7	Charles Droz	Miller	28
9	Oliver Stemsrud	Stockholm	34
10	Herbert Moak	Selby	23
11	Cottonwood Field Station	Cottonwood	28
12	Art Schafer	Boxelder	8
13	Penn Brothers	Buffalo	36
14	Ray Anderson	Buffalo	29
15	Nagel Brothers	Gettysburg	41
17	John Leiferman	Kimball	33
19	Bernard Beastrom	Blunt	23
20	Oakley Eide, Jr.	Burke	38
22	Walter Feugen	Pukwana	28
23	Gay Hatle	Meadow	20
27	F. O. Butler Inc.	Hot Springs	70
28	Earnest Leiferman	Kimball	34
30	Wooster Brothers	Reliance	22

Figure 1. Name, Address, Location and Number of Calves from each Ranch

Feeding and Management Practices

The feeding and management practices in the feedlot varied somewhat from year to year and the details concerning these practices will be discussed for each year. Year refers to the year in which the steers were marketed. Salt and minerals were fed free choice during the entire feeding period each year. Alfalfa hay was fed free choice and amounted to approximately 4 pounds per head daily most years.

1959. Initial weights were taken on December 5 and final weights on August 21 for a feeding period of 259 days. The grain mixture at the start of the feeding period was 50 percent corn and 50 percent oats. This ration was fed until late March when the oats content was gradually reduced until a full feed of corn was reached about the middle of April. The steers were implanted with 36 mg. of diethylstilbestrol on April 24. The steers were marketed in 2 groups, on August 24 and 31.

1960. Initial weights were taken on November 24 and final weights on August 20 for a feeding period of 270 days. The calves were started on a ration consisting of half corn and half oats. This grain mixture was fed until late March when the oats content was gradually reduced until the calves were on a full feed of corn by the middle of April. The steers were marketed in three groups, on August 22, 29 and September 6. The steers were implanted with 24 mg. of diethylstilbestrol on February 8 and May 17.

1961. Initial weights were taken on December 6. The feeding period lasted 237 days with final weights being taken on July 31. The steers were marketed in 2 groups, on August 14 and 16. The grain

mixture at the start of the period was 50 percent corn and 50 percent oats and was full fed. Dynafac was added to the ration at a rate of 2 grams per head daily. The corn content in the ration was increased 5 percent each month until the mixture was 75 percent corn. Vitamin A was added to the ration for the last month. One half of the steers in each sire group were implanted with 24 mg. of diethylstilbestrol on December 8 and again in the middle of the trial. The other half of the steers in each sire group were not implanted either time. Each treatment group was considered a separate year for analysis purposes.

1962. Initial weights were taken on December 8 and final weights were taken on July 31, for a feeding period of 237 days. The steers were implanted with 24 mg. of diethylstilbestrol on January 8 and April 27. The grain mixture was 50 percent corn and 50 percent oats at the beginning of the trial and the corn content was increased 5 percent per month until the ration contained 90 percent corn. Marketing was done in 2 groups, on August 13 and 20.

1963. Initial weights were taken on November 20 and final weights on August 21 for a feeding period of 274 days. They were slaughtered in 2 groups, on August 27 and 28. The grain mixture at the start of the feeding period contained 50 percent corn and 50 percent oats with the corn being increased 10 percent each month until the ration contained 80 percent corn. All steers were implanted with 24 mg. of diethylstilbestrol on February 22. Vitamin A was added to the ration to provide an adequate level.

1964. Initial weights were taken on December 12 and final weights on July 28 for a 223 day feeding period. The cattle were slaughtered in 2 groups, on August 11 and 12. The grain mixture at the beginning was 50 percent oats and 50 percent corn. The corn was increased 10 percent per month until 80 percent of the grain mixture was corn. The steers were implanted with 24 mg. of diethylstilbestrol on December 31 and May 11. Aureomycin was fed at the rate of 75 mg. per head daily and Vitamin A at the rate of 10,000 I. U. per head daily.

1965. Initial weights were taken shortly after the steers arrived in the feedlot and before having access to feed or water. The date that the initial weights were taken ranged from October 8 to November 24. The steers were sold by ranch groups when the ranch average weight was near 1000 pounds. Marketing dates ranged from June 21 to August 16. The grain mixture at the start of the feeding period was 80 percent oats and 20 percent corn. The corn content was gradually increased until it reached 80 percent on April 2. Vitamin A was fed at the rate of 2000 I. U. per hundred pounds of body weight daily and Aureomycin was fed at the rate of 70 mg. per head daily. All steers were implanted with 24 mg. of diethylstilbestrol on January 20 and May 25.

1966. Initial weights were taken in the same manner as in 1965. This date ranged from October 2 to November 20. The steers were marketed by ranch groups in the same manner as in 1965. This date ranged from July 6 to August 10. The grain mixture at the start of the feeding period was 80 percent oats and 20 percent corn. The corn content was gradually increased until the ration contained 80 percent

corn on April 8. All steers were implanted with 24 mg. of diethylstilbestrol on December 29 and May 9. Vitamin A was added at the rate of 2000 I. U. per hundred pounds of body weight daily and Aureomycin was added at the rate of 70 mg. per head daily.

Production Traits Studied

Weaning Weight. All calves were weighed on their respective ranches at weaning. This weight was adjusted for age using the factors derived by Johnson and Dinkel (1951) and adjusted for age of dam using the additive correction factors derived by Minyard and Dinkel (1965a).

Daily Gain. This trait was calculated by dividing the total gain during the feeding period by the number of days on feed. Both the initial and final weight used to calculate daily gain were taken after a 12 hour period without feed and water.

Final Weight. This was the shrunk weight taken at the end of the feeding period.

Final Conformation. Shortly before the animals were slaughtered, members of the Animal Science staff subjectively scored the animals for conformation using a coding system from 1 to 17 where 1 denoted a lack of desirable conformation and 17 denoted excellent conformation.

Final Muscling. Shortly before the animals were slaughtered in 1962-66, members of the Animal Science staff subjectively scored the animals for indications of muscling. The same coding system as that used for conformation scores was used with 1 representing poor muscling and 17 representing excellent muscling.

Final Condition. This was a subjective score which indicated the amount of finish on the animals. The coding system used ranged from 1 to 14 with 1 being low condition and 14 being high condition or a high degree of finish.

Slaughter Grade. An estimate of the carcass grade of each animal within one-third of a grade was made by a buyer at the packing plant prior to slaughter. A coding system was used where 17 represented average good, 20 represented average choice and 23 represented average prime.

Estimated Fat Thickness. An estimate of fat thickness at the 12th rib was made by members of the Animal Science staff shortly before the animals were marketed in 1961-66.

Estimated Rib-eye Area. An estimate of the rib-eye area in square inches at the 12th rib was made by Animal Science staff members shortly before marketing in 1961-66.

Carcass Composition Traits Studied

Dressing Percent. This trait was determined by dividing the chilled carcass weight by the slaughter weight taken in the feedlot just prior to being trucked to the packing plant following a 12 hour period without feed or water.

Fat Thickness. This trait was obtained as an average of three measurements from an acetate tracing taken at the 12th rib (Naumann, 1951).

Rib-eye Area. This trait was determined by measuring the acetate tracing mentioned above with a polar compensating planimeter.

Percent Kidney Fat. A subjective estimate of the amount of kidney and pelvic fat expressed as a percent of carcass weight was made by a representative of the U.S.D.A. Meat Grading Service.

Cutability. The estimated percent retail cuts were calculated from the following equation (Murphy et al., 1960): estimated percent retail cuts = $52.56 - 4.95 (\text{single fat thickness, in.}) - 1.06 (\text{estimated kidney fat, \%}) + 0.682 (\text{rib-eye area, sq. in.}) - 0.008 (\text{carcass weight, lb.})$.

Edible Portion. This trait was determined for the 1962-64 steers by the University of Illinois Central Food Stores. It was derived by summation of all individual retail cuts and lean trim from the right side of the carcass. The retail cuts were trimmed to an external fat cover of three-eighths of an inch and were practically boneless except for a small amount of bone in the rib and loin cuts. The lean trim contained 25-30 percent fat. Edible portion for the 1959-61 steers was estimated using the following multiple regression equation (Busch et al., 1968): kilograms of edible portion from one side of the carcass = $21.05 + 0.2698 (\text{chilled carcass weight, kg.}) - 0.4188 (\text{separable fat in the 9-10-11 rib cut, \%}) + 0.0889 (\text{rib-eye area, cm.}^2)$. Data from the 1962-64 steers were used to develop this multiple regression prediction equation which accounted for 89 percent of the variation in edible portion. The equation estimates the kilograms of edible portion which was converted to pounds for this study. Edible portion for the 1965-66 steers was estimated using the following multiple regression equation (Tuma et al., 1967): pounds of edible portion from one side of the

carcass = $6.04 + 0.2381$ (chilled carcass weight, lb.) - 15.7024 (single fat thickness, in.) - 0.4498 (untrimmed round weight, lb.) + 1.7359 (edible portion of the round, lb.) - 1.0347 (pelvic and kidney fat, lb.). This multiple regression prediction equation was developed from data taken on the 1962-63 steers and the equation was tested with data from the 1964 steers. The equation accounted for 94 percent of the variation in edible portion in the 1962-63 steers and was slightly more accurate when tested with the 1964 data. Reference to edible portion refers to edible portion either actual or estimated.

Percent Edible Portion. This trait was derived by dividing the weight of the edible portion by one-half of the chilled carcass weight. Reference to percent edible portion refers to percent edible portion either actual or estimated.

Fat Trim. This trait was determined for the 1962-64 steers from actual cutout data obtained at the Central Food Stores, University of Illinois. Fat trim was not available for the 1959-61 steers or for the 1965-66 steers. Therefore, a preliminary analysis was conducted to determine whether fat trim could be accurately predicted using multiple regression techniques. Data from the 1962-64 steers were used for this analysis which was conducted on a within ranch-year-sire subclass basis. Two different multiple regression prediction equations were developed because certain traits that were accurate indicators of fat trim were not available in both groups where actual fat trim was not available. The following equation ($R^2 = 0.81$) was developed to estimate fat trim for the 1959-61 steers: pounds of fat trim from one side of the carcass

= - 68.24 + 0.1452 (chilled carcass weight, lb.) + 14.1523 (fat thickness, in.) + 1.0322 (separable fat in the 9-10-11 rib cut, %).

The following equation ($R^2 = 0.87$) was developed to estimate fat trim for the 1965-66 steers: pounds of fat trim from one side of the carcass = - 22.04 + 0.0616 (chilled carcass weight, lb.) + 21.8106 (single fat thickness, in.) + 1.8152 (kidney and pelvic fat, lb.) + 2.2140 (cod fat, lb.) + 1.8062 (round fat trim, lb.). Reference to fat trim refers to fat trim either actual or estimated.

Percent Fat Trim. This trait was determined by dividing the weight of the fat trim by one-half of the chilled carcass weight. Reference to percent fat trim refers to percent fat trim either actual or estimated.

Carcass Quality Traits Studied

Carcass Grade. This trait was determined by a representative of the U.S.D.A. Meat Grading Service. The coding system used for slaughter grade was also used for carcass grade.

Marbling. An estimate of the intra-muscular fat deposition of the longissimus dorsi muscle at the 12th rib. The estimate was made by a representative of the U.S.D.A. Meat Grading Service using classifications from devoid to extremely abundant, coded from 1 to 12 respectively.

Tenderness. Steaks were taken from the area of the 12th rib at the South Dakota State University Meats Laboratory about 10 days after the steers were slaughtered. The steaks were then frozen until the tenderness evaluation was made. The steaks were thawed at room

temperature and cooked with dry heat at 325 degrees Fahrenheit in a gas oven. The steaks were removed from the oven when the internal temperature reached 150 degrees Fahrenheit. Three cores, 1 inch in diameter, were removed from the medial, central and lateral areas of the muscle. Two shear values were obtained on each of the cores with a Warner-Bratzler shearing device. The average of all six values was taken as the measure of tenderness. Tenderness was measured as pounds of force required to shear the one inch core, therefore a lower value indicates more tender meat. This trait was measured on the 1962-66 steers.

Lean Color. This trait was a subjective evaluation of the relative color of the muscle at the 12th rib, ranging from very dark red to dark pink, coded from 1 to 7, respectively. This evaluation was made by a representative of the U.S.D.A. Meat Grading Service on the 1962-66 steers.

Lean Firmness. This trait was a subjective evaluation of the firmness of the muscle at the 12th rib, ranging from extremely soft to very firm, coded from 1 to 7, respectively. This evaluation was made by a representative of the U.S.D.A. Meat Grading Service on the 1962-66 steers.

STATISTICAL PROCEDURES

Effects of Age on Production Traits, Tenderness, Lean Color and Lean Firmness

Linear and quadratic effects of initial age on the production traits, tenderness, lean color and lean firmness were studied using partial regression techniques. The main objective of estimating these effects was to adjust the data prior to obtaining heritability estimates and genetic, phenotypic and environmental correlations. Partial regression refers to the change in a given dependent variable (Y_i) associated with a unit change in the independent variable (X_i) with all other X_i 's held constant. The linear and quadratic effects of age were calculated simultaneously on an intra year-ranch-sire subclass basis and nonsignificant ($P > .05$) quadratic regressions were dropped from the model and the linear regressions recalculated.

Effects of Age and Weight on Carcass Composition Traits, Carcass Grade and Marbling

Linear and quadratic effects of initial age and carcass weight on the carcass composition traits, carcass grade and marbling were studied using partial regression techniques. These effects were studied simultaneously on a within subclass basis and nonsignificant ($P > .05$) quadratic regressions were dropped from the model. In subsequent calculations nonsignificant ($P > .05$) linear regressions were dropped from the model.

Heritability Estimates

The complete model for the analysis of these data is as follows:

$$Y_{ijkl} = \mu + Y_i + R_j + YR_{ij} + S:R_{jk} + YS:R_{ijk} + e_{ijkl} \text{ where:}$$

μ = the population mean

Y_i = the effect common to all animals in the i^{th} year

R_j = the effect common to all animals from the j^{th} ranch

YR_{ij} = the interaction effect of the i^{th} year and the j^{th} ranch

$S:R_{jk}$ = the effect common to all animals out of the k^{th} sire
within the j^{th} ranch

$YS:R_{ijk}$ = the interaction effect of the i^{th} year and the k^{th}
sire within the j^{th} ranch

e_{ijkl} = the random effect peculiar to the l^{th} individual out of
the k^{th} sire within the j^{th} ranch in the i^{th} year that
causes its observation to deviate from the expected.

As shown by the mean square expectations (table 1), year and ranch effects were regarded as fixed and the sire within ranch and the sire x year within ranch interaction effects as random variables. The most desirable analysis of these data would be to complete a Method 3 analysis of Henderson (1953). However, since the programs were not available for an IBM 1620 Data Processing System to compute the k values for Henderson's Method 3, the adjusted sum of squares for sires within ranch were calculated by Henderson's Method 2 (1953) according to the following steps:

1. The equations for the ranch-sire subclasses were absorbed into the equations for years and the year x ranch interaction equations.

TABLE 1. ANALYSIS OF VARIANCE AND MEAN SQUARE EXPECTATIONS OF THE COMPLETE MODEL FOR THE ENTIRE SET OF DATA

Source of variation	Degrees of freedom	Mean square expectations
Year (Y)	8	$\sigma_e^2 + k_8\sigma_y^2$
Ranch (R)	25	$\sigma_e^2 + k_5\sigma_{ys:r}^2 + k_6\sigma_{s:r}^2 + k_7\sigma_r^2$
YR	41	$\sigma_e^2 + k_4\sigma_{yr}^2$
Sire:Ranch (S:R)	75	$\sigma_e^2 + k_2\sigma_{ys:r}^2 + k_3\sigma_{s:r}^2$
YS:R	35	$\sigma_e^2 + k_1\sigma_{ys:r}^2$
Error	674	σ_e^2

In order to fit the year x ranch interaction equations at least one ranch must be present in all years, and all ranches must be present in at least one year. It can be seen from the distribution of year-ranch subclasses (table 2) that these restrictions do not hold. However by arranging the data into sets of ranches it is possible to have a row and column filled in each set. In addition, in order to fit the year x ranch interaction equations on a within sire basis, it has to be assumed that year effects can be estimated on a within sire basis in each ranch. This assumption does not hold in these data because sire effects are completely confounded with year effects in some ranches.

Due to this confounding, some of the year-ranch subclasses were eliminated (table 2) before the data were arranged into sets (table 3). Arranging the data into sets results in some of the degrees of freedom for the year x ranch interaction being included in the year equations. However, since the primary purpose of forming sets was to adjust other effects for the year and the year x ranch interaction effects this does

TABLE 2. DISTRIBUTION OF FILLED YEAR RANCH SUBCLASSES (X = SUBCLASSES ANALYZED, X* = SUBCLASSES REMOVED) FOR THE ENTIRE SET OF DATA

Ranch	Year								
	1959	1960	1961U	1961T	1962	1963	1964	1965	1966
5		X	X	X	X			X*	
6		X	X	X	X	X	X	X	X
7	X*	X	X	X	X*				
8	X*								
9	X	X	X	X	X*				X*
10	X	X							
11	X	X							
12			X	X					
13		X	X	X					
14			X	X	X				
15			X	X	X	X			
17		X	X	X	X		X*	X*	X*
19		X	X	X					
20			X	X	X	X			
21		X*							
22					X	X			
23					X		X		
25						X*			
26							X*		
27						X	X	X	X
28							X	X	X
29							X*		
30								X	X
31								X*	
33									X*
34								X*	

not matter (Harvey, 1967). The sums of squares for years and the year x ranch interaction were pooled over the 4 sets to get a more powerful test of these effects. However, the appropriate error term is not the mean square for residual from this analysis since it contains the within smallest subclass variance plus the year x sire within ranch interaction, that is:

$$\text{Residual } (E_1) = E:\text{YRS} + \text{YS}:\text{R}$$

TABLE 3. ARRANGEMENT OF DATA INTO SETS

Ranch	Year									Set number
	1959	1960	1961U	1961T	1962	1963	1964	1965	1966	
7		X	X	X						1
9	X	X	X	X						
10	X	X								
11	X	X								
5		X	X	X	X					2
6		X	X	X	X	X	X	X	X	
14			X	X	X					
15			X	X	X	X				
17		X	X	X	X					
20			X	X	X	X				
22					X	X				
23					X		X			
27						X	X	X	X	3
28							X	X	X	
30								X	X	
12			X	X						4
13		X	X	X						
19		X	X	X						

2. The within year-ranch-sire sum of squares (E_2) was calculated and the sum of squares for the year x sire within ranch interaction derived by subtracting E_2 from E_1 . Year effects, the year x ranch interaction and the year x sire within ranch interaction were all tested with the within year-ranch-sire mean square.

3. If the year x sire within ranch interaction was non-significant ($P > .05$), the procedure followed was to complete a Method 2 of Henderson from the analysis in (1) by obtaining an adjusted sum of squares for sires within ranch.

To obtain the components of variance required to estimate heritability, the intra ranch variance must be separated into 2 classes: (B), the within sire mean square, representing the variance between

animals sired by the same bull; and (A), the additional variance between animals sired by different bulls. The components A and B were obtained from an analysis of variance as shown in table 4. The expected value of the between sires mean square is $B + k_0 A$, where k_0 is the average number of progeny in each sire group. The mean squares in table 4 were adjusted for year effects and the year x ranch interaction effect.

The genic deviations of half-sibs in a random mating population are correlated by one fourth, the dominance deviations are uncorrelated and the epistatic deviations are correlated by a small amount depending on the number of genes involved in such effects (Lush, 1948). If the assumptions are made that environmental and non-additive genetic deviations between half-sibs are not correlated, that genetic environmental interactions are non existent, and A is composed of genic variance only, then A is equal to $1/4 V_G$ and B is equal to $3/4 V_G + V_E$. The genetic (V_G), environmental (V_E) and phenotypic (V_P) variances can be derived as follows: $V_G = 4A$; $V_E = B - 3A$; and $V_P = V_G + V_E$.

The use of inbred sires allows half-sib progeny to receive some additional common inheritance. According to Dickerson (1942) the use of $\frac{4}{1+f}$, instead of 4, in deriving V_G will correct for this influence where f is the average inbreeding coefficient of all sires used.

The within sire mean square would also be affected since the genetic variance derived from the sire component would be greater than $1/4$. This effect may be removed from the environmental component by the use of $\frac{1-r}{r}$ instead of 3, where r is the relationship among members of

TABLE 4. ANALYSIS OF VARIANCE FOR OBTAINING PATERNAL HALF-SIB HERITABILITY ESTIMATES

Source of variation	Composition of the mean square
Between sires	$B + k_o A$
Within sires	B

a half-sib family. Although the average inbreeding of all sires used was small (.032), these corrections were made. According to these assumptions, the formula for estimating heritability becomes:

$$h^2 = \frac{V_G}{V_P}$$

The standard errors of the paternal half-sib heritability estimates were computed as follows (Hazel and Terrill, 1945):

$$S_{h^2} = \frac{B(B + k_o A)}{(A + B)^2 \sqrt{1/2(k_o - 1) k_o n}}$$

Genetic, Phenotypic and Environmental Correlations

The methods used in deriving the genetic, phenotypic and environmental correlations were the same as those used to calculate the heritability estimates.

An estimate of the relationship between two traits is obtained from the components of variance and covariance. The following equation shows how these relationships were derived:

$$r_{X_1 X_2} = \frac{CV_{X_1 X_2}}{\sqrt{(V_{X_1}) (V_{X_2})}}$$

V_{X_1} and $CV_{X_1 X_2}$ are either genetic, phenotypic or environmental components of variance or covariance. According to Falconer (1960), estimates of genetic correlations are usually subject to large sampling errors. The standard errors of the genetic correlations were calculated according to the method of Tallis (1959).

RESULTS AND DISCUSSION

Effect of Age on Production Traits, Tenderness, Lean Color and Lean Firmness

Linear and quadratic partial regression coefficients for the production traits, tenderness, lean color and lean firmness on initial age are shown in table 5. Initial age was coded by dividing by 10, thus the regression coefficients represent a change per 10 days of age.

The quadratic effect of age was nonsignificant for all traits (table 5). The F values were less than 1.10 for all traits except final conformation (1.37), slaughter grade (2.26) and final condition (1.91). When the quadratic effect of age was dropped from the model, the linear effect of age was significant for some traits (table 5).

Age had a highly significant ($P < .01$) positive effect on estimated rib-eye area, final weight and final condition and a significant ($P < .05$) positive effect on final conformation. This agrees with Shelby et al. (1963) who found that final weight increased with age and Schalles and Marlowe (1967) who found that final type score increased with age. Age had a significant negative effect on lean color indicating that older animals have darker colored lean. This is in disagreement with Shelby et al. (1963) who found that age had no effect on lean color.

The effect of age on final muscling, daily gain, slaughter grade and estimated fat thickness was nonsignificant with F values less than 1.10 except for estimated fat thickness (2.73). Shelby et al. (1963) found that daily gain and slaughter grade decreased with increasing age

TABLE 5. REGRESSION OF PRODUCTION TRAITS, TENDERNESS, LEAN COLOR AND LEAN FIRMNESS ON INITIAL AGE

Trait	n	Regression coefficients		
		Initial age/10		Initial age/10
		Linear	Quadratic	Linear only
Daily gain	679	-.0218	0.0004	-.0056
Final weight	679	-5.9170	0.4155	11.6272**
Final conformation	679	-.2985	0.0091	0.0862*
Final muscling	341	0.0297	-.0001	0.0244
Slaughter grade	679	-.3335	0.0087	0.0349
Estimated fat thickness	529	-.0237	0.0007	0.0075
Estimated rib-eye area	529	-.0359	0.0027	0.0784**
Final condition	679	-.2955	0.0098	0.1185**
Lean color	341	-.1319	0.0014	-.0711*
Lean firmness	341	-.2032	0.0049	0.0111
Tenderness	341	-1.0239	0.0232	-.0053

* $P < .05$ ** $P < .01$

which is in disagreement with these results. Schalles and Marlowe (1967) however, found that age had little influence on daily gain.

The influence of age was nonsignificant (F values less than 1.10) on lean firmness and tenderness. Hiner and Hankins (1949) and Tuma et al. (1962) found that tenderness decreased with age on animals that ranged in age from veal calves to 5 1/2 year old cows and from 12 to 90 months, respectively. Field et al. (1966) working with animals from 300 to 700 days of age, found that tenderness was not influenced by age which is in agreement with the results in this study.

Final weight, final conformation, estimated rib-eye area, final condition and lean color were adjusted to an initial age of 220 days using the regression coefficients shown in table 5.

Effect of Age and Carcass Weight on Carcass Composition Traits, Carcass Grade and Marbling

Linear and quadratic partial regression coefficients for the carcass composition traits, carcass grade and marbling on initial age and carcass weight are shown in table 6. Initial age and carcass weight were coded by dividing by 10, thus the regression coefficients represent a change per 10 days of age or 10 pounds of carcass weight.

The quadratic effect of age on all traits was nonsignificant and dropped from the model in subsequent calculations. The F values for this effect were less than 1.10 for all traits except rib-eye area (1.61) and cutability (2.72).

The quadratic effect of carcass weight was nonsignificant for all traits except dressing percent ($P < .05$) and percent fat trim ($P < .05$). For both of these traits the linear regression coefficient was positive while the quadratic regression coefficient was negative, indicating that these two traits increase at a decreasing rate with increased carcass weight. This is in disagreement with Swiger et al. (1966) who reported that carcass weight had a negligible curvilinear effect on percent fat trim. Other analyses of these data (unpublished) have shown that the quadratic effect of carcass weight on percent fat trim for the 3 years where actual fat trim was obtained was nonsignificant, indicating that one of the equations used to predict fat trim may have introduced some curvilinearity when fat trim is expressed as a percent of carcass weight. Another possible explanation is that there were more degrees of freedom in this analysis to detect curvilinearity.

TABLE 6. REGRESSION OF CARCASS COMPOSITION TRAITS, CARCASS GRADE AND MARBLING ON INITIAL AGE AND CARCASS WEIGHT

Trait	n	Regression coefficients			
		Initial age/10		Carcass weight/10	
		Linear	Quadratic	Linear	Quadratic
Dressing percent	679	a	a	0.4101**	-.0024*
Carcass grade	679	0.0859*	a	0.0559**	a
Rib-eye area	679	a	a	0.0738**	a
Fat thickness	679	a	a	0.0143**	a
Marbling	679	0.0734**	a	0.0477**	a
Edible portion	679	a	a	2.4451**	a
Percent edible portion	679	a	a	-.2235**	a
Fat trim	679	a	a	2.0430**	a
Percent fat trim	679	a	a	0.9123**	-.0050*
Percent kidney fat	529	a	a	0.0268**	a
Cutability	529	a	a	-.1341**	a

a nonsignificant ($P > .05$) and dropped from the model

* $P < .05$

** $P < .01$

Figure 2 shows the relationship of dressing percent to carcass weight and Figure 3 shows the relationship of percent fat trim to carcass weight. The regression lines shown appear to be a good fit for the data in both figures. F values for the quadratic effect of carcass weight on the other traits were less than 1.10 except for carcass grade (1.84) and percent edible portion (2.57).

Rib-eye area, fat thickness, edible portion, percent edible portion, fat trim, percent kidney fat and cutability were significantly ($P < .01$) influenced by the linear effect of carcass weight while the linear effect of age was nonsignificant for all of these traits. F values for the linear effect of age were less than 1.10 for all of these traits except fat thickness (2.48). Cutability and percent edible portion decreased with increasing carcass weight while the

Figure 2. The Relationship of Dressing Percent to Carcass Weight

Figure 3. The Relationship of Percent Fat Trim to Carcass Weight

other traits increased with increasing carcass weight. This is in agreement with the results of Damon et al. (1960), Goll et al. (1961), Swiger et al. (1966) and Riley and Schoonover (1967).

Carcass grade and marbling were the only traits significantly influenced by both age and carcass weight. The regression coefficients indicate that when carcass weight or age is held constant, older or heavier animals respectively, have more marbling and a higher carcass grade. Harwin et al. (1961) and Swiger et al. (1966) both reported that marbling increased with age and Damon et al. (1960) reported that carcass grade increased with carcass weight. However, none of these workers studied the effect of age and weight simultaneously on these traits as was done in this study.

Carcass grade and marbling were adjusted to a carcass weight of 600 pounds and to an initial age of 220 days prior to any further calculations in this study. All other traits were adjusted to a carcass weight of 600 pounds. The partial regression coefficients (table 6) were used to make these adjustments.

Year Effects, the Year x Ranch Interaction Effect and the Year x Sire within Ranch Interaction Effect

All traits were not measured every year so 3 different groups were analyzed in order to obtain all of the genetic parameters.

1959-66 Data. The analysis of variance for year effects, the year x ranch interaction effect and the year x sire within ranch interaction effect for the traits measured every year are shown in table 7.

TABLE 7. YEAR, YEAR X RANCH INTERACTION, YEAR X SIRE WITHIN RANCH INTERACTION AND RESIDUAL
MEAN SQUARES OF THE TRAITS STUDIED IN ALL YEARS

Trait	Source of variation			
	Year ^a	Year x ranch interaction ^b	Year x sire within ranch interaction ^c	Residual ^d
Weaning weight	3472**	3625**	1808	1643
Daily gain	0.3393**	0.0672*	0.0503	0.0405
Final weight	42955**	9941**	4963	4770
Final conformation	7.85**	3.88**	2.08	1.72
Slaughter grade	4.05**	2.44**	0.98	0.96
Final condition	12.63**	2.39*	1.60	1.43
Dressing percent	9.44**	2.50**	1.57	1.37
Carcass grade	14.05**	2.22**	0.99	0.98
Rib-eye area	3.56**	1.11	0.99	0.80
Fat thickness	0.0514**	0.0286	0.0219	0.0198
Marbling	10.60**	1.19**	0.69	0.66
Edible portion	224**	31	33	30
Percent edible portion	21.77**	3.77	3.83	3.33
Fat trim	433**	44	49	46
Percent fat trim	50.53**	4.70	5.55	4.97

a degrees of freedom = 15

b degrees of freedom = 26

c degrees of freedom = 41

d degrees of freedom = 527

* $P < .05$

** $P < .01$

Year effects were highly significant ($P < .01$) for all traits in this analysis. The year x ranch interaction effect was highly significant ($P < .01$) for weaning weight, final weight, final conformation, slaughter grade, dressing percent, carcass grade and marbling; significant ($P < .05$) for daily gain and final condition and nonsignificant for rib-eye area, fat thickness, edible portion, percent edible portion, fat trim and percent fat trim.

The sire x year within ranch interaction was nonsignificant for all traits.

1961-66 Data. The traits studied in this group in addition to those studied all years were estimated fat thickness, estimated rib-eye area, percent kidney fat and cutability.

The results in this analysis (table 8) for year effects were essentially the same as those in table 7. Year effects were highly significant ($P < .01$) for all traits except weaning weight ($P < .05$) and estimated fat thickness (nonsignificant).

The year x ranch interaction effect was highly significant ($P < .01$) for final conformation, slaughter grade, estimated fat thickness and percent kidney fat; significant ($P < .05$) for dressing percent and carcass grade and nonsignificant for all other traits. This is in agreement with the analysis shown in table 7 except for weaning weight, daily gain and final weight. Some ranches not present in this group may have contributed the most variance to this interaction for these traits. The year-ranch subclass means for weaning weight for all years (table 9) show that in 1959 ranch 11 had the

TABLE 8. YEAR, YEAR X RANCH INTERACTION, YEAR X SIRE WITHIN RANCH INTERACTION AND RESIDUAL
MEAN SQUARES OF THE TRAITS STUDIED IN 1961-66

Trait	Source of variation			
	Year ^a	Year x ranch interaction ^b	Year x sire within ranch interaction ^c	Residual ^d
Weaning weight	3476*	2027	1800	1600
Daily gain	0.4602**	0.0510	0.0528	0.0420
Final weight	42421**	6320	5470	4715
Final conformation	10.45**	2.64**	1.17	1.34
Slaughter grade	4.26**	2.90**	0.98	1.06
Estimated fat thickness	0.0134	0.0311**	0.0086	0.0136
Estimated rib-eye area	3.42**	0.52	0.57	0.47
Final condition	17.40**	1.38	1.02	1.28
Dressing percent	11.37**	2.21*	1.34	1.41
Carcass grade	15.23**	1.89*	1.20	1.07
Rib-eye area	2.03**	1.03	0.99	0.72
Fat thickness	0.0603**	0.0213	0.0263	0.0198
Percent kidney fat	3.09**	0.53**	0.32*	0.19
Cutability	7.98**	1.19	1.16	1.13
Marbling	6.59**	1.00	0.79	0.69
Edible portion	241**	34	38	34
Percent edible portion	21.82**	4.25	4.40	3.82
Fat trim	526**	43	58	51
Percent fat trim	61.70**	4.90	6.60	5.66

^a degrees of freedom = 10

^b degrees of freedom = 21

^c degrees of freedom = 32

^d degrees of freedom = 405

* $P < .05$

** $P < .01$

TABLE 9. YEAR-RANCH SUBCLASS MEANS FOR WEANING WEIGHT

Ranch	Year								
	1959	1960	1961U	1961T	1962	1963	1964	1965	1966
5		402	461	433	384				
6		389	410	390	386	383	382	414	369
7		433	361	361					
9	392	389	428	416					
10	385	410							
11	430	387							
12			431	459					
13		446	424	444					
14			438	426	415				
15			381	388	390	361			
17		476	422	417	456				
19		389	437	432					
20			352	341	382	391			
22					398	378			
23					419		433		
27						468	430	402	401
28							442	411	401
30								347	368

highest weaning weight and ranch 10 had the lowest weaning weight while in 1960 ranch 11 had the lowest weaning weight and ranch 10 had one of the higher weaning weights. A comparison of ranches 17 and 19 also supports the possibility that certain ranches used in 1959 and 1960 were contributing the most variance to the year x ranch interaction. Ranch 17 had an 87 pound advantage over ranch 19 in 1960, but in the next two years ranch 19 had an advantage of 15 pounds over ranch 17. From 1961 on the ranches appear to maintain a more stable weaning weight relative to each other. The year-ranch means for daily gain and final weight also indicated that the ranches in 1959 and 1960 had more variation relative to each other than in later years.

The year x sire within ranch interaction was nonsignificant for all traits except percent kidney fat ($P < .05$). This effect on percent kidney fat is difficult to explain, due to the fact that the interaction was nonsignificant for several other measures of fatness. Percent kidney fat was eliminated from further analysis because this interaction was significant.

1962-66 Data. The traits studied in this group (table 10) in addition to those presented in table 8 were tenderness, lean color, lean firmness and final muscling.

Year effects were highly significant ($P < .01$) for all traits except slaughter grade, estimated fat thickness and lean color (all nonsignificant), which is in good agreement with the results shown in tables 7 and 8.

The year x ranch interaction effect was highly significant ($P < .01$) for estimated fat thickness and lean firmness; significant ($P < .05$) for rib-eye area and percent kidney fat; and nonsignificant for all other traits, which is generally in good agreement with the results shown in table 8 but not with the results shown in table 7. This further supports the possibility that certain ranches included in the analysis of traits taken all years were contributing the most variance to this interaction.

The year x sire within ranch interaction effect was nonsignificant for all traits except marbling ($P < .05$). This is difficult to explain because this effect on marbling was nonsignificant in the data shown in tables 7 and 8. The genetic, phenotypic and

TABLE 10. YEAR, YEAR X RANCH INTERACTION, YEAR X SIRE WITHIN RANCH INTERACTION AND RESIDUAL
MEAN SQUARES FOR TRAITS STUDIED IN 1962-66

Trait	Source of variation			
	Year ^a	Year x ranch interaction ^b	Year x sire within ranch interaction ^c	Residual ^d
Weaning weight	5846**	735	2149	1676
Daily gain	0.3653**	0.0435	0.0741	0.0443
Final weight	41895**	7291	8051	5230
Final conformation	8.77**	1.96	1.53	1.10
Final muscling	6.22**	0.31	0.77	0.60
Slaughter grade	0.73	1.23	1.00	1.03
Estimated fat thickness	0.0230	0.0406**	0.0148	0.0134
Estimated rib-eye area	1.34**	0.49	0.76	0.46
Final condition	20.77**	0.73	1.26	1.16
Dressing percent	6.26**	2.51	0.96	1.36
Carcass grade	6.16**	1.49	1.83	1.00
Rib-eye area	1.58**	1.39*	0.60	0.62
Fat thickness	0.0651**	0.0194	0.0316	0.0186
Percent kidney fat	3.19**	0.29*	0.13	0.13
Cutability	9.18**	2.02	1.57	1.09
Marbling	2.60**	0.86	1.29*	0.66
Edible portion	213**	30	44	38
Percent edible portion	18.86**	3.15	4.25	4.12
Fat trim	506**	60	69	67
Percent fat trim	58.42**	5.96	6.87	6.04
Lean color	0.98	0.30	0.37	0.53
Lean firmness	4.65**	1.60**	0.25	0.53
Tenderness	75.81**	4.07	9.39	9.82

^a degrees of freedom = 7

^b degrees of freedom = 7

^c degrees of freedom = 11

^d degrees of freedom = 278

* P < .05

** P < .01

environmental correlations between marbling and tenderness, lean color and lean firmness were not calculated because this interaction was significant.

Heritability Estimates of Production Traits

The between sires mean square, the sire component of variance (A), the within sires mean square (B) and the heritability estimate with it's standard error for each production trait are shown in table 11. Sire effects were highly significant ($P < .01$) for all production traits except estimated fat thickness (nonsignificant).

The heritability estimate of 40 percent for weaning weight compares favorably with estimates of 43 and 33 percent obtained by Brinks et al. (1964) and Minyard and Dinkel (1965b). However, this estimate is slightly higher than most workers have reported. Knapp and Clark (1950), Koch and Clark (1955), Swiger (1961), Shelby et al. (1963) and Swiger et al. (1963) reported estimates of 28, 24, 25, 24 and 28 percent, respectively. The estimate is lower than the 58 percent reported by Swiger et al. (1965).

The heritability estimate for daily gain was 55 percent. Other estimates have ranged from 39 percent by Koch and Clark (1955) to 93 percent by Brown and Gacula (1964). This estimate agrees favorably with estimates of Knapp and Clark (1950), 65 percent; Shelby et al. (1963), 48 percent; and Swiger et al. (1965), 60 percent.

Heritability of final weight was estimated at 85 percent. This is in agreement with estimates of 86 and 85 percent reported by Knapp

TABLE 11. BETWEEN SIRES MEAN SQUARE, WITHIN SIRES MEAN SQUARE (B), SIRE COMPONENT OF VARIANCE (A), HERITABILITY ESTIMATE AND THE STANDARD ERROR OF THE HERITABILITY ESTIMATE FOR EACH PRODUCTION TRAIT

Trait	Between sires mean square ^a	Within sires mean square (B)	Sire component of variance (A)	Heritability estimate	Standard error
Weaning weight ^{b,d}	4035**	1655	188	0.40	±.13
Daily gain ^d	0.1196**	0.0412	0.0068	0.55	±.14
Final weight ^{c,d}	18935**	4784	1336	0.85	±.17
Final conformation ^{c,d}	4.55**	1.75	0.23	0.45	±.13
Slaughter grade ^d	1.57**	0.96	0.03	0.10	±.09
Final condition ^{c,d}	2.24**	1.44	0.03	0.07	±.09
Estimated fat thickness ^e	0.0170	0.0132	-.0001	0.00	
Estimated rib-eye area ^{c,e}	1.27**	0.47	0.07	0.53	±.16
Final muscling ^f	1.20**	0.60	0.04	0.25	±.16

^a between sires within ranch; adjusted for year effects and the year x ranch interaction effect

^b adjusted for age and age of dam

^c adjusted for age

^d degrees of freedom between sires = 52; degrees of freedom within sires = 568

^e degrees of freedom between sires = 45; degrees of freedom within sires = 437

^f degrees of freedom between sires = 30; degrees of freedom within sires = 289

** P<.01

and Clark (1950) and Brown and Gifford (1962). It is higher than most estimates, however, which have ranged from 41 percent reported by Brinks et al. (1964) to 72 percent reported by Swiger et al. (1965).

The heritability estimate obtained for final conformation was 45 percent which is higher than the estimate of 27 percent by Koch and Clark (1955) and lower than the estimate of 85 percent by Brown and Gifford (1962). It is in good agreement with estimates of 40 and 47 percent reported by Blackwell et al. (1962) and Swiger et al. (1963), respectively.

The heritability estimate of 10 percent obtained for slaughter grade is lower than estimates of 58 percent and 45 percent reported by Dawson et al. (1955) and Carter and Kincaid (1959a), respectively.

No heritability estimates were found in the literature for final muscling, estimated fat thickness, estimated rib-eye area and final condition. Heritability estimates obtained for these traits were 25, 0, 53 and 7 percent, respectively. The sire component of variance for estimated fat thickness was actually negative, meaning that there was more variation within than between sire groups. This was interpreted as a heritability of 0.00. The heritability estimate for final condition was also low. Theoretically the heritability of these two traits should be similar as both traits are a subjective evaluation of the amount of finish an animal has. In making these evaluations, either estimate will be influenced to some extent by the other.

The heritability estimates obtained for weaning weight, daily gain, final weight and final conformation were generally higher than

most estimates reported in the literature and were all higher than the average of several studies reported by Warwick (1958). Heritability estimates of 38, 52, 45 and 40 percent for weaning weight, daily gain, final weight and final conformation, respectively, were obtained from a previous analysis of the first four years of this study (Wilson et al., 1963). The estimate for final weight obtained in this study is considerably higher than the previous estimate while the estimates for weaning weight, daily gain and final conformation are slightly higher.

It is important to consider the factors that affect the size of heritability estimates. Heritability measures the genetic distinctness of the families involved. Obtaining a sample of animals that are more uniform than the population from which they were selected would lower the estimate of the genetic variance. Data for this study came from several different sources and a wide variety of environments and may be more representative of the beef cattle population than data collected from only one herd. Even though the analysis was conducted on a within ranch basis there may be more variation between sires in some ranches than others. Although the environment after they were put in the feedlot was controlled as much as possible, Wilson (1965) showed that initial blood traits were more accurate in predicting subsequent body composition than were final blood traits. This suggests that pre-weaning environment has an important effect on an animal through a large proportion of the growth cycle.

Another possible explanation for the higher heritability estimates is the fact that the bulls leased from the experiment station

were all performance tested and the information was made available to each rancher. If this leased bull was selected on the index composed of both conformation and growth and the bull he purchased from a private breeder was selected on conformation only, the difference in breeding value for the bulls could be larger than if both were selected on the same basis.

Another possible explanation is the fact that the year x ranch interaction was significant for all of these traits and the data were adjusted for it prior to calculating the heritability estimates. Removing this environmental effect may have left a larger proportion of the variance to be attributed to sire effects and thereby increased the heritability estimate. This interaction was not accounted for in some previous studies. This component is also present in studies where the data came from only one herd and it would depend on the method of analysis whether it increased or decreased the estimate of heritability.

Heritability refers to the proportion of the observed variation that is due to the average effects of genes and indicates the reliability of an individual's phenotype as a predictor of the genic value of that individual. The genic value determines the animal's influence on the next generation but in mass selection animals are selected on the basis of their phenotype. Heritability estimates obtained in this study for the growth traits (weaning weight, daily gain and final weight) were large enough to indicate that mass selection should be effective in bringing about genetic improvement for these traits. This is important for both the rancher and the cattle

feeder. Heavier weaning weights will increase a ranchers income and faster gains will increase a cattle feeders income due to lower fixed costs and improved feed efficiency.

Heritability Estimates of Carcass Composition Traits

The between sires mean square, the sire component of variance (A), the within sires mean square (B) and the heritability estimate with it's standard error for each carcass composition trait are given in table 12. Sire effects were highly significant ($P < .01$) for all carcass composition traits.

The heritability estimate derived for dressing percent was 15 percent which is considerably lower than most estimates except for estimates of 1 percent by Knapp and Nordskog (1946b) and 25 percent by Blackwell et al. (1962). Dawson et al. (1955), Shelby et al. (1955), Christians et al. (1962) and Shelby et al. (1963) reported estimates ranging from 57 to 74 percent with an average of 68 percent.

Heritability for rib-eye area was estimated at 25 percent which agrees with the estimate of 26 percent by Shelby et al. (1963). It is considerably less than other estimates that have been reported however. Five other workers (Knapp and Nordskog, 1946b; Knapp and Clark, 1950; Shelby et al., 1955; Christians et al., 1962 and Cundiff et al., 1964) have reported estimates from 68 to 76 percent for rib-eye area.

Swiger et al. (1965) reported a heritability estimate of 50 percent for fat thickness which is similar to the estimate of 57 percent obtained in this study. Other estimates for fat thickness

TABLE 12. BETWEEN SIRES MEAN SQUARE, WITHIN SIRES MEAN SQUARE (B), SIRE COMPONENT OF VARIANCE (A), HERITABILITY ESTIMATE AND THE STANDARD ERROR OF THE HERITABILITY ESTIMATE FOR EACH CARCASS COMPOSITION TRAIT

Trait	Between sires mean square ^a	Within sires mean square (B)	Sire component of variance (A)	Heritability estimate	Standard error
Dressing percent ^{b,c}	2.42**	1.38	0.05	0.15	±.10
Rib-eye area ^{b,c}	1.65**	0.82	0.06	0.25	±.11
Fat thickness ^{b,c}	0.0593**	0.0199	0.0034	0.57	±.14
Edible portion ^{b,c}	.72**	30	3	0.38	±.13
Percent edible portion ^{b,c}	7.98**	3.36	0.36	0.38	±.12
Fat trim ^{b,c}	111**	46	5	0.39	±.13
Percent fat trim ^{b,c}	12.95**	5.01	0.65	0.45	±.13
Cutability ^{b,d}	3.46**	1.13	0.23	0.66	±.17

^a between sires within ranch; adjusted for year effects and the year x ranch interaction effect

^b adjusted for carcass weight

^c degrees of freedom between sires = 52; degrees of freedom within sires = 568

^d degrees of freedom between sires = 45; degrees of freedom within sires = 437

** P<.01

have been somewhat lower however. They vary from 24 percent reported by Shelby et al. (1963) to 43 percent reported by Cundiff et al. (1964).

The heritability estimate for cutability was 66 percent. This is higher than the estimate of 40 percent reported by Cundiff et al. (1964) which was the only one found in the literature for cutability.

The heritability of edible portion and percent edible portion were both estimated at 38 percent. Swiger et al. (1965) reported estimates of 65 and 24 percent for edible portion and percent edible portion, neither of which are in agreement with the estimates reported here. One possible explanation for this disagreement is that the estimates by Swiger et al. (1965) were not adjusted for the effect of carcass weight. No other estimates were found for these two traits.

Two additional traits were studied for which no estimates were found in the literature. They were fat trim and percent fat trim, for which heritability estimates of 39 and 45 percent were obtained.

The four different measures of overall carcass composition (edible portion, percent edible portion, fat trim and percent fat trim) all had similar heritability estimates (38 to 45 percent) indicating that there is the same amount of genetic variation present for muscle and fat measured either in weight or as a percent. Dinkel et al. (1965) indicated that evaluating animals for certain traits expressed as a ratio or a percent where the denominator is quite variable is questionable. In this study, however, all of the carcass composition traits were adjusted for weight before heritability was estimated.

The estimates reported here for the carcass composition traits are lower than estimates reported in the literature with the exception of fat thickness. A possible explanation for this is that most previous estimates were made from data not adjusted for differences in weight. Carcass weight had a significant influence on all carcass composition traits. Removing this source of variation may have lessened the sire differences and as a result, lowered the heritability estimates obtained. This is not undesirable however, because the variation removed by this adjustment will still be accounted for by the genetic correlations between the growth and carcass composition traits.

Heritability Estimates of Carcass Quality Traits

The between sires mean square, the within sires mean square (B), the sire component of variance (A), and the heritability estimate with it's standard error for each carcass quality trait are shown in table 13. Sire effects were highly significant ($P < .01$) for all traits except tenderness (nonsignificant).

The heritability estimate obtained for carcass grade was 34 percent. This estimate is in good agreement with estimates of 33 percent by Knapp and Clark (1950) and 32 percent by Swiger et al. (1965). This estimate is higher than the 16 and 17 percent reported by Shelby et al. (1955 and 1963). It is lower than the estimates of 84, 67, 58, 59 and 62 percent reported by Knapp and Nordskog (1946b),

TABLE 13. BETWEEN SIRES MEAN SQUARE, WITHIN SIRES MEAN SQUARE (B), SIRE COMPONENT OF VARIANCE (A), HERITABILITY ESTIMATE AND THE STANDARD ERROR OF THE HERITABILITY ESTIMATE FOR EACH CARCASS QUALITY TRAIT

Trait	Between sires mean square ^a	Within sires mean square (B)	Sire component of variance (A)	Heritability estimate	Standard error
Carcass grade ^{b,d}	2.22**	0.98	0.09	0.34	±.12
Marbling ^{b,d}	1.45**	0.66	0.06	0.31	±.12
Lean color ^{c,e}	0.97**	0.53	0.03	0.19	±.15
Lean firmness ^e	1.09**	0.52	0.04	0.29	±.16
Tenderness ^e	8.94	9.80	-.57	0.00	

^a between sires within ranch; adjusted for year effects and the year x ranch interaction effect

^b adjusted for age and carcass weight

^c adjusted for age

^d degrees of freedom between sires = 52; degrees of freedom within sires = 568

^e degrees of freedom between sires = 30; degrees of freedom within sires = 289

** P<.01

Dawson et al. (1955), Christians et al. (1962), Blackwell et al. (1962) and Cundiff et al. (1964), respectively.

An estimate of 31 percent was obtained for marbling. The only estimate found in the literature for marbling was 5 percent reported by Harwin et al. (1961) which is not in agreement with this estimate. The heritability of marbling and carcass grade should be similar as carcass grade is highly dependent on marbling. The estimates in this study are in close agreement (marbling, 31 percent; carcass grade, 34 percent).

The heritability estimate obtained for tenderness was zero.

Actually the sire component of variance was negative, resulting in a negative heritability estimate which means that there was more variation within sires than between sires and was interpreted as a heritability of 0.00. Most heritability estimates reported for tenderness have been quite high. Yao and Hiner (1953), Alsmeyer et al. (1958), Kieffer et al. (1958) and Christians (1962) reported estimates of 77, 51, 92 and 68 percent, respectively. Alsmeyer et al. (1958), however, did report a heritability estimate of zero for progeny of Shorthorn and crossbred sires in the same study that they derived an estimate of 51 percent for progeny of Brahman sires. Possible explanations for the difference between this and previous estimates are that there were twice as many sires represented and a lower standard deviation for tenderness in this study.

Heritability estimates obtained for lean color and lean firmness were 19 and 29 percent, respectively. Shelby et al. (1955) reported an estimate of 31 percent for lean color which is not in agreement with

the estimate obtained in this study. No other estimates for lean color and no estimates for lean firmness were found in the literature.

Based on the heritability estimates obtained in this study, the amount of genetic variation present for the carcass quality traits appears to be quite low. The amount of improvement that could be made for these traits through selection would be small in addition to the problem of measuring them accurately in the live animal.

Genetic, Phenotypic and Environmental Correlations among the Production Traits

The genetic, phenotypic and environmental correlations among the production traits are shown in table 14.

The genetic, phenotypic and environmental correlations between final weight and weaning weight were 0.83, 0.62 and 0.46, respectively. These values are in good agreement with the results of Swiger (1961), Brinks et al. (1962), Brinks et al. (1964) and Swiger et al. (1965). The genetic, phenotypic and environmental correlations between final weight and daily gain of 0.99, 0.82 and 0.56, respectively, are also in good agreement with most previous estimates of these correlations (Koch and Clark, 1955; Blackwell et al., 1962; and Swiger et al., 1965). It would be expected that the correlations between final weight and either weaning weight or daily gain would be high because final weight is actually the sum of the other two traits.

The genetic correlation between weaning weight and daily gain of 0.77 indicates that many of the genes that increase growth prior to weaning also increase growth after weaning. This is in contrast to

TABLE 14. GENETIC (G), PHENOTYPIC (P) AND ENVIRONMENTAL (E) CORRELATIONS AMONG PRODUCTION TRAITS

		Daily gain	Final weight	Final conformation	Final muscling	Slaughter grade	Estimated fat thickness	Estimated rib-eye area	Final condition ^{b,c}
Weaning weight ^{a,c}	G)	0.77±.18	0.83±.10	-.18±.26	0.38±.26	-.19±.42	f	1.02±.15	-.33±.50
	P)	0.17	0.62	0.11	0.21	0.23	0.35	0.53	0.21
	E)	-.36	0.46	0.32	0.14	0.37	0.41	0.25	0.36
Daily gain ^c			0.99±.03	0.23±.23	0.26±.37	0.31±.36	f	0.84±.10	0.19±.45
			0.82	0.30	0.26	0.41	0.46	0.66	0.39
			0.56	0.38	0.29	0.53	0.59	0.45	0.54
Final weight ^{b,c}				0.14±.22	0.24±.34	0.18±.35	f	0.93±.05	0.18±.41
				0.29	0.32	0.45	0.52	0.81	0.41
				0.70	0.84	1.05	1.10	0.69	0.98
Final conformation ^{b,c}					0.87±.15	0.50±.34	f	0.01±.31	1.48±.62
					0.70	0.45	0.63	0.46	0.87
					0.65	0.48	0.68	0.83	0.86
Final muscling ^e						1.18±1.12	1.37±1.61	0.44±.29	g
						0.36	0.39	0.62	0.50
						0.26	0.30	0.97	0.44
Slaughter grade ^c							f	0.35±.44	-.54±.62
							0.52	0.44	0.50
							0.60	0.56	0.59
Estimated fat thickness ^d								f	f
								0.49	0.77
								0.68	0.80
Estimated rib-eye area ^{b,d}									g
									0.51
									0.80

^a adjusted for age and age of dam^b adjusted for age^c degrees of freedom = 568^d degrees of freedom = 437^e degrees of freedom = 289^f negative sire component for estimated fat thickness^g negative sire component for final condition

genetic correlations of 0.03 and -0.20 reported by Koch and Clark (1955) and Brinks et al. (1964). However, the correlation found in this study is in agreement with several other reports (Carter and Kincaid, 1959b; Swiger, 1961; Shelby et al., 1963; and Swiger et al., 1965). The phenotypic correlation of 0.17 is in agreement with most previous studies, some of which have been negative but were near zero. The negative environmental correlation between weaning weight and daily gain (-0.36) indicates that animals with a poor preweaning environment tend to compensate for it in post-weaning daily gain. Koch and Clark (1955), Blackwell et al. (1962), Brinks et al. (1964) and Swiger et al. (1965) all reported a negative environmental correlation between weaning weight and daily gain.

Final conformation had a genetic correlation of -0.18 with weaning weight, 0.23 with daily gain and 0.14 with final weight indicating that final conformation is inherited independently of the growth traits. Swiger et al. (1963) found low genetic correlations between final conformation and both weaning weight and final weight. Blackwell et al. (1962) reported a low genetic correlation between final conformation and both daily gain and final weight but found a correlation of -0.48 between final conformation and weaning weight. Koch and Clark (1955) found a low genetic correlation (0.23) between weaning weight and final conformation but reported genetic correlations of 0.44 and 0.49 between final conformation and daily gain and final weight, respectively. Final conformation had a phenotypic correlation of 0.11 with weaning weight, 0.30 with daily gain and 0.29 with final

weight. These values are midway between the values near zero reported by Blackwell et al. (1962) and the values of 0.26, 0.35 and 0.56, respectively, reported by Koch and Clark (1955). Final conformation had an environmental correlation of 0.32 with weaning weight, 0.38 with daily gain and 0.70 with final weight. These estimates are in close agreement with the results of Koch and Clark (1955) but are higher than the values reported by Blackwell et al. (1962) which were all near zero.

The genetic, phenotypic and environmental correlations between the growth traits and final muscling, slaughter grade and final condition followed much the same pattern as the correlations between the growth traits and final conformation. The genetic correlations indicate that these scores are inherited independently of the growth traits. The environmental correlations were somewhat higher and indicate that an environment that results in increased growth will also result in higher scores for final muscling, final condition and slaughter grade. Phenotypically, these scores had low relationships with the growth traits, although they were all positive.

The other live traits studied were estimated fat thickness and estimated rib-eye area. The genetic correlations between estimated fat thickness and the other production traits could not be estimated because of the negative sire component for estimated fat thickness. The phenotypic and environmental correlations between the growth traits and estimated fat thickness were all positive and in general, were all moderate to high. The genetic, phenotypic and environmental correlations between the growth traits and estimated rib-eye area were

all high and were positive. When the evaluations for estimated rib-eye area and fat thickness were made, the weight of each animal was known. Based on the phenotypic correlations between these two traits and the growth traits, each individual relied heavily on the knowledge of the animals weight in making these estimates.

The genetic correlation between final conformation and final muscling of 0.87 indicates that many of the genes that result in a high conformation score also result in a high muscling score. The phenotypic and environmental correlations were also high between these two traits (0.70 and 0.65, respectively).

The other genetic, phenotypic and environmental correlations among the production traits that were subjective in nature were moderate to high and all positive except for the genetic correlation between slaughter grade and final condition of -0.54 . This is puzzling because final condition was an evaluation of the amount of finish while estimated rib-eye area and final muscling were an evaluation of muscling. It would not be expected that the relationships among all of these traits would be positive. The phenotypic correlations between final weight and all of these scores were high enough to indicate that weight influences these scores and they may need to be weight adjusted to better evaluate the genetic correlations among them as well as their genetic correlations with the carcass traits.

A genetic correlation defines the relationship between two traits which is due to common action of one or more genes. This is known as pleiotropy. The genes responsible for this action may

increase merit in one trait and lower merit in another trait. This would result in a negative genetic correlation. On the other hand, if the common action of these genes affect the merit of both traits in the same direction, a positive genetic correlation will be obtained.

There are two factors that can result in apparent genetic relationships between traits. One of these is gene linkage. If a gene that lowers the merit of trait 1 is located on the same chromosome as another gene that increases the merit of trait 2, a negative genetic correlation between these traits will result. These combinations will be broken up by crossing over in a random mating population and since the population from which the data in this study were selected was mated at random, gene linkage should not be an important source of apparent genetic correlations. Another factor that is capable of causing apparent genetic correlations is differences between subpopulations in the selection pressure applied to different traits. If the selection in one subgroup was primarily on trait A while in the other subgroup, selection was primarily on trait B, a negative genetic correlation would result if these subgroups were studied without regard to origin. This analysis was conducted on a within ranch basis which should remove this influence.

Genetic, Phenotypic and Environmental Correlations among the Carcass Composition Traits

The genetic, phenotypic and environmental correlations among the carcass composition traits are shown in table 15.

TABLE 15. GENETIC (G), PHENOTYPIC (P) AND ENVIRONMENTAL (E) CORRELATIONS AMONG CARCASS COMPOSITION TRAITS

	Rib-eye area	Fat thickness	Cutability	Edible portion	Percent edible portion	Fat trim	Percent fat trim ^a
Dressing G)	0.47±.43	0.25±.34	-.23±.48	0.64±.41	0.60±.41	-.02±.39	0.08±.37
percent ^a P)	0.07	0.14	-.09	-.07	-.07	0.12	0.12
E)	-.02	0.12	-.05	-.31	-.29	0.17	0.15
Rib-eye area ^a		-.59±.31	0.72±.15	0.20±.30	0.32±.28	-.37±.35	-.38±.34
		-.28	0.59	0.41	0.42	-.32	-.31
		-.10	0.50	0.51	0.47	-.29	-.28
Fat thickness ^a			-.75±.29	-.88±.29	-.87±.29	0.86±.09	0.88±.08
			-.63	-.53	-.53	0.66	0.65
			-.46	-.24	-.25	0.48	0.42
Cutability ^{a,b}				0.77±.13	0.79±.12	-.82±.36	-.83±.34
				0.69	0.70	-.70	-.69
				0.66	0.68	-.64	-.57
Edible portion ^a					1.01±.01	-.94±.42	-.94±.39
					0.98	-.88	-.88
					0.96	-.84	-.84
Percent edible portion ^a						-.92±.42	-.93±.40
						-.89	-.90
						-.87	-.88
Fat trim ^a							1.00±.01
							0.99
							0.99

^a adjusted for carcass weight

^b degrees of freedom = 437; all other traits = 568

The genetic correlation of 0.47 between dressing percent and rib-eye area is in good agreement with the value of 0.40 reported by Shelby et al. (1963). The genetic correlation of 0.25 between dressing percent and fat thickness is lower than the 0.60 reported by Shelby et al. (1963). Shelby et al. (1963) found phenotypic correlations of 0.32 between dressing percent and rib-eye area and 0.28 between dressing percent and fat thickness which are higher than the values of 0.07 and 0.14 between dressing percent and rib-eye area and fat thickness, respectively, obtained in this study. The phenotypic correlations between dressing percent and the other carcass composition traits were all low (-0.07 to 0.14). The environmental correlations between dressing percent and the other composition traits were all low except for the correlations of -0.31 and -0.29 between dressing percent and edible portion and percent edible portion, respectively.

The genetic correlations between dressing percent and edible portion and percent edible portion (0.64 and 0.60, respectively) were the highest genetic correlations with dressing percent and indicate that many of the genes that increase dressing percent also increase edible portion and percent edible portion. The genetic correlations between dressing percent and fat trim and percent fat trim (0.02 and 0.08, respectively) indicate that these traits are inherited independently of dressing percent. The genetic correlation of -0.23 between dressing percent and cutability is surprising because it would be expected that it would be similar to the one between dressing percent and edible portion.

Extremely high genetic correlations were found among edible portion, percent edible portion, fat trim and percent fat trim. The genetic correlation between edible portion and percent edible portion of 1.01 indicates that all of the genes that affect one, affect the other and although expressed differently, they are really the same trait. This is in contrast with the value of 0.15 reported by Swiger et al. (1965). A possible explanation for this disagreement is that in this study both traits were adjusted for weight while Swiger et al. (1965) adjusted for age.

The genetic correlation of 1.00 between fat trim and percent fat trim would indicate that these two traits are the same, although expressed differently. The genetic correlations between edible portion or percent edible portion and fat trim or percent fat trim were all high and negative (-.92 to -.94). The phenotypic and environmental correlations among these four traits were of the same magnitude and sign as the genetic correlations.

Cutability, also considered an evaluation of overall carcass composition, had high positive genetic correlations with edible portion and percent edible portion (0.77 and 0.79, respectively) and high negative genetic correlations with fat trim and percent fat trim (-.82 and -.83, respectively). The phenotypic and environmental correlations between cutability and these traits were of the same magnitude and sign as the genetic correlations.

The high genetic correlations between cutability and edible portion and percent edible portion would indicate that many of the

genes that affect muscle growth of an animal are the same regardless of how it is measured. Cutability includes only the retail cuts from the round, rib, loin and chuck, while edible portion includes the retail cuts and lean trim from the entire carcass. Another difference is that the cutability equation was developed from cattle from many different sources, while edible portion was obtained from actual cutout data from the animals in this study or predicted from equations developed from part of the animals in this study. However, cutability had a higher heritability estimate than edible portion or percent edible portion. Several workers have developed equations for predicting carcass composition. Further study is needed on the heritability of and genetic relationships among these traits.

The genetic, phenotypic and environmental correlations between rib-eye area and fat thickness were $-.59$, $-.28$ and $-.10$, respectively. Shelby et al. (1963) and Cundiff et al. (1964) reported small but positive genetic correlations between these two traits (0.30 and 0.08 , respectively) which is not in agreement with the values reported here. One possible explanation of this disagreement is the fact that carcass weight had a highly significant positive effect on both traits. A positive relationship could result by not adjusting for carcass weight as was the case in the studies by Shelby et al. (1963) and Cundiff et al. (1964). The phenotypic correlations between rib-eye area and fat thickness reported by Shelby et al. (1963) and Cundiff et al. (1964) (0.05 and $-.07$, respectively) are slightly lower than the value reported here. Cundiff et al. (1964) reported a negative environmental

correlation (-.40) between rib-eye area and fat thickness which agrees in sign but not in magnitude with the value of -.10 found in this study.

The genetic, phenotypic and environmental correlations between fat thickness and cutability were -.75, -.63 and -.46, respectively. These values are in fair agreement with the values of -.93, -.83 and -.74 reported by Cundiff et al. (1964). The genetic, phenotypic and environmental correlations between rib-eye area and cutability were 0.72, 0.59 and 0.50, respectively. They are very similar in magnitude but opposite in sign to the relationships between fat thickness and cutability. Both rib-eye area and fat thickness are part of the equation used to estimate cutability and it would be expected that the relationships between these two traits and cutability would be high and of the same sign as the partial regression coefficients in the prediction equation.

Fat thickness had high positive genetic, phenotypic and environmental correlations with fat trim and percent fat trim and high negative relationships with edible portion and percent edible portion. The genetic, phenotypic and environmental correlations between fat thickness and percent edible portion are in good agreement with the values of -.77, -.52 and -.42 reported by Swiger et al. (1965).

Rib-eye area had positive genetic, phenotypic and environmental correlations with edible portion and percent edible portion and negative relationships with fat trim and percent fat trim but these relationships were low to moderate. The fact that rib-eye area had

low relationships with these four overall carcass composition traits while fat thickness had high relationships with the same traits supports the conclusions of several previous reports. Brungardt and Bray (1963), Iwanaga and Cobb (1963) and Fitzhugh et al. (1965) all reported that fat thickness was a more accurate indicator of different measures of carcass composition than rib-eye area. Rib-eye area did have a high genetic correlation with cutability but this is probably due to rib-eye area being part of the cutability equation.

Genetic, Phenotypic and Environmental Correlations among the Carcass Quality Traits

The genetic, phenotypic and environmental correlations among the carcass quality traits are shown in table 16.

The genetic correlations between tenderness and the other carcass quality traits could not be estimated because the sire component for tenderness was negative. The phenotypic and environmental correlations between tenderness and the other carcass quality traits were low and indicate that tenderness cannot be predicted by an evaluation of carcass grade, marbling, lean color or lean firmness.

The genetic, phenotypic and environmental correlations of 0.90, 0.83 and 0.79 respectively, between carcass grade and marbling would indicate that they are practically the same trait and that most of the variation in carcass grade is accounted for by marbling. Although other factors such as carcass conformation, maturity and lean color determine carcass grade to some extent, the major influence is marbling. Positive relationships were found between carcass grade and

TABLE 16. GENETIC (G), PHENOTYPIC (P) AND ENVIRONMENTAL (E)
CORRELATIONS AMONG CARCASS QUALITY TRAITS

	Marbling	Lean color	Lean firmness	Tenderness ^d
Carcass grade ^{a,c}	G) 0.90±.07 P) 0.83 E) 0.79	0.40±.52 0.37 0.36	0.11±.52 0.31 0.37	e -.03 -.08
Marbling ^{a,c}		0.22±.61 0.24 0.25	0.47±.47 0.32 0.29	e -.08 -.11
Lean color ^{b,d}			-.19±.52 0.05 0.13	e -.09 -.19
Lean firmness ^d				e 0.08 0.14

^a adjusted for age and carcass weight

^b adjusted for age

^c degrees of freedom = 568

^d degrees of freedom = 289

^e negative sire component for tenderness

lean color and lean firmness and also between marbling and lean color and lean firmness.

The genetic, phenotypic and environmental correlations between lean color and lean firmness were -.19, 0.05 and 0.13, respectively. The genetic correlation of -.19 indicates that these two traits are inherited independently of each other.

Genetic, Phenotypic and Environmental Correlations between Carcass Composition and Quality Traits

The genetic, phenotypic and environmental correlations between the carcass composition and quality traits are shown in table 17.

TABLE 17. GENETIC (G), PHENOTYPIC (P) AND ENVIRONMENTAL (E)
CORRELATIONS BETWEEN CARCASS COMPOSITION AND
CARCASS QUALITY TRAITS

		Carcass grade ^{c,d}	Marbling ^{c,d}	Lean color ^{a,f}	Lean firmness ^f	Tenderness ^f
Dressing percent ^{b,d}	G)	0.38±.39	0.50±.40	0.47±.65	-1.10±.66	g
	P)	0.07	0.06	0.04	-.08	0.00
	E)	-.02	-.05	-.06	0.21	-.20
Rib-eye area ^{b,d}		-.43±.33	-.17±.34	1.00±.42	0.61±.41	g
		-.06	-.01	0.13	-.11	-.01
		0.10	0.06	-.22	-.49	-.02
Fat thickness ^{b,d}		0.43±.24	0.38±.25	0.81±.37	-.34±.33	g
		0.10	0.09	0.06	-.02	-.04
		-.17	-.13	-.89	0.53	0.59
Cutability ^{b,e}		-.32±.34	0.26±.31	-.39±.41	0.60±.34	g
		-.14	-.09	0.02	-.04	-.04
		-.04	-.40	0.32	-.68	-.46
Edible portion ^{b,d}		-.38±.30	0.02±.30	-1.13±.48	-.25±.40	g
		-.15	-.13	-.03	-.10	0.01
		-.02	-.21	0.47	-.02	-.31
Percent edible portion ^{b,d}		-.38±.30	0.01±.30	-.91±.46	-.17±.40	g
		-.18	-.15	-.02	-.13	-.01
		-.06	-.23	0.39	-.11	-.34
Fat trim ^{b,d}		0.37±.26	0.09±.29	0.72±.41	-.13±.38	g
		0.17	0.15	0.07	0.06	0.03
		0.05	0.18	-.25	0.19	0.44
Percent fat trim ^{b,d}		0.39±.25	0.10±.28	0.66±.40	-.10±.37	g
		0.18	0.16	0.07	0.06	0.01
		0.05	0.19	-.29	0.20	0.49

a adjusted for age

b adjusted for carcass weight

c adjusted for age and carcass weight

d degrees of freedom = 568

e degrees of freedom = 437

f degrees of freedom = 289

g negative sire component for tenderness

The genetic correlation between carcass grade and dressing percent of 0.38 is lower than the value of 1.09 reported by Blackwell et al. (1962) but is in agreement with the value of 0.55 reported by Shelby et al. (1963). The phenotypic correlation between these two traits (0.07) is lower than the values of 0.39 and 0.34 reported by Blackwell et al. (1962) and Shelby et al. (1963), respectively. The environmental correlation of $-.02$ agrees with the value of $-.05$ reported by Blackwell et al. (1962).

The genetic, phenotypic and environmental correlations between carcass grade and rib-eye area were $-.43$, $-.06$ and 0.10 , respectively. Shelby et al. (1963) and Cundiff et al. (1964) reported genetic correlations of $-.11$ and 0.08 , respectively, between carcass grade and rib-eye area which are not in agreement with the value found in this study. Shelby et al. (1963) and Cundiff et al. (1964) reported phenotypic correlations of 0.22 and 0.05 , respectively, compared to the value of $-.06$ reported here. Cundiff et al. (1964) reported an environmental correlation of $-.89$ between carcass grade and rib-eye area which is not in agreement with the value of 0.10 in this study.

The genetic, phenotypic and environmental correlations between carcass grade and fat thickness were 0.43 , 0.10 and $-.17$, respectively. Shelby et al. (1963), Cundiff et al. (1964) and Swiger et al. (1965) all reported positive genetic correlations between carcass grade and fat thickness that ranged from 0.23 to 1.00 . These workers also reported positive phenotypic correlations between these two traits but were slightly higher (0.31 to 0.44) than the value found here.

Cundiff et al. (1964) reported a negative environmental correlation ($-.40$) between carcass grade and fat thickness, while Swiger et al. (1965) reported an environmental correlation of 0.14 between these two traits.

The relationships between marbling and dressing percent, rib-eye area and fat thickness were similar to the ones between carcass grade and the same traits. The genetic correlation of 0.38 between marbling and fat thickness indicates that while a few genes that cause deposition of intra-muscular fat also cause subcutaneous fat deposition, there are some genes that affect fat deposition in one part of the animal but not in other parts.

Although the relationship between marbling and carcass grade was high these traits did not have similar genetic relationships with edible portion, percent edible portion, fat trim and percent fat trim. The genetic correlations between marbling and these traits were all low (0.01 to 0.10). The genetic correlations between carcass grade and edible portion and percent edible portion were both $-.38$. Swiger et al. (1965) reported a similar genetic correlation of $-.48$ between carcass grade and retail product. The genetic correlations between carcass grade and fat trim and percent fat trim were 0.37 and 0.39 indicating that a few of the genes that increase carcass grade also increase carcass fat. The fact that carcass grade and marbling do not have similar genetic correlations with these traits suggests that there may be a negative genetic relationship between carcass muscle and one

or more of the other factors besides marbling that are used to determine carcass grade.

The genetic, phenotypic and environmental correlations between carcass grade and cutability were $-.32$, $-.14$ and $-.04$, respectively. Cundiff et al. (1964) reported a negative genetic correlation between carcass grade and cutability but it was higher than the value found here ($-.80$). They reported phenotypic and environmental correlations of $-.34$ and 0.11 between these two traits which are similar to the values found in this study.

The genetic correlations between tenderness and the carcass composition traits could not be calculated because the sire component for tenderness was negative. The phenotypic correlations between tenderness and all of the carcass composition traits were essentially zero indicating that it would be difficult to evaluate tenderness from traits that can be measured on carcasses in a packing plant. Cover et al. (1956), Matthews and Bennett (1962), Magee (1965) and Suess et al. (1966) all reported low phenotypic relationships between tenderness and several carcass traits.

Some of the environmental correlations between tenderness and the carcass composition traits were higher. The highest value was 0.59 between tenderness and fat thickness. Tenderness was determined by the pounds of force required to shear a 1 inch core of the longissimus dorsi muscle so a lower value indicates more tender meat. Thus, the correlation of 0.59 between fat thickness and tenderness indicates that an environment that increases fat thickness at a

constant weight decreases tenderness. The environmental correlations between tenderness and fat trim (0.44), percent fat trim (0.49), cutability (-.46), edible portion (0.31) and percent edible portion (-.34) also indicate that an environment that increases muscling increases tenderness.

Favorable genetic correlations were found between lean color and dressing percent (0.47), and rib-eye area (1.00). Unfavorable genetic correlations were found between lean color and fat thickness (0.81), fat trim (0.72), percent fat trim (0.66), cutability (-.39), edible portion (-1.13) and percent edible portion (-.91). These correlations indicate that the genes that increase carcass muscle cause darker colored lean.

The phenotypic correlations between lean color and the carcass composition traits were essentially zero (-.03 to 0.13).

The environmental correlations between lean color and the following carcass traits: fat thickness (-.89), cutability (0.32), edible portion (0.47), percent edible portion (0.39), fat trim (-.25) and percent fat trim (-.29) indicate that an environment that increases muscling also results in a more desirable lean color.

The genetic correlations between lean firmness and the carcass composition traits were generally lower than the ones between lean color and the same traits. The genetic correlation between lean firmness and dressing percent (-1.10) indicates that many of the genes that increase dressing percent result in softer lean. Favorable genetic correlations were found between lean firmness and rib-eye area (0.61),

fat thickness (-.34) and cutability (0.60). Genetic correlations between lean firmness and the other carcass composition traits were low.

The phenotypic correlations between lean firmness and the carcass composition traits were all low (-.13 to 0.06).

The environmental correlations between lean firmness and rib-eye area (-.49), fat thickness (0.53) and cutability (-.68) indicate that an environment that increases some of the muscling traits will result in softer lean but the correlations between lean firmness and edible portion, percent edible portion, fat trim and percent fat trim were low (-.11 to 0.20).

Genetic, Phenotypic and Environmental Correlations between Production and Carcass Composition Traits

The genetic correlations between production and carcass composition traits (table 18) are important because they can be used to determine how much progress can be made in improving composition traits through correlated response. It is difficult to measure carcass composition traits on the live animal in order to practice any selection for them directly. However, with a high favorable correlation between a composition trait and a production trait, selection for the production trait will bring about improvement in the carcass trait as well.

The genetic correlations between estimated fat thickness and all of the carcass composition traits and between final condition and

TABLE 18. GENETIC (G), PHENOTYPIC AND ENVIRONMENTAL (E) CORRELATIONS BETWEEN PRODUCTION AND CARCASS COMPOSITION TRAITS

		Dressing percent ^{c,d}	Rib-eye area ^{c,d}	Fat thickness ^{c,d}	Cutability ^{c,e}	Edible portion ^{c,d}	Percent edible portion ^{c,d}	Fat trim ^{c,d}	Percent fat trim ^{c,d}
Weaning weight ^{a,d}	G)	-.81±.42	0.46±.30	-1.00±.24	1.08±.24	1.11±.20	1.16±.20	-1.20±.24	-1.17±.22
	P)	-.09	0.04	-.13	0.12	0.08	0.08	-.11	-.12
	E)	0.15	-.15	0.69	-.64	-.57	-.60	0.60	0.64
Daily gain ^d		-.08±.36	0.49±.27	-.25±.22	0.50±.22	0.48±.23	0.55±.22	-.81±.22	-.79±.21
		-.18	0.03	-.03	0.09	0.11	0.09	-.09	-.11
		-.24	-.27	0.24	-.53	-.22	-.30	0.53	0.56
Final weight ^{b,d}		-.23±.34	0.54±.24	-.56±.19	0.74±.16	0.80±.16	0.86±.16	-1.02±.18	-.99±.17
		-.18	0.05	-.12	0.16	0.15	0.14	-.16	-.18
		-.26	-.58	1.04	-1.55	-.98	-1.11	1.37	1.45
Final conformation ^{b,d}		-.17±.37	0.41±.30	-.22±.23	-.17±.29	0.19±.27	0.19±.28	-.22±.25	-.22±.24
		-.05	-.06	0.18	-.20	-.21	-.21	0.25	0.24
		-.01	-.32	0.60	-.26	-.49	-.50	0.59	0.62
Final muscling ^f		-.64±.62	-.15±.43	-.46±.36	0.19±.37	0.29±.40	0.22±.40	-.53±.42	-.54±.40
		-.03	0.07	-.09	0.09	0.16	0.17	-.15	-.16
		-.13	0.17	-.43	0.02	0.09	0.14	-.08	-.11
Slaughter grade ^d		0.46±.67	0.32±.52	-.12±.39	0.56±.60	0.50±.50	0.56±.52	-.64±.42	-.62±.41
		-.09	-.02	0.15	-.14	-.14	-.14	0.18	0.17
		-.16	-.09	0.30	-.48	-.32	-.33	0.42	0.42
Estimated fat thickness ^e	g	g	g	g	g	g	g	g	g
		-.06	-.10	0.23	-.27	-.31	-.32	0.37	0.35
		-.02	-.18	0.61	-.53	-.56	-.57	0.68	0.71
Estimated rib-eye area ^{b,e}		-1.08±.73	0.47±.27	-.90±.22	0.95±.15	0.91±.21	0.90±.21	-1.29±.28	-1.24±.26
		-.13	0.05	-.11	0.19	0.15	0.15	-.17	-.18
		0.16	-.29	0.81	-.93	-.44	-.44	0.72	0.76
Final condition ^{b,d}		-.46±.81	1.03±.83	-.72±.53	h	0.55±.69	0.58±.72	-.75±.51	-.70±.50
		-.07	-.03	0.20	-.22	-.24	-.26	0.30	0.29
		-.02	-.20	0.53	-.32	-.44	-.46	0.56	0.57

^a adjusted for age and age of dam^b adjusted for age^c adjusted for carcass weight^d degrees of freedom = 568^e degrees of freedom = 437^f degrees of freedom = 289^g negative sire component for estimated fat thickness^h negative sire component for final condition

cutability could not be calculated because of negative sire components for estimated fat thickness and final condition, respectively.

The genetic correlations between weaning weight and the carcass composition traits were favorable except for the correlation of $-.81$ with dressing percent. They indicate that the genes that increase weaning weight increase rib-eye area and carcass muscle and decrease fat thickness and fat trim. The genes that increase weaning weight will decrease dressing percent. Blackwell et al. (1962) and Shelby et al. (1963) reported genetic correlations of 1.56 and 0.40 , respectively, between weaning weight and dressing percent which are not in agreement with the correlation of $-.81$ found in this study. Shelby et al. (1963) reported a genetic correlation between weaning weight and fat thickness of 0.91 which is not in agreement with the value of -1.00 found here. Swiger et al. (1965) reported a genetic correlation of 0.91 between weaning weight and weight of the retail product which is similar to the correlation of 1.11 reported here.

The phenotypic correlations between weaning weight and the carcass composition were all low. Weaning weight and carcass weight would be expected to have a high relationship. By adjusting the carcass composition traits for carcass weight, the relationship between weaning weight and these same traits would be forced to near zero.

The genetic correlation between daily gain and dressing percent was essentially zero ($-.08$) and is in agreement with the value reported by Shelby et al. (1963) but is not with the value of 0.94 reported by Blackwell et al. (1962). The genetic correlations between daily gain

and the other carcass composition traits were moderate to high and indicate that genes that increase daily gain also increase carcass muscle and decrease measures of fat. The phenotypic correlations between daily gain and the carcass composition traits were all low.

The genetic correlation between final weight and dressing percent of $-.23$ indicates that dressing percent is inherited independently of final weight and that very little change would be expected by selecting for final weight. Shelby et al. (1963) also found a low genetic correlation between final weight and dressing percent. Desirable genetic correlations were found between final weight and rib-eye area (0.54), fat thickness ($-.56$), cutability (0.74), edible portion (0.80), percent edible portion (0.86), fat trim (-1.02) and percent fat trim ($-.99$). These indicate that selection for final weight will result in considerable improvement in carcass muscle without selecting for any of these traits directly. Swiger et al. (1965) reported a genetic correlation of 0.96 between final weight and retail product which is in agreement with this study. Using the heritability estimate of 38 percent from this study for edible portion and assuming that edible portion could be measured accurately on the live animal, the expected progress per generation would be 2.4 pounds of edible portion. However, if selection was practiced for final weight, the correlated response would result in a 2.9 pound improvement in edible portion per generation which is more than the expected progress by direct selection for edible portion. This is due

to the high genetic correlation between final weight and edible portion and the higher estimate of heritability for final weight.

Final conformation had low genetic correlations with all of the carcass composition traits except rib-eye area (0.47). Blackwell et al. (1962) reported a genetic correlation of 0.03 between yearling grade and dressing percent which is in agreement with the correlation of $-.17$ found in this study. No reports were found in the literature of genetic correlations between conformation and any measures of carcass muscling. From the estimates derived in this study it would appear that the carcass composition traits are inherited independently of final conformation.

Final muscling followed nearly the same trend as final conformation, as most of the genetic correlations between final muscling and the carcass composition traits were low. The exceptions were between final muscling and dressing percent ($-.64$) and fat thickness ($-.46$).

Slaughter grade had a low genetic correlation ($-.12$) with fat thickness but the genetic correlations between slaughter grade and the other carcass composition traits were higher. The genetic correlations between slaughter grade and the carcass composition traits indicate that the genes that make an animal appear to be higher grading affect dressing percent and carcass muscle in a positive manner and carcass fat in a negative manner.

The genetic correlations between estimated rib-eye area and the carcass composition traits were quite high. It appears that the genes

that make an animal appear to have a larger rib-eye also affect carcass muscle in a positive manner and dressing percent and carcass fat in a negative manner. The genetic correlation between estimated rib-eye area and rib-eye area was 0.47 but the phenotypic correlation was essentially zero (0.06). This indicates that it is difficult to estimate weight adjusted rib-eye area on the live animal and substantiates the earlier assumption that the knowledge of the animals weight was heavily relied on in making this estimate.

Final condition had positive genetic correlations with rib-eye area (1.03), edible portion (0.55) and percent edible portion (0.58) and negative genetic correlations with fat thickness (-.72), fat trim (-.75) and percent fat trim (-.70). This is in contrast to what would be expected and difficult to explain because final condition score was intended to be an evaluation of the amount of finish the animal had. It would be expected that it would be positively related to carcass fat rather than carcass muscle.

Genetic, Phenotypic and Environmental Correlations between Production and Carcass Quality Traits

The genetic, phenotypic and environmental correlations between the production and carcass quality traits are shown in table 19.

The genetic correlation of -.75 between weaning weight and carcass grade does not agree with the values of 0.84 and 0.92 reported by Carter and Kincaid (1959b) and Blackwell et al. (1962), respectively. Swiger et al. (1965) reported a genetic correlation of -.43 between weaning weight and carcass grade.

TABLE 19. GENETIC (G), PHENOTYPIC (P) AND ENVIRONMENTAL (E)
CORRELATIONS BETWEEN PRODUCTION AND CARCASS QUALITY TRAITS

		Carcass grade ^{b,d}	Marbling ^{b,d}	Lean color ^{a,f}	Lean firmness ^f	Tenderness ^f
Weaning weight ^{c,d}	G)	$-.75 \pm .28$	$-.40 \pm .30$	$-.99 \pm .52$	$0.05 \pm .42$	h
	P)	-.17	-.12	-.06	-.01	0.12
	E)	0.17	0.04	0.29	-.05	-.07
Daily gain ^d		$-.12 \pm .26$	$0.15 \pm .27$	$0.13 \pm .42$	$-.42 \pm .36$	h
		0.08	0.10	0.16	-.03	0.09
		0.24	0.06	0.21	0.28	-.17
Final weight ^{a,d}		$-.29 \pm .24$	$0.02 \pm .25$	$-.29 \pm .38$	$-.27 \pm .34$	h
		-.04	0.01	0.06	-.05	0.12
		0.38	-.01	0.72	0.37	-.46
Final conformation ^{a,d}		$0.04 \pm .28$	$-.04 \pm .28$	$-.14 \pm .43$	$-.94 \pm .36$	h
		0.14	0.08	0.06	-.11	0.09
		0.21	0.15	0.18	0.49	0.05
Final muscling ^f		$-.43 \pm .57$	$-.19 \pm .61$	$-.31 \pm .56$	$-.49 \pm .50$	h
		-.07	-.10	0.00	-.10	0.10
		0.04	-.08	0.09	0.05	-.04
Slaughter grade ^d		$-.62 \pm .47$	$0.17 \pm .47$	$-1.02 \pm .56$	$-.27 \pm .97$	h
		0.06	0.06	0.09	-.10	-.07
		0.22	0.04	0.34	-.08	-.19
Estimated fat thickness ^e	g	g		$-.09 \pm 1.14$	$-1.03 \pm .57$	h
	0.07	0.04		0.07	-.07	0.08
	0.20	0.15		0.09	0.26	0.06
Estimated rib-eye area ^{a,e}		$-.43 \pm .35$	$0.06 \pm .33$	$-.65 \pm .39$	$-.01 \pm .36$	h
		-.08	-.06	0.06	-.07	0.10
		0.10	-.14	0.66	-.15	-.27
Final condition ^{f,d}		$-.12 \pm .54$	$-.17 \pm .56$	i	i	h
		0.12	0.06	0.05	-.10	0.05
		0.17	0.11	0.13	0.21	0.04

a adjusted for age

b adjusted for age and carcass weight

c adjusted for age and age of dam

d degrees of freedom = 568

e degrees of freedom = 437

f degrees of freedom = 289

g negative sire component for estimated fat thickness

h negative sire component for tenderness

i negative sire component for final condition

The genetic correlation of $-.12$ between daily gain and carcass grade agrees with values reported by Shelby et al. (1963) and Swiger et al. (1965) but not with the 0.85 reported by Carter and Kincaid (1959b).

The genetic correlation of $-.29$ between final weight and carcass grade agrees with values reported by Shelby et al. (1963) and Swiger et al. (1965) but not with the value of 0.88 reported by Blackwell et al. (1962).

The genetic correlation of $-.62$ between slaughter grade and carcass grade is surprising because slaughter grade was supposed to be an estimate of carcass grade. It is difficult to explain why the genes that make an animal appear to be higher grading affect carcass grade in a negative manner. The phenotypic correlation between these two traits was essentially zero and indicates that it is difficult to estimate carcass grade on the live animal.

The phenotypic and environmental correlations between carcass grade and the production traits were all low.

The genetic correlations between marbling and the production traits were all low except for the correlation of $-.40$ between marbling and weaning weight. This correlation indicates that selection for weaning weight would result in a decrease in marbling. The phenotypic and environmental correlations between marbling and the production traits were all low.

Some of the genetic correlations between the production traits and lean color indicate that many of the genes that increase these

traits also result in carcasses with darker, less desirable colored lean. These traits and their genetic correlations with lean color were: weaning weight ($-.99$), slaughter grade (-1.02), and estimated rib-eye area ($-.65$). There were also antagonistic genetic correlations between lean color and final muscling ($-.31$) and final weight ($-.29$) but these correlations were not high. The phenotypic correlations between lean color and the production traits were all low ($-.06$ to 0.16), indicating that it would be difficult to predict the lean color of an animal from the production traits studied. The environmental correlations between lean color and the production traits were all positive, but most of them were low.

Unfavorable genetic correlations were found between lean firmness and the following production traits: final conformation ($-.94$), final muscling ($-.49$), daily gain ($-.42$), final weight ($-.27$) and slaughter grade ($-.27$). The phenotypic correlations between lean firmness and the production traits were all low ($-.11$ to 0.05). The environmental correlations between lean firmness and weaning weight, final muscling, slaughter grade and estimated rib-eye area were essentially zero. The environmental correlations between lean firmness and the rest of the production traits were slightly higher and all positive.

The genetic correlations between tenderness and the production traits could not be calculated because of a negative sire component for tenderness. The phenotypic correlations between tenderness and the production traits were all essentially zero ($-.07$ to 0.12). This was

also true for the phenotypic correlations between the rest of the carcass quality traits and the production traits indicating that predicting carcass quality traits from any of the production traits in this study would be difficult.

From the result of this study it appears that if beef cattle selection was to be practiced for one trait only, that trait should be final weight. The heritability estimate of 85 percent for final weight indicates that considerable progress can be made for this economically important trait through mass selection. In addition, the desired improvement in weaning weight, daily gain and carcass muscling could be expected due to high positive genetic correlations between final weight and these traits. Selection for final weight would result in little change in dressing percent or marbling and only a slight decrease in carcass grade, lean color and lean firmness.

Considerable emphasis has been placed on final conformation scores at various ages and on other visual appraisals in beef cattle selection. From the results of this study it appears that this emphasis has been unwarranted. These traits have no economic value in themselves and are therefore useful only if they are accurate indicators of traits that do have economic importance. The genetic correlations between the growth traits and final conformation and final muscling were essentially zero. This indicates that the genes that increase growth are inherited independently of the genes that make an animal appear desirable from the standpoint of visual appraisal. The genetic correlations between edible portion and final conformation

and final muscling were also essentially zero indicating that these traits are not accurate indicators of muscle growth.

The significant year x ranch interaction for the production traits has implications in regard to beef cattle testing stations. This interaction might be expected for weaning weight because of variation in rainfall and pasture conditions between ranches from year to year. The fact that this interaction was significant for daily gain indicates that preweaning environment has an influence on an animal's performance after weaning. Therefore, testing cattle from different ranches in a testing station under the same environment and assuming that the differences will all be genetic is not possible. This interaction also demonstrates that cattle feeders cannot evaluate the performance of calves from a ranch based on one year's trial.

The nonsignificant year x sire within ranch interaction is of interest to the beef cattle industry from the implications it has in regard to progeny testing. Some breeders and artificial insemination organizations carry on progeny testing programs to evaluate potential herd sires. In this study sire rankings remained the same from year to year and indicate that sires can be evaluated on the basis of one progeny test.

SUMMARY

Data collected over an eight year period from 679 grade Hereford steers out of 70 sires from 18 ranches were used to obtain heritability estimates of and genetic, phenotypic and environmental correlations among certain production, carcass composition and carcass quality traits of beef cattle. The steers were purchased at weaning and selected only to minimize variation in age both within and between sire groups from the same ranch. Feeding and management practices varied somewhat from year to year, but in general they were fed a full feed of a high concentrate ration and marketed at about 1000 pounds.

The effect of age on the production traits, tenderness, lean color and lean firmness was studied and results indicated that age has a significant influence on final weight, final conformation, estimated rib-eye area, final condition and lean color. These traits were adjusted for age prior to any further calculations. The effect of age and carcass weight on the carcass composition traits, carcass grade and marbling were also studied. Carcass weight had a significant influence on all of the composition traits and adjustments were made for this effect prior to any further calculations. Carcass grade and marbling were influenced by both age and carcass weight and were adjusted for these effects.

Paternal half-sib heritability estimates were obtained by Henderson's Method 2 from the adjusted sums of squares (adjusted for year effects and the year x ranch interaction effect) for sires within ranch. Genetic, phenotypic and environmental correlations were

obtained from the crossproducts for sires within ranch. These crossproducts were adjusted for the same effects as the sums of squares.

Heritability estimates obtained for weaning weight, daily gain and final weight were 40, 55 and 85 percent, respectively. These estimates are slightly higher than most previous estimates of these traits and indicate that the desired improvement in these economically important traits can be brought about through mass selection. The genetic correlations among these traits were all high and positive indicating that selection for any one of them would also improve the others. Several other production traits that were subjective in nature were studied. Heritability estimates for these ranged from zero for estimated fat thickness to 53 percent for estimated rib-eye area. These traits should not be considered as endpoints, however, as they are useful only if they are accurate indicators of traits that have major economic importance. The genetic correlations between most of these traits and the growth traits were low and indicate that the genes that increase growth are not the same genes that make an animal appear desirable from the standpoint of visual appraisal.

Heritability estimates for most of the carcass composition traits were low to moderate indicating that progress through mass selection for these traits would be slower than for the growth traits. In addition, there is the added problem of accurately measuring them on the live animal. Genetic correlations between the growth traits and the carcass muscling traits were all high and positive and should allow for selection to be practiced for growth and expect some

improvement in carcass muscling through correlated response. The correlated response for edible portion through selection for final weight would be larger than the expected response through selection for edible portion directly. The only antagonistic genetic correlation between the growth traits and the carcass composition traits was between weaning weight and dressing percent ($-.81$).

Heritability estimates for the carcass quality traits were all low indicating that little progress could be expected for these traits even if they could be measured accurately on the live animal. The genetic correlations between weaning weight and carcass grade, marbling and lean color were antagonistic and the genetic correlation between daily gain and lean firmness was also antagonistic. Final weight had a low genetic relationship with marbling and only slight genetic antagonisms with carcass grade, lean color and lean firmness. From the standpoint of carcass quality traits, final weight would be the most desirable single growth trait to select for. A combination of weaning weight and daily gain in a selection index would also be good because the antagonisms between weaning weight and carcass grade, marbling and lean color would be offset by daily gain and the antagonism between daily gain and lean firmness would be offset by weaning weight.

If beef cattle selection was to be practiced for one trait only, that trait should be final weight. In addition to improving final weight, improvement could be expected for weaning weight, daily gain and carcass muscling, with no change in dressing percent and marbling and only slight decreases in carcass grade, lean color and lean firmness.

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